Analysis

Assessing the Costs of Adaptation to Climate Change for Developing Countries: Efforts so far and Challenges Ahead

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Abstract

Several recent studies have reported the costs of adapting to climate change for developing countries and have proven to be influential in international negotiations given the role of adaptation in a post-2012 climate agreement. However, their estimates range from US$4 to US$109 billion a year. This wide range is indicative of the poor state of knowledge. Indeed, compared to the mitigation literature, adaptation cost research is still in its infancy. Important knowledge gaps remain both in terms of scope (whether all impacts are covered) and depth (whether for a given impact all adaptation options are considered). Moreover, the additional costs of adaptation have sometimes been calculated as climate mark-ups against low levels of assumed investments. In many developing countries, low levels of investment have led to a current 'adaptation deficit', and this deficit will need to be overcome to prevent the case that the funding for adaptation will largely be insufficient to face the challenge of climate change. Based on a literature review, this article presents the results, underlying hypothesis and main shortcomings of the most recent studies on adaptation costs for developing countries.

Keywords: climate change adaptation, adaptation costs, adaptation deficit, international adaptation finance, adaptation and development, UNFCCC

1. Introduction

The terms of the commitment of developed countries to fund adaptation in developing countries constitute key elements of the post-2012 climate regime currently under negotiation (Stern, 2010). The 15th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) held in Copenhagen in December 2009 outlined the prospects for significant funds for adaptation in developing countries. These prospects were confirmed during the negotiations of the 16th Conference of the Parties in December 2010 in Cancun. Developed countries then committed themselves to jointly provide "new and additional" resources to the tune of $30 billion for 2010-2012 to fund a "Fast Start" Fund, and agreed on the goal of jointly mobilizing $100 billion per year by 2020 to feed a "Green Climate Fund" to meet the needs – both in terms of mitigation and adaptation – of developing countries (UNFCCC, 2010a: para. 8-10). The question of methods and sources of capital

for this fund could be set during the last UNFCCC Conference in Durban in December 2011 and will continue to be hotly debated during the next COPs. The issue of the cost of adaptation for developing countries is therefore subject to significant political interest in the chief of negotiators, as they want to quantify the magnitude of envisaged financial transfers (Drouet, 2009; Fankhauser, 2010).

To date, studies focusing on the cost of adaptation for developing countries provide estimates ranging from US$4 to 109 billion per year. This wide range undeniably poses questions about the robustness of the implemented calculation methods. The evaluation of the overall cost of adaptation is a relatively new field of analysis, as many results have only been published since 2006 (Fankhauser, 2010; IPCC 2012; Parry et al., 2009).[1] The figures from these studies are frequently quoted in both scientific and institutional literature but they are rarely questioned or – at least – discussed in a nuanced manner. These estimates, however, have not been subjected to a systematic and rigorous review process. This has not prevented them from playing an important role in political negotiations since they represent the only objective basis for discussion (Tubiana et al., 2010).

However, existing estimates suffer from significant limitations that we briefly want to highlight in this article. Indeed, assessing the costs – and benefits[2] – of adaptation in developing countries requires to simplify a very complex problem involving multiple countries, institutions and policy makers, and to perform various projections of economic growth, structural changes, climate changes and human behaviour in the coming decades. Such estimates are further complicated by the wide range of adaptation measures that can be implemented (Drouet, 2009).

In this article, we first discuss some crucial points to appreciate climate change adaptation from an economic perspective. We then attempt to take account of the early attempts to assess the costs of adaptation, both at sectoral and national levels. Finally, based on a literature review, we present the results, underlying assumptions and major limitations of the main estimates of adaptation costs for developing countries performed to date.

[1] According to the IPCC Fourth Assessment Report, « comprehensive multi-sectoral estimates of global costs and benefits are currently lacking » (IPCC, 2007: 56).

[2] It should be noted that the benefits of adaptation are rarely quantified, either in sectoral, national or global studies. These various studies very rarely estimate the cost of the impacts that are avoided by adaptation; therefore,

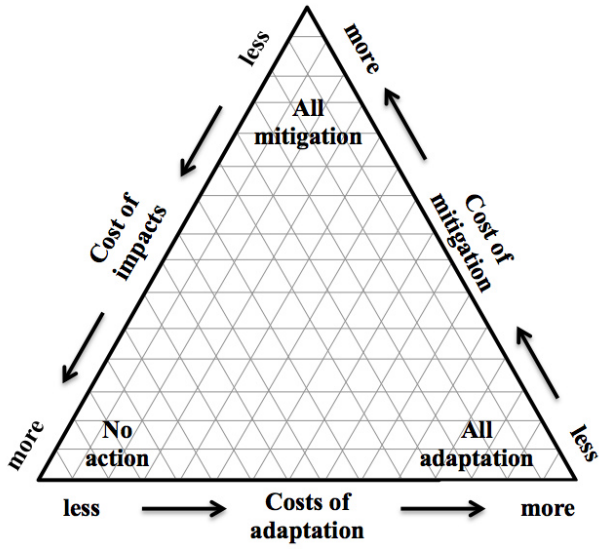
[2] It should be noted that the benefits of adaptation are rarely quantified, either in sectoral, national or global studies. These various studies very rarely estimate the cost of the impacts that are avoided by adaptation; therefore, they cannot determine whether the benefits of adaptation actions exceed their costs (Parry et al., 2009).

2. The answer to climate change from an economic perspective

2.1. Mitigation, adaptation and residual impacts

For a better understanding of the costs of adaptation to climate change issue, it is important to consider adaptation in the broader context of the climate problem. Adaptation is indeed a part of the answer to this problem and, therefore, only a part of the costs associated with it (Parry et al., 2009). It is common to distinguish between three elements of the total economic impact of climate change: (i) the costs of mitigation, to reduce the magnitude of climate change, (ii) the costs of adaptation, to reduce the impacts of climate change and (iii) the costs of residual impacts. The relationships between these three elements are illustrated in Figure 1.

Figure 1. A schematic overview of inter-relationships between adaptation, mitigation and impacts



Source: Klein et al. (2007)

Thus, a given society may want to limit the increase in global temperature to 2°C and as a result decrease its greenhouse gas (GHGs) emissions – this is mitigation –, invest in water defenses to limit the negative impacts of 2°C global warming – this is adaptation – and accept the loss of certain coastlines that cannot be protected at reasonable cost – these are the residual impacts (Fankhauser, 2010).

If we consider a simplistic economic analysis framework, a society will adjust its mitigation and adaptation efforts to the point where the aggregate costs of mitigation, adaptation and residual damages

are the lowest (Parry et al., 2009). Table 1 summarizes the results of such an analysis applied to flood risk in the European Union (EU), without adaptation and with adaptation.

Table 1. Peope at risk of being flooded, damage and adaptation cost in the EU – without and with adaptation[3]

	People at risk of being flooded (thousand/year)		**Adaptation cost** (billion EUR/year)		**(Residual) damage cost** (billion EUR/year)		**Total cost** (billion EUR/year)	
	Without adaptation	**With adaptation**	**Without adaptation**	**With adaptation**	**Without adaptation**	**With adaptation**	**Without adaptation**	**With adaptation**
A2								
2030	21	6	0	1,7	4,8	1,9	4,8	3,6
2050	35	5	0	2,3	6,5	2,0	6,5	4,2
2100	776	3	0	3,5	16,9	2,3	16,9	5,8
B1								
2030	20	4	0	1,6	5,7	1,6	5,7	3,2
2050	29	3	0	1,9	8,2	1,5	8,2	3,5
2100	205	2	0	2,6	17,5	1,9	17,5	4,5

Source: EEA (2010)

There are more advanced analytical frameworks that also consider the unequal distribution of climate change impacts, the risk of threshold effects, including threats to unique natural systems (see e.g. Bosello et al., 2007). However, finding the right balance between mitigation and adaptation efforts has complex economic and ethical issues (Grasso, 2010). A major difficulty associated with the process of optimizing spending to fight against climate change is that a simple comparison between the annual costs of mitigation and adaptation would not reflect the complexity of reality (Parry and al., 2009). Indeed, on the one hand, the climate system's low inertia means that lower emissions today will not reduce the immediate costs of adaptation and residual impacts. On the other hand, it is unlikely that an economically optimal adaptation will address all impacts of climate change. There will be substantial residual damages that adaptation cannot cover, for economic and technical[4] reasons, but also for social and cultural reasons in particular (see e.g. Adger et al., 2009).

[3] Two scenarios are analysed here: the IPCC's A2 and B1 emission scenarios. These emissions scenarios were elaborated by Nakičenovič et Swart (2000) and have been used to make projections of possible future climate change in the IPCC Third Assessment Report, published in 2001, and in the IPCC Fourth Assessment Report, published in 2007. Assumptions about future technological development as well as the future economic development are thus made for each scenario. These emissions scenarios are organized into families, which contain scenarios that are similar to each other in some respects.

[4] Some impacts cannot be avoided because the necessary technology to mitigate them (*i.e.,* in the case of ocean acidification) does not exist at all.

2.2. Adaptation in an Economic Perspective

From an economic perspective, adaptation can be assessed, among other means, by determining the balance of costs and benefits of adaptation actions (Agrawala and Fankhauser, 2008). However, we will see that significant analytical difficulties are associated with the estimation of these costs and benefits. Uncertainties related to the specific, primarily local effects of climate change will also influence the calculations of the costs and benefits of adaptation; these uncertainties also persist in regards to the timing of implemented adaptation actions (Hallegate, 2009). Thus, to determine the optimal time to make a given investment in adaptation, we could compare the profits or losses in present value caused by this investment today with the profits or losses induced by this adaptation action tomorrow.[5] Both values are composed of adaptation costs[6] – incurred in the present or future – and a stream of residual costs – e.g. costs of flooding – which are reduced from the time the adaptation action is implemented. It is important to note that there may be significant differences between direct costs and benefits of adaptation measures and indirect costs and benefits that result for the economy as a whole – for example, the effects of a large-scale coastal defence program on the construction sector in a given country (Bosello et al., 2007; de Bruin et al., 2009, World Bank, 2010c).

Moreover, it is necessary to determine the level of impact that we want to adjust to. An adaptation strategy will result in different costs if it seeks to avoid (i) all impacts that reduce the human welfare, (ii) all impacts to which it is economically rational to adapt – i.e. impacts for which adaptation leads to more benefits than costs – or (iii) all impacts to which it is possible to adapt given a budget constraint – e.g. the size of international funds for adaptation. It is important to keep these considerations in mind when interpreting estimates of costs and benefits of adaptation.

2.3. Adaptation Deficit

For thousands of years, human societies have tried – with varying degrees of success – to adapt to climatic conditions they have faced[7]. Climate adaptation is ubiquitous in everyday life: the design and

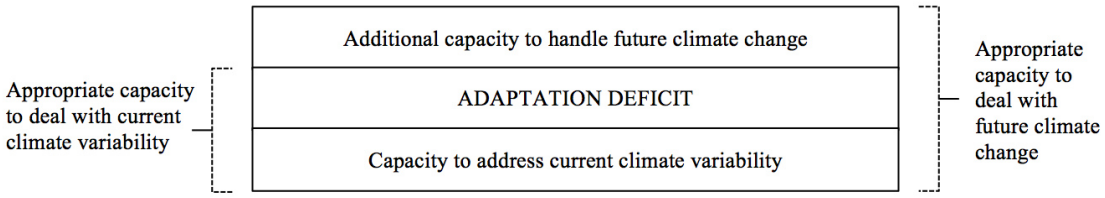
[5] The actualisation consists of weighing equally financial flows that are not directly comparable as they are occurring at different times. Note that the result of a valuation by discounting depends heavily on choosing a discount rate reflecting the agents' preference for this. Such a choice is therefore highly controversial, we refer the reader to Hardelin and Marical (2011) for a good overview of the elements involved in this subject in the field of environmental policy.

[6] A thorough assessment of adaptation costs would ideally consider the present value of a project over its total lifetime, taking into account the costs of preparation, investment costs, operational costs and decommissioning costs.

[7] The interested reader will find in de Menocal (2001) a study of ancient societies' adaptive responses to various stress conditions.

location of buildings and infrastructure are partly a reflection of this adaptation, as further shown by life choices, consumption patterns or economic decisions (Fankhauser, 2010). In theory, adaptation to anthropogenic climate change should be measured from the current level of adaptation to natural climate variability. Studies of the costs of adaptation thus aim to identify the additional costs induced by anthropogenic climate change alone. In practice, however, it is difficult to distinguish between these two 'types' of adaptation – natural climate variability, on the one hand, and anthropogenic climate change, on the other. This is particularly true for developing countries where there is a very important "adaptation deficit". Proposed by Burton (2004), the concept of "adaptation deficit" – which we display in a simplified illustration in Figure 2 – captures the notion that countries – both developed and developing – are more or less under-prepared to cope with current climate conditions and, *a fortiori*, future climate change. In this sense, adaptation to current climate variability and extremes is a prerequisite to the process of adapting to climate change[8].

Figure 2. A simplified interpretation of the adaptation deficit



Source: World Bank (2010b)

The relevance of the concept of "adaptation deficit" is particularly high in studies of adaptation costs. Indeed, to determine the baseline[9] against which to measure the additional costs induced by anthropogenic climate change, it is necessary to quantify the adaptation deficit. However, such an effort is extremely complex[10]. Thus, one might, at first glance, consider that the funds needed to cover the deficit of adaptation in developing countries is equal to those needed to make all these countries as prepared to natural climate variability as developed countries (World Bank, 2010b). However, the resources that countries spend to cope with natural climate variability depend on a number of national conditions. For example, if more lives can be saved with an equal level of resources, a poor country can theoretically devote fewer resources than a rich one to prevent deaths due to floods, but more

[8] However, if the concept of adaptation deficit has the merit of highlighting the under-preparedness in regard to the current climate, it does not draw attention to the fact that adaptation to the new phenomenon of anthropogenic climate change is in many regards a different process than adapting to natural climate variability.
[9] The reference level in Figure 2 is the 'appropriate capacity to cope with current climate'.
[10] The reader can see for example World Bank (2010b) for a detailed discussion of analytical problems relating to the operationalization of the adaptation deficit.

resources to fight malaria (World Bank, 2010b). Furthermore, such an effort to quantify the baseline theoretically implies evaluating the components of development initiatives that improve resilience to anthropogenic climate change (Smith et al., 2011). We will see that existing studies on the costs of adaptation for developing countries avoid addressing those difficulties.

3. Early attempts to assess the costs of adaptation

3.1. Impact studies

Research on the costs of adaptation began in the 1990s with relatively early attempts to estimate the economic cost of climate change (e.g. Cline, 1992; Fankhauser, 1995; Nordhaus, 1994; Smith and Tirpak, 1989; Tol, 1995). The objective of this early work was not to measure the costs of adaptation *per se,* but rather to refine the understanding of climate change impacts; this meant including adaptive responses of actors in impact analysis (Parry et al., 2009). Thus, Tol et al. (1998) concluded, for example, that many impact categories covered in the literature concerned with the economic cost of climate change were in fact costs of adaptation. In particular, it was those costs associated with coastal protection expenditures or heating and cooling.

3.2. Assessments at the sector level

Over the years, the consideration of adaptation in models of global impact was refined by a series of sectoral studies (Nicholls and Toll, 2006; Parry et al., 2004). However, except for coastal areas, the knowledge of the costs – and benefits – of adaptation is still relatively limited at this level of analysis (Agrawala and Fankhauser, 2008). As an exception, more research has been conducted on quantifying the benefits rather than the costs of adaptation strategies for the agricultural sector (Fankhauser, 2010). Additionally, there exists a fairly comprehensive literature on studies of adaptation costs for coastal areas and for agriculture (Agrawala and Fankhauser, 2008). Information on adaptation costs is more limited and patchy for other sectors (Parry et al., 2009). The study of the energy sector, for example, was largely confined to the United States where the majority of studies concludes that the costs associated with additional air conditioning necessitated by climate change will outweigh the savings in heating (Agrawala and Fankhauser, 2008). Moreover, only very sporadic and local information is available concerning the costs and benefits of adaptation in the sectors of water, public health, tourism and infrastructure (Agrawala and Fankhauser, 2008).

3.3. National level assessments

In addition to these sectoral studies, the costs of adapting to climate change are increasingly studied by adopting a country perspective (Parry et al., 2009). These multi-sector studies are relatively recent and generally emerge as part of a broader planning programme aimed at developing a national strategy to adapt to climate change (Parry et al., 2009)[11]. However, these studies are rarely complete and extrapolating information to derive national aggregate estimates is difficult (Fankhauser, 2010).

The National Adaptation Programmes of Action (NAPAs) are among the few tangible products of multilateral cooperation in adaptation (UNDP, 2007) and are examples of such planning programmes. Developed Under the Article 4.9 of the UNFCCC (1992) and funded through the Fund for the Least Developed Countries under the Global Environment Facility (GEF), NAPAs are intended to identify urgent and immediate adaptation actions within least developed countries (LDCs), while developing a framework for integrating adaptation into national planning (UNDP, 2007).

To date, 45 NAPAs have been established. They vary in quality and scope, with cost estimations ranging from less than US$4 million for Madagascar, Comoros and the Central African Republic to hundreds of millions in Ethiopia and the Gambia, the only two countries that include significant infrastructural investments within adaptation programmes (Fankhauser, 2010). Moreover, the priorities of NAPAs predominantly contain preparatory measures and capacity building, especially in agriculture and water management (Agrawala and Fankhauser, 2008). As such, NAPAs are poor indicators of long-term adaptation spending in LDCs but they can give an approximate indication of the initial costs and sectoral priorities (Baudoin, 2010; Parry et al., 2009).

4. Estimates of adaptation costs for developing countries

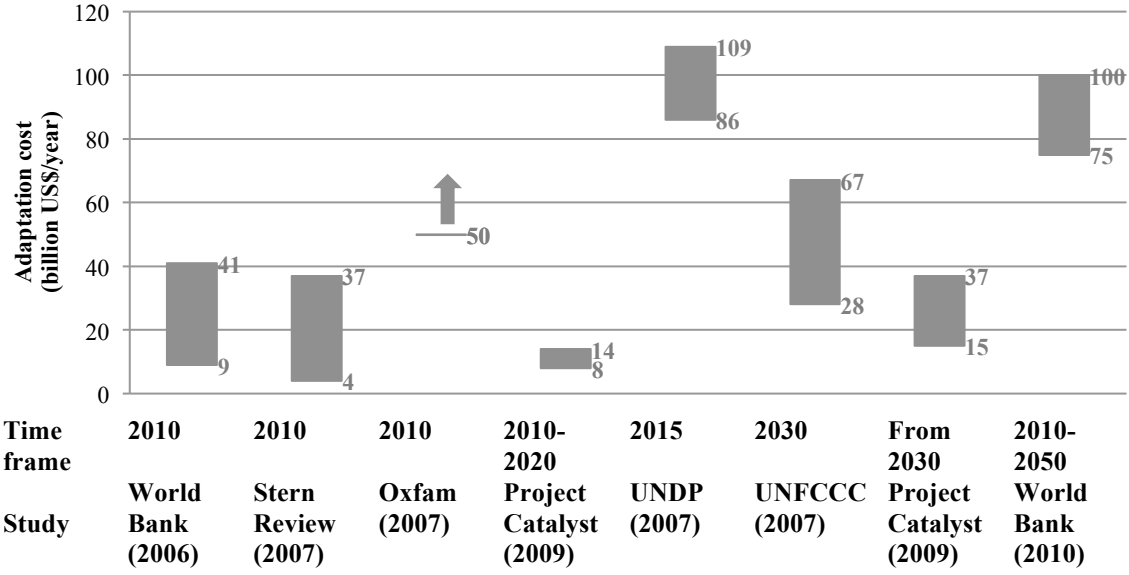
Interest in adaptation has dramatically increased a few years ago when it became clear that the relatively inert nature of the climate system would make a certain level of warming inevitable, whatever the effort to reduce GHG emissions would be (Parry et al., 2008; Rahmstorf, 2007; Solomon et al., 2009). The issue of adaptation in developing countries has also emerged as a key aspect of post-Kyoto negotiations (Tubiana et al., 2010). Multiple factors have since then contributed to the emergence of a growing interest in assessing the overall costs of adaptation (Drouet, 2009). Firstly,

[11] Early examples are, among others, some studies funded by the World Bank in Bangladesh (Smith et al., 1998) and the Pacific (World Bank, 2000). More recently, McKinsey in collaboration with Swiss Re and GEF have studied the costs of adaptation and adaptation priorities in eight case studies covering both developed and developing countries (Haas, 2009).

such estimations may contribute in climate adaptation agenda-setting. Then, they can serve as a guideline for international donors who wish to improve the climate resilience of their projects and development activities. Finally, they can help shape the discussion around the needs of developing countries for climate change adaptation in the context of international climate negotiations.

Following a long period of total absence of empirical estimates of adaptation costs in developing countries, five evaluations have explicitly addressed this issue within a very short period of time, between mid-2006 and late 2007, followed by two more evaluations in 2009 and 2010. Several international institutions have assessed the costs of adaptation: the World Bank (2006; 2010c), the United Nations Development Programme (UNDP, 2007) and the UNFCCC Secretariat (2007). Some government agencies and nongovernmental organizations have also provided various estimates: for example the Stern report (2007), the Oxfam study (2007) and the Catalyst Project (2009). The results of these various estimates are shown in Figure 3.

Figure 3. Estimates of costs of adaptation to climate change for developing countries[12]



Draws on material from Oxfam (2007); Project Catalyst (2009); Stern (2007); UNDP (2007); UNFCCC (2007); World Bank (2006 ; 2010c)

Whereas all of these seven studies examined the costs of adaptation for developing countries, Parry et al. (2009) and Fankhauser (2010) noted that only three of them can be considered independent. The

[12] For the Stern Review (2007), the World Bank (2006; 2010) and Oxfam (2007) studies, the analysis of costs of climate proofing in developing countries was based on ODA recipients. In UNFCCC (2007), "developing countries" were defined as non-Annex I parties to the UNFCCC. The two categories overlap, but there are nevertheless some differences.

first of these independent studies is World Bank (2006) on which the Stern Review (2007), Oxfam (2007) and UNDP (2007) were largely based. One more step was taken by the UNFCCC Secretariat (2007)[13], on which the Catalyst Project (2009) is based. The third and most recent assessment is World Bank (2010c), which attempted, in turn, to go beyond previous efforts.

4.1. First generation of estimates

Initial estimates are all based on the same method, originally developed by the World Bank (2006). It initially considered the amount of current investment, then estimated the fraction of this investment that was "sensitive" to the climate and finally used a "mark up" factor that intended to reflect the additional cost for making such investments resistant to climate change. World Bank (2006) assumed that 2–10% of gross domestic investment (GDI), 10% of foreign direct investment (FDI), and 40% of official development assistance (ODA) was sensitive to climate change and used a "mark up" factor that comprised between 10% and 20% of these investments [14]. It concludes that the costs of adaptation in developing countries are between US$9 and 41 billion a year.

Parry et al. (2009) indicate that regarding fractions of climate-sensitive investments and "mark up" factors used in the study by the World Bank (2006), only those for ODA had an empirical justification[15]. This has not prevented some future studies to adopt identical assumptions – as table 2 shows very clearly.

[13] It should be noted that regarding the infrastructure sector, this study is based largely on assumptions made by the World Bank (2006).
[14] These investments were USD at that time to 1500, 160 and 100 billion per year (World Bank, 2006).
[15] The ODA figures used by the World Bank (2006) were derived from a study of six developing countries on climate risk (Agrawala, 2005). The adjusting factor used in this study, however, was considerably larger (12% to 65%) and the author warned against drawing generalised conclusions from the results.

Table 2. First-Generation Estimates of Adaptation Costs in Developing Countries[16, 17]

	Investment (billion US$)	**Of which climate sensitive**	**"Mark up" factor**	**Adaptation costs (billion US$)**
World Bank (2006)				
GDI	1500	2-10 %	10-20 %	3-30
FDI	160	10 %	10-20 %	2-3
ODA	100	40 %	10-20 %	4-8
			Total:	**9-41**
Stern Review (2007)				
GDI	1500	2-10 %	5-20 %	2-30
FDI	160	10 %	5-20 %	1-3
ODA	100	20 %	5-20 %	1-4
			Total :	**4-37**
UNDP (2007)				
GDI	2724	2-10 %	5-20 %	3-54
FDI	281	10 %	5-20 %	1-6
ODA	107	17-33 %	5-20 %	1-7
Additionam adaptation				44
			Total:	**86-109**

Draws on material from Agrawala and Fankhauser (2008); UNDP (2007); Stern (2007); World Bank (2006).

The Stern Report (2007) modifies the "mark up" factor to 5-20% and reduces the fraction of ODA sensitive to climate change to 20%, but makes no further adjustment to the method used by the World Bank (2006). Differing assumptions are not justified, however, apart from the fact that they derive from "discussions with the World Bank" (Parry et al., 2009). The Stern Report leads to a range of US$4 to 37 billion per year.

Oxfam (2007) adopted the World Bank figures (2006) but added some additional costs such as those of the work of nongovernmental organizations (NGOs) at the community level in developing countries, on the one hand, and the implementation of NAPAs, on the other. Parry et al. (2009) maintain that these two additions were based on sufficiently strong assumptions, even though the costs of adaptation at the community work level were extrapolated from three projects only. Oxfam concludes that adaptation in developing countries requires more than US$50 billion per year.

UNDP (2007) also adopted the World Bank (2006) approach. Nevertheless, it used more data on investment and considered a different fraction of ODA sensitive to climate change (17-33%). In addition, it includes the costs of adaptation strategies for poverty reduction ($44 billion per year). For

[16] Oxfam (2007) is not included in this table as this study relied on the same underlying assumptions than World Bank (2006) with regards to "mark up" factors and fractions of investments sensitive to climate change.
[17] Neither the time horizon nor the underlying climate scenario is usually specified in these studies, but the use of current investment flows as the basis implies that the numbers represent short-term adaptation needs (Fankhauser, 2010).

the rest, it adopted the assumptions made in the Stern Review (2007) and resulted in a range of US$86 to 109 billion per year by 2015.

Taking these studies into account, some commentators, especially in their initial opinions, concluded that there was a convergence of evidence and a relative unanimity in estimating the cost of adaptation for developing countries (Parry et al., 2009). However, none of these studies can truly be deemed independent. Moreover, even if they were based on common methodology, they resulted in a very wide cost range, from US$4 to 109 billion per year. This large range of estimates is partially due to a fundamental problem that lies within these approaches: the lack of empirical information about the fraction of investments sensitive to climate change and other "mark up" factors to be applied, which are probably situation-specific (Parry et al., 2009).

4.2. Second generation of estimates

Just as the World Bank (2006) inspired the first generation of estimates of adaptation costs, the UNFCCC Secretariat (2007) report provided the basis for a number of subsequent studies (IPCC, 2012). Even if it is incomplete, this study considers a large number of elements in different sectors and therefore constitutes an important step forward in understanding the costs of adaptation (Fankhauser, 2010; Parry et al., 2009). The UNFCCC Secretariat commissioned six studies that provide estimates of adaptation costs in 2030, generally assuming emission scenarios A1B and B1. These estimates cover the following sectors: agriculture, forestry and fishing (US$7 billion/year), water (US$9 billion/year), health (US$5 billion/year), coasts (US$4 billion/year), infrastructure (US$2-41 billion/year) and ecosystems[18]. The UNFCCC Secretariat (2007) concluded that the financial needs for adaptation in developing countries during 2030 and beyond range from US$27 to 66 billion per year. The largest item by far is the high estimate for the infrastructure sector, accounting for more than three-quarters of the total costs of adaptation.

The Catalyst Project[19] (2009) relied on estimates by the UNFCCC Secretariat (2007). Nevertheless, this study did not specifically focus on developing countries' cost of adaptation, but rather on additional international funds necessary for these countries to adapt to climate change. The Catalyst Project paid particular attention to sequencing adaptation actions by focusing on planning, preparation

[18] The results from the 'ecosystems' sector were not included in the total because they were not considered sufficiently robust.
[19] The Catalyst Project brought together a number of climate change thinkers compiled by the Climate Works Foundation (http://www.climateworks.org/).

and research during the early years, before focusing on physical adaptation. The study therefore leads to lower estimates for immediate infrastructural adaptation (Fankhauser, 2010). Moreover, it considers the benefits associated with adaptation actions and therefore reduces the cost estimates. The Catalyst Project (2009) found that the funds needed for adaptation in developing countries are between US$8 and 14 billion per year for 2010-2020 and between US$15 and 37 billion annually until the year 2030.

4.3. Towards a third generation of estimates?

The World Bank (2010b) recently published a new detailed study of the costs of adaptation for developing countries. This study adopts a relatively similar approach compared to that of the UNFCCC Secretariat (2007) for sectors such as agriculture and coastal protection, but attempted to more accurately approximate the infrastructure sector. It also examined the costs of adaptating to extreme events. Furthermore, this study analyses the effects of adaptation on the economy as a whole[20].

According to the World Bank (2010b), the cost for developing countries to adapt to a world that will approximately be 2°C warmer in 2050 as compared to the preindustrial era, is between US$75 and 100 billion a year between 2010 and 2050. In its estimates, the World Bank considered two contrasting climatic precipitation scenarios: a "dry" scenario and a "wet" scenario; regarding the socio-economic scenario, the SRES A2 IPCC scenario was used[21]. The costs of adaptation varies depending on the particular climate scenario: the "dry" scenario leads to lower overall costs than the "wet" scenario, largely because the costs for the infrastructure sector are much lower in this first scenario, which more than offsets the additional costs for the sectors of water and flood management. The World Bank (2010b) also indicates that the absolute costs of adaptation increases over time regardless of the climate scenario used but decreases in relative share of gross domestic product (GDP). However, there are very significant regional variations: the relative cost of adaptation is considerably higher in Sub-Saharan Africa than in other parts of the world, partly because this region has a comparatively low GDP and also because of high costs – related to changes in rainfall patterns – in the area of water resources.

According to Fankhauser (2010), one of the weaknesses of the World Bank estimate (2010b) is that it defines adaptation as all the measures needed to restore pre-climate change levels of welfare. This

[20] Bosello et al. (2007) and de Bruin et al. (2009), among others, investigated the effects of adaptation on the economy as a whole ((the "general equilibrium effects")

[21] This is one of the scenarios developed by Nakicenovic and Swart (2000) as presented above. The canvas A2 describes a world experiencing a continuously increasing population with a primarily regionally oriented economic development, where per capita economic growth and technological change are more fragmented and slower than in other scenarios.

means that adaptation is pushed to the point where there is no residual damage rather than to the point where marginal costs equal marginal benefits of adaptation; the figures must therefore be regarded as a *proxy* for the costs of adaptation and of residual impacts in developing countries (Fankhauser, 2010). Nevertheless, the broader sectoral coverage and a more thorough study, accompanied by extensive explanations about the method used and its limitations, significant improvements were achieved by this study as compared to previous estimates. Table 3 provides a summarised overview of the various estimates of the cost of adaptation for developing countries.

Table 3. Estimates of costs of adaptation to climate change for developing countries

Study	**Adaptation cost** (billion US$/year)	**Time frame**	**Coverage**	**Sectors**	**Comments on methodology**
World Bank (2006)	9-41 (in 2000 US$)	Present	ODA recipients	Unspecified[22]	Cost of climate-proofing foreign direct investments, gross domestic investments, and Official Development Assistance. Costs of climate-proofing are assumed in the analysis.
Stern Review (2007)	4-37 (in 2000 US$)	Present	ODA recipients	Unspecified[22]	Update, with slight modifications, of World Bank (2006).
Oxfam (2007)	More than 50 (in 2000 US$)	Present	ODA recipients	Unspecified[23]	World Bank (2006) plus extrapolation of cost estimates from NAPAs and NGO projects.
UNDP (2007)	86-109 (in 2005 US$)	2015	ODA recipients	Unspecified[22]	World Bank (2006) plus costing of targets for adapting poverty reduction programmes and strengthening disaster response systems
UNFCCC (2007)	28-67 (in 2005 US$)	2030	Non-Annex I parties to the UNFCCC	Agriculture, forestry, and fisheries; water supply; human health; coastal zones; infrastructure; ecosystems (but no estimate for 2030 for ecosystem adaptation)	In-depth costing of specific adaptations in water, health and coastal zones. Less detailed costing for agriculture, infrastructure, and ecosystems. Infrastructure more abstract.
Project Catalyst (2009)	8-14 (in 2005 US$) 15-37	2010-2020 From	ODA recipients	Agriculture, forestry, and fisheries; water supply; coastal	Project Catalyst asked how much additional international funding might be needed for adaptation under the post-

[22] Presumably all sectors where ODA, FDI, and GDI are directed.
[23] Presumably all sectors where ODA, FDI, GDI, and NGO interventions are directed.

	(in 2005 US$)	2030		zones; infrastructure	2012 climate change architecture. Much more attention was paid to the sequencing of adaptation measures.
World Bank (2010c)	75-100 (in 2005 US$)	2010-2050	ODA recipients	Agriculture, forestry, and fisheries; water supply and flood protection; human health; coastal zones; infrastructure; extreme weather events	Impact costs linked to adaptation costs, improvement upon UNFCCC (2007): climate-proofing existing and new infrastructure, more precise unit cost, inclusion of cost of maintenance and port upgrading, risks from sea level rise and storm surges, riverine flood protection, education investment to neutralize impacts of extreme weather events. It defined adaptation as the measures needed to restore pre-climate change levels of welfare (no residual damage).

Draws on material from Agrawala et Fankhauser (2008); IPCC (2012); Oxfam (2007); Project Catalyst (2009); Stern (2007); UNDP (2007); UNFCCC (2007); World Bank (2006; 2010c)

5. Main limitations of existing global assessments

Estimates of global and multi-sectoral adaptation costs are very recent. They suggest that adaptation to climate change in developing countries will amount to several tens of billions of dollars annually. Even though these estimates are potentially relevant to inform international climate negotiations, most commentators agree that they are preliminary, incomplete and unreliable (Agrawala and Fankhauser, 2008; Fankhauser, 2010; IPCC 2012; Parry et al., 2009). There was, according to these authors, a very rapid and premature convergence around initial estimates particularly sensitive to two assumptions. Firstly, the percentage of assets or cash flow at risk climate conditions and secondly, the "mark up" factor used to reflect the additional cost for making such investments resilient to climate change. Very little analytical information about these two parameters is currently available, and yet they are the basis for most estimates of adaptation costs in developing countries. The figures may therefore negatively bias policies if insufficient attention is paid to the underlying assumptions of these estimates.

According to Agrawala and Fankhauser (2008) and Parry et al. (2009), significant gaps remain in the existing analyses in terms of scope, depth, the costing of measures and the treatment of uncertainty. Many of these limitations are exacerbated by the lack of an operational definition of adaptation. The question therefore is in how far and in what sense the gaps in knowledge lead to biased estimates. It is

difficult to answer this question, since there are many omissions within the studies in question, but it is likely that adaptation costs have been underestimated so far (Agrawala and Fankhauser, 2008). Without providing their own estimates, Parry et al. (2009) indicate that adaptation costs in the evaluated areas are probably two to three times higher than projected in the the UNFCCC (2007) study. If the sectors that were not included in this estimate were considered, the costs would be even more important (Parry et al., 2009).

5.1. Scope of analysis

The analysis of adaptation costs is still predominantly a field of case studies (Parry et al., 2009). Currently, only a small number of studies try to provide an estimate of the cost of adaptation for developing countries. In addition, the first generation of these studies only measures the costs of new investments resistant to climate change.

The most extensive study at present – i.e. the World Bank (2010c) – investigated only seven sectors. Thus, some areas with very clear adaptation needs, such as the energy, the mining or the tourism sectors, are simply not taken into account; the same applies for certain coping strategies that are potentially very important, like planned migrations (Agrawala and Fankhauser, 2008). Moreover, in these sectors, the analysis is often incomplete, as most studies have only considered a small number of climate change impacts for which sufficient data existed. In addition, many studies did not consider the full spectrum of risks and focused only on the mean changes without considering extreme events. However, the type of impact affects the choice of optimal adaptation; taking into account extreme events therefore is susceptible to a significant increase of costs of adaptation, as shown by the study of the World Bank (2010c). Furthermore, it should be noted that there are problems of double counting, and extrapolating to overall levels from very limited and often local information (Agrawala and Fankhauser, 2008).

5.2. Depth of analysis

The effects of the insufficient depth of these studies are difficult to assess. In effect, even in detailed case studies, it is difficult to systematically consider all available adaptation options (Parry et al., 2009). Adaptation is indeed too broad a concept to be able to analytically capture it in a comprehensive way. The problem is clearly exacerbated by global studies that had to simplify or ignore local

conditions. According to Agrawala and Fankhauser (2008), this introduces at least two forms of bias, one leading to an overestimation and the other in an underestimation of the costs of adaptation.

On the one hand, assessments of the overall costs of adaptation only take into account what is called "hard adaptation", while neglecting "soft" adaptation measures. "Hard adaptation" mainly refers to direct actions on infrastructure and buildings. These consist in, among others, building – or strengthening – dams, roads and irrigation projects. "Soft adaptation" refers to (i) the production and dissemination of information on climate change, its impacts and various ways to adapt, (ii) the modification of technical and architectural standards, diverse regulations and taxations that frame the action of public and private actors, and (iii) the strengthening of institutional capacity to identify the early signs of tension and crisis, to balance the interests of different stakeholders and to implement the proposed solutions (de Perthuis et al., 2010). Changing the pricing of water and energy, establishing insurance schemes and social safety nets, managing ecosystems[24] and relocating people to safer areas are examples of "soft" measures[25].

The studies reviewed in this paper only consider the "hard" options in their estimates[26]. The existence of this major bias is partially due to the fact that "hard" answers are easier to identify, to analytically approach and to evaluate in monetary terms than "soft" actions – but they are also potentially much more costly. Soft adaptation measures require a sound institutional and political basis to be effective. The estimated costs of implementing such options therefore leads to important methodological challenges that existing studies have preferred to avoid. Thus, studies of the overall costs of adaptation do not really incorporate any institutional, political or cultural analysis. Yet these factors are crucial if we are to understand the adaptation process and to determine what is feasible versus what is desirable from an economic standpoint.

On the other hand, assessments of the overall costs of adaptation focus on public adaptation and ignore private adaptation. Public measures are in fact much easier to identify than countless individual

[24] Most studies on adaptation costs have only considered ecosystems as a capital to protect against climate change. Yet they can be mobilized to strengthen the adaptive capacity of societies to these changes. This is what is meant by the notion of ecosystem-based adaptation. For example, the natural wetlands offer a very effective protection from storm tides and storm surges, and can replace or supplement a seawall or other forms of protection, avoiding or reducing negative impacts on biodiversity, landscapes and tourist attractions (de Perthuis et al., 2010).

[25] For this last example, the term "soft adaptation" should not obscure the various difficulties involved in relocating people to other areas.

[26] There are however few exceptions to this, particularly for the agricultural sector where most adaptations involve autonomous adjustments at the farm level (Agrawala & Fankhauser, 2008). The study of the World Bank (2010c) focuses on adaptation measures but identifies – without evaluating them in monetary terms – the opportunities with regards to soft adaptation in various case studies).

adaptations that may be implemented by individuals and businesses. However, certainly in terms of numbers, and perhaps also in terms of costs, private measures will dominate the global adaptive response since individuals and companies will, among other actions, insulate their buildings, adjust their spending on heating or air conditioning, reduce their water consumption, change their tourist destinations and even relocate (Berkhout et al., 2006).

5.3. Costing of measures

A thorough assessment of adaptation costs would ideally consider the present value of an adaptation project during its total lifetime, taking into account design costs, capital costs, operating costs and decommissioning costs (de Bruin et al., 2009). In fact, in the studies reviewed above, attention is often only paid to initial capital expenditure. Another omission, particularly significant in the context of developing countries, is the set of institutional and administrative costs associated with simply expending funds for adaptation (Baudoin, 2010; Parry et al., 2009).

In addition, Parry et al. (2009) indicate that even though some assumptions are made in terms of the effects of investments in adaptation on the economy as a whole, there are few analytical elements that explain the nature and significance of these effects[27]. More generally, proposed adaptation options are seldomly subject to a cost-effectiveness test, suggesting that more efficient options could potentially be identified (Fankhauser, 2010).

5.4. Treatment of uncertainty

All estimates of adaptation costs in developing countries considered in this article assume that the impacts of climate change are known with certainty (Agrawala and Fankhauser, 2008). In reality, planners will have to face considerable uncertainty about the exact nature, frequency, extent and spatial occurrence of climate change impacts at local or regional levels (Dessai et al., 2009; Hallegate, 2009; Ranger et al., 2010). While climatology has made great strides recently, it remains particularly difficult to predict future impacts of climate change with sufficient sophistication to justify investments in adaptation measures specifically targeted at a particular impact (Klein & Persson, 2008).

To refine their coping strategies, policy makers need to know how climate change will occur at the local level, not only in terms of average temperatures but also in terms of precipitation, wind speed or extreme weather (Fankhauser & Burton, 2011). The planning of specific measures based on projections

[27] An exception to this is the latest study from the World Bank (2010c).

of future climate conditions represents a challenge, exacerbated by the lack of resources in developing countries (Klein & Persson, 2008). However, decision-making in an uncertain environment is not confined to adaptation to climate change, indeed there is a considerable body of literature on this subject within other research fields (Gollier, 2001). The tools developed in these fields are also increasingly applied to the area of adaptation (Hallegatte, 2009; Ranger et al., 2010)[28].

In some cases, uncertainty might justify a postponement of decision-making on adaptation until more information is available – which in effect reduces the adaptation costs but increases the residual impacts. However, in most cases, this will force planners to extend the range of adaptation actions in order to cope with a wider range of impacts (Agrawala and Fankhauser, 2008). The uncertainties thereby promote methods that cause significant short-term benefits and no regrets actions that can be justified however important climate change may be (Adger et al., 2009; Fankhauser & Burton, 2011).

5.5. Adaptation and development: a complex relationship

We noted above that studies on adaptation costs for developing countries aim to identify the additional costs induced by anthropogenic climate change. In these studies, adaptation is indeed interpreted as an adaptation to specific climatic changes, without considering the underlying factors of vulnerability to climate change. Adaptation actions are therefore treated in their narrowest sense and are understood as separate from, and supplementary to, development efforts. Yet there is a significant overlap between operational activities of adaptation and development (McGray et al., 2007)[29]. This overlap is at the heart of the current debate on adaptation finance (Fankhauser and Schmidt-Traub, 2010). Thus, the distinction between adaptation and development activities is politically understandable, as international negotiators want to distinguish between – basic – funding for development and – additional – funding for adaptation. However, from an operational point of view, this analytical distinction has important implications for the implementation of effective adaptation processes; significant synergies can indeed be created between adaptation and development efforts (Klein, 2010).

[28] For example, the map of the Thames Estuary in 2100 developed by the Environment Agency (2009) identifies a range of adaptation options to be approached in the context of uncertainty. The Plan concludes with a series of improvements to existing infrastructure, the decision to invest in a brand new physical device protecting against flooding may be delayed until a number of uncertainties concerning climate risk raise the level of knowledge.

[29] The complex relationships between adaptation and development are not unequivocal. Conceptually, the adaptive capacity cannot solely be analyzed with one level of development – which, however, is a central determinant (Tubiana et al., 2010). Even if adaptation has some specific characteristics in relation to development, the issue of adaptation and development are closely linked in practice.

To determine the costs of adaptation to anthropogenic climate change, the studies reviewed in this article had to determine a baseline against which to measure these sole costs. However, determining this level – and therefore quantifying the adaptation deficit – is particularly complex. In theory, such an effort would involve the evaluation of the components of development initiatives that improve resilience to anthropogenic climate change (Smith et al., 2011). Studies of the costs of adaptation have dreaded those difficulties and only considered a vaguely defined reference level (Parry et al., 2009). However, this adaptation deficit is particularly important in developing countries: in these countries, current investments are often well below what they should be to ensure adequate capacity to cope with present climatic variability and extremes. Applying a "mark up" factor to the fraction of investment that is considered as climate sensitive – a method used by studies of the first generation – does therefore not constitute a fully satisfying method for determining the costs of adaptation. Furthermore, if the adaptation deficit is not filled, the funds for adaptation will largely be insufficient to meet the challenges posed by anthropogenic climate change.

6. Conclusions

In comparison with the literature focusing on the costs of emissions abatement, research on the costs of adaptation to climate change is still in its infancy (Agrawala and Fankhauser, 2008; Fankhauser, 2010; IPCC, 2007; 2012; Parry et al., 2009). The most recent estimates of adaptation costs in developing countries range from US$4 to over 100 billion per year. For Fankhauser (2010), this wide range is symptomatic of the precarious state of knowledge. Accordingly, these estimates should be considered as indicative and incomplete, and should be approached with caution (Agrawala and Fankhauser, 2008; Parry et al., 2009; IPCC 2012). The costs of adaptation are likely to increase over time, as the impacts of climate change will be more commonly noticed. Moreover, if global warming cannot be kept at the 2-3°C level as it is assumed by the current generation of studies, the costs of adaptation are likely to increase exponentially (Fankhauser, 2010).

According to Agrawala and Fankhauser (2008) and Parry et al. (2009), future studies should pay particular attention when specifying their time frame. These authors also indicate that it would be useful to analyse the costs of adaptation in relation to different levels of impact, and the costs of residual impacts that adaptation would be unable to avoid.

The cost analysis of adaptation at the sectoral, national and global levels also leads to more fundamental difficulties. Adaptation is a concept with insufficiently defined boundaries. Which themes should be addressed within the area of adaptation is ambiguous, which in turn can lead to significantly affected cost calculations. Moreover, it is difficult to separate the adaptation to climatic stimuli from the adaptation to other risks. For example, agricultural practices, spatial planning and infrastructure design can all reflect some consideration of current and anticipated climate conditions, however it is difficult to assess the cost of the climate component of these investments since they are simultaneously also conditioned by many other factors. In addition, separating the costs of adaptation to natural climate variability and the costs of adaptation to anthropogenic impacts on the climate adds a significant layer of complexity to the analysis. Few examples of adaptation are indeed as clear as the raising of a dam to protect against rising sea levels.

Finally, the benefits of adaptation are rarely quantified, either at the sectoral, national or global levels. Various existing studies rarely price the impacts that are avoided by adaptation actions; therefore they cannot determine whether the benefits of these actions exceed their costs (Parry et al., 2009). This undoubtedly creates bias against adaptation strategies, since only the costs are known and therefore visible. This is another illustration – if any were needed – of the necessity to deploy additional research efforts into the emerging field of study to assess the overall costs and benefits of adaptation to climate change.

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