Chapter 2

Empirical Estimates of Adaptation Costs and Benefits: A Critical Assessment

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Empirical estimates of costs and benefits can serve as a key criterion for making decisions on adaptation. They can also be useful for establishing "price tags" for overall adaptation needs that would then need to be met through international, domestic, and private funding sources. There is a relatively large amount of information on adaptation costs at the sectoral level, although it is unevenly distributed. Studies for coastal zones show that while significant investment will be needed for coastal protection, total costs of protection represent a relatively small percentage of national Gross Domestic Product (GDP). However, there are significant regional differences and the normalised protection costs might be significantly higher for certain regions. In the agricultural sector, a general finding from available studies is that relatively modest adaptation measures can significantly offset declines in projected yield as a result of climate change, although these benefits depend upon the crop, growing region, and level of climate change. For the other sectors there are only a few isolated estimates of adaptation costs and benefits. Aggregate, multi-sectoral studies on costs of adaptation are also becoming available at the global level and, in some cases, at the national level. While potentially relevant from a policy perspective, available global and national estimates of adaptation costs have significant limitations: scaling up to aggregate levels from a limited (and very local) evidence base; issues of both under counting as well as double-counting; and finally lack of clear articulation of the benefits of the adaptation measures that are costed.

Introduction

Assessment of adaptation costs and benefits is driven, in principle, by two objectives. First, adaptation costs and benefits are relevant for sectoral or project level decision makers exposed to particular climate risks who need to make decisions about whether, how much, and when to invest in adaptation. The optimisation that is sought here is how to minimise the total costs of climate change – composed here of the cost of adaptation investments and the cost of residual damages. Costs can also serve as a key – but not the only[1] – criterion for selecting amongst competing adaptation measures. Such information has the potential to be of direct operational relevance at the sectoral and project level. In fact, most of the studies on adaptation costs and/or benefits are at the sectoral or project level. Second, at the international level, cost estimates can be used to establish "price tags" for overall adaptation needs that inform policy makers (and climate negotiators). They would then need to be met through international, domestic, and private funding sources. The precise benefits of such measures are usually not quantified. This is a relatively new and rapidly developing area of analysis, with many of the key results having emerged only since 2006.

This chapter provides a critical assessment of adaptation costs and benefits that address both the above mentioned objectives. The next section discusses the empirical estimates of adaptation costs and benefits in various climate sensitive activities/regions including coastal zones, agriculture, water resources, energy demand, infrastructure, public health, and tourism. The following section assesses available national level cross-sectoral cost estimates of priority adaptation actions identified in the National Adaptation Programmes of Action (NAPAs) of the Least Developed Countries (LDCs). The penultimate section then evaluates the results and underlying assumptions of a number of estimates of the global, multi-sectoral costs of adaptation that have become available since 2006. These include estimates published by the World Bank, Stern Review, Oxfam, the United Nations Framework Convention on Climate Change (UNFCCC), and the United Nations Development Programme (UNDP). Finally, the last section provides an overall assessment of the key messages, strengths and limits of the sectoral, national, and global estimates of adaptation costs and benefits.

1. Other criteria might include social acceptability, ease of implementation, ancillary effects, and long-term viability.

Sectoral estimates

Although sectoral and project level assessments offer fewer headline estimates than global assessments of adaptation costs, they generally offer more insight into the specific adaptation responses that are being costed compared to multi-sectoral assessments at the global and national levels, which are much more abstract. Therefore, information on sectoral climate change impacts and costs/benefits of measures should, in principle, provide the basis for higher order assessments.

There is a relatively large amount of information available about adaptation costs and benefits at the sectoral level, although it is unevenly distributed across sectors (Table 2.1). In particular, there is a significant body of literature accumulated since the early 1990s on assessing adaptation in coastal zones, including on the costs and benefits of such measures. Significant work has also been done on quantifying the benefits of adaptation strategies in agriculture, although very limited information is available on the costs of such measures. There is also literature in the energy sector on costing enhanced energy demand for air-conditioning and reduced demands for space heating as a result of warmer temperatures, to the extent such responses fall within the purview of adaptation. Beyond that, the literature on adaptation costs and benefits is both diffuse and limited, with a small number of local studies in water resources, health, infrastructure, and tourism.

Table 2.1. **Coverage of sectoral estimates of adaptation costs and benefits**

Sector	Coverage	Cost estimates	Benefit estimates
Coastal zones	Comprehensive – covers most coastlines	√	√
Agriculture	Comprehensive – covers most crops and growing regions	–	√
Water	Isolated case studies in specific river basins	√	√
Energy (Demand for space cooling and heating)	Primarily North America	√	√
Infrastructure	Cross-cutting issue – covered partly in coastal zones and water resources. Also isolated studies of infrastructure in permafrost areas.	√	–
Health	Very limited	√	–
Tourism	Very limited – winter tourism	√	–

The following sections review sectoral estimates of adaptation costs and benefits for coastal zones, agriculture, water resources, energy demand, infrastructure, tourism and public health. The precise structure of each section is dependent on the type of studies available. For example, while the discussion on coastal zones is more skewed towards adaptation costs the section on agriculture has a primary focus on adaptation benefits and has only very limited information on costs, in view of the available literature. Likewise there is fairly comprehensive geographical coverage in the case of coastal zones and agriculture, which makes some broad conclusions possible. However, the discussion on energy demand is largely limited to the United States, while only sporadic and largely local level information on adaptation costs and benefits is available for water resources, public health, tourism and infrastructure.

Coastal zones

Climate change will have complex impacts on coastal zones that will exacerbate existing pressures. Anticipated climate related changes include: an accelerated rise in sea level; further rise in sea surface temperatures; an intensification of tropical and extra tropical cyclones; larger extreme waves and storm surges; altered precipitation/run-off; ocean acidification; and degradation of coastal ecosystems. A majority of studies on climate change and coastal zones have focused narrowly on sea level rise. Consequently, studies estimating costs of adaptation in coastal zones have tended to focus on costs of adaptation to sea level rise, which is expected to reach 18-59 cm by the end of the 21^{st} century (IPCC, 2007a, Chapter 10). This range, however, does not include uncertainties associated with the potential melt of the Greenland and West Antarctic ice sheets, which could raise sea level by many metres in the long run (Oppenheimer *et al.*, 2007). In addition, due to the slow response of sea level rise to changes in climate, there is already a certain "commitment to sea level rise" irrespective of future cuts in greenhouse gas emissions. Given these long-term trends and the long lifetime of coastal structures, anticipatory adaptation to sea level rise becomes even more critical over the near and medium term.

Adaptation in coastal zones

Adaptation in coastal zones can take a wide range of forms, including planned retreat, coastal protection, beach nourishment, "flood-proofing", property insurance and changes in water management and aqua/agriculture. In general, there are three broad types of adaptation strategies:

- **Protect**: aims to protect the land from the sea so that existing land uses can continue, by constructing hard structures (*e.g.* seawalls) as well as using soft measures (*e.g.* beach nourishment).
- **Accommodate**: increases society's ability to cope with the effects of the event. This strategy implies that people continue to occupy the land but make some adjustments (*e.g.* elevating buildings on piles, growing flood- or salt-tolerant crops).
- **Retreat**: reduces the risk of the event by limiting its potential effects. This strategy involves no attempt to protect the land from the sea. In an extreme case, the coastal area is abandoned.

A summary of the major physical impacts and potential adaptation responses to sea level rise is provided in Table 2.2.

Table 2.2. **Physical impacts and examples of potential adaptation responses to sea level rise**

Physical impacts		Examples of adaptation responses (P = protection; A = accommodation; R = retreat)
Inundation, flood and storm damage	a. Surge (sea) b. Backwater effect (river)	Dikes/surge barriers (P) Building codes/floodwise buildings (A) Land use planning/hazard delineation (A/R)
Wetland loss (and change)		Land use planning (A/R) Managed realignment/forbid hard defences (R) Nourishment/sediment management (P)
Erosion (direct and indirect change)		Coast defences (P) Nourishment (P) Building setbacks (R)
Saltwater intrusion	a. Surface waters	Saltwater intrusion barriers (P) Change water abstraction (A)
	b. Groundwater	Freshwater injection (P) Change water abstraction (A)
Rising water tables and impeded drainage		Upgrade drainage systems (P) Polders (P) Change land use (A) Land use planning/hazard delineation (A/R)

Source: UNFCCC (United Nations Framework Convention on Climate Change) (2007), "Investment and Financial Flows to Address Climate Change", background paper on analysis of existing and planned investment and financial flows relevant to the development of effective and appropriate international response to climate change.

Empirical estimates of adaptation (protection) costs

The majority of studies assessing impacts of climate change on coastal zones have focused on impacts of, and adaptation to, sea level rise.

Table 2.3 summarises the results from a wide range of studies in different countries and regions, as well as at the global level. Typically, such cost estimates are based on models that seek to minimise the total costs of climate change, *i.e.* the costs of protection and the residual (unprotected) damages that will be incurred through loss of valuable endowments, such as land and natural habitats. The benefits in this case are the damages avoided as a result of protection. While not always reported explicitly, they are nevertheless a key component to computing optimal levels of protection. In regions with extremely valuable assets, total protection might indeed be optimal. In other cases, the optimal strategy might well be to invest in partial (or incomplete) protection and accept a certain amount of residual damages.

While Table 2.3 is clearly an abstraction and cannot fully capture all the complexities and nuances that might differentiate individual studies, three broad conclusions are nevertheless possible.

First, there is extensive information on adaptation costs for coastal regions worldwide, as well as on a global basis. Such costs though are only for coastal protection (as opposed to other possible adaptations), and have traditionally been estimated only for a 1 metre sea level rise.

Second, the reviewed studies show that optimal levels of coastal protection – defined as the percentage of coastline that is protected from sea level rise to minimise the total costs of sea level rise (*i.e.* costs of protection and residual damages) – are often quite high, if not total in most regions of the world. Exceptions include countries or regions where coastal land values are low (usually because of lower population densities) and therefore lower protection levels might be considered optimal.

Third, these studies show that the annualised cost estimates for optimal levels of protection are typically relatively modest in normalised terms, frequently less than 0.1% (or even 0.05%) of national GDP. However, adaptation costs may be high relative to the GDP of coastal areas, as it is not guaranteed that protection costs will be absorbed fully at the national level. There are also significant regional differences and the share of protection costs as a percentage of GDP will be significantly higher for certain small island states. For example, Nicholls and Tol (2006) estimate that adaptation will cost in the range of 5-13.5% of GDP for Micronesia under a range of scenarios for the 2080s.

Table 2.3. **Costs of coastal protection**

Regions/countries		Reference	Sea level rise considered	Protection level (% of coastline protected, unless otherwise noted)	Annual protection costs (In USD billions, unless otherwise noted)	% GDP or GNP
World	Global	Nicholls, 2007[1]	8.9-9.1 cm by 2030 (average); max 44.4-52.7 cm by 2080	Not available(N/A)	4-10.6	Not available (N/A)
		Tol, 2002	1 m	89%[7]	10.55	N/A
		Tol *et al.*, 1998	1 m	88%[2]	N/A	0.056% GNP[5] (average)
Europe and former Soviet Union (fSU)	OECD Europe	Nicholls, 2007[1]	8.9-9.1 cm by 2030 (average); max 44.4-52.7 cm by 2080	N/A	0.62-1.79	N/A
	Europe	EC, 2007	B2 (low sea level rise) and A2 (high sea level rise) scenarios for 2020 and 2080	N/A	EUR 1.3-4.0 billion for 2020 EUR 1.3-9.3 billion for 2080	N/A
	OECD Europe CEE fSU	Tol, 2002	1 m	86% 93%	1.36 0.53	N/A
	Western Europe	Deke *et al.*, 2001	1 m	Total	1.6	0.02% GDP[4]
	Northern and Western Europe Baltic States Northern Mediterranean Former Soviet Union	Tol *et al.*, 1998	1 m	0[2] 0[2] 16%[2] 0[2]	N/A	0.02% GNP[5] 0.08% GNP[5] 0.02% GNP[5] 0.02% GNP[5]
	Netherlands Poland	Tol *et al.*, 1998	1 m	95%[2]	N/A	0.05% GNP[5] 0.02% GNP[5]

Table 2.3. **Costs of coastal protection (cont.)**

Regions/countries		Reference	Sea level rise considered	Protection level (% of coastline protected, unless otherwise noted)	Annual protection costs (In USD billions, unless otherwise noted)	% GDP or GNP
North and Central America, Caribbean	OECD North America	Nicholls, 2007[1]	8.9–9.1 cm by 2030 (average); max 44.4-52.7 cm by 2080	N/A	0.88-2.02	N/A
	OECD America	Tol, 2002	1 m	77%	0.83	N/A
	North America	Deke *et al.*, 2001	1 m	Total	1.4	0.02% GDP[4]
	North America Central America	Tol *et al.*, 1998	1 m	47%[2] 89%[2]	N/A	0.02% GNP[5] 0.23% GNP[5]
	Antigua	Tol *et al.*, 1998	1 m	59%[2]	N/A	0.32% GNP[5]
South America and Latin America	Latin America	Nicholls, 2007[1]	8.9–9.1 cm by 2030 (average); max 44.4-52.7 cm by 2080	N/A	0.57-1.60	N/A
	Latin America	Tol, 2002	1 m	86%	1.47	N/A
	Latin America	Deke *et al.*, 2001	1 m	Total	0.12	0.01% GDP[4]
	South American Atlantic Coast South American Pacific Coast	Tol *et al.*, 1998	1 m	88%[2] 89%[2]	N/A	0.25% GNP[5] 0.01% GNP[5]
	Guyana	Nicholls and Tol, 2006	20-35 cm by 2080s	N/A	N/A	0.1-0.4% GDP[6]

Table 2.3. **Costs of coastal protection (cont.)**

Regions/countries		Reference	Sea level rise considered	Protection level (% of coastline protected, unless otherwise noted)	Annual protection costs (In USD billions, unless otherwise noted)	% GDP or GNP
Africa and Middle East	Africa Middle East	Nicholls, 2007[1]	8.9–9.1 cm by 2030 (average); max 44.4-52.7 cm by 2080	N/A	0.53-1.32 0.06-0.17	N/A
	Africa Middle East	Tol, 2002	1 m	80% 30%	0.92 0.05	N/A
	Middle East and North Africa Sub-Saharan Africa	Deke *et al.*, 2001	1 m	Total	0.44 0.17	0.08% GDP[4] 0.06% GDP[4]
	Southern Mediterranean African Atlantic Coast African Indian Ocean Coast Gulf States	Tol *et al.*, 1998	1 m	88%[2] 89%[2] 89%[2] 79%[2]	N/A	0.07% GNP[5] 0.25% GNP[5] 0.38% GNP[5] 0.05% GNP[5]
	Mozambique Guinea-Bissau	Nicholls and Tol, 2006	20-35 cm by 2080s	N/A	N/A	0.1-0.8% GDP[6] 0-0.6% GDP[6]
	Egypt	Tol *et al.*, 1998	1 m	-300%[2,3]	N/A	0.45% GNP[5]

Table 2.3. **Costs of coastal protection (cont.)**

Regions/countries		Reference	Sea level rise considered	Protection level (% of coastline protected, unless otherwise noted)	Annual protection costs (In USD billions, unless otherwise noted)	% GDP or GNP
Asia	Developing Asia	Nicholls, 2007[1]	8.9–9.1 cm by 2030 (average); max 44.4-52.7 cm by 2080	N/A	0.80-2.18	N/A
	South and South East Asia CPA	Tol, 2002	1 m	93% 93%	3.05 1.71	N/A
	South East Asia East Asia Asia Indian Ocean Coast Indian Ocean Small Islands	Tol *et al.*, 1998	1 m	89%[2] 87%[2] 89%[2] 88%[2]	N/A	0.2% GNP[5] 0.06% GNP[5] 0.52% GNP[5] 0.72% GNP[5]
	Pacific Asia OECD Pacific Asia China India	Deke *et al.*, 2001	1 m	Total	1.9 1.4 0.7 0.5	0.05% GDP[4] 0.19% GDP[4] 0.2% GDP[4] 0.25% GDP[4]
	Maldives Vietnam Cambodia	Nicholls and Tol, 2006	20-35 cm by 2080s	N/A	N/A	0-0.2% GDP[6] 0-0.2% GDP[6] 0-0.1% GDP[6]
	Singapore	Ng and Mendelsohn, 2005	20-86 cm by 2100	Total	NPV in 2000 USD: 0.17-3.08 million	N/A

Table 2.3. **Costs of coastal protection (cont.)**

Regions/countries		Reference	Sea level rise considered	Protection level (% of coastline protected, unless otherwise noted)	Annual protection costs (In USD billions, unless otherwise noted)	% GDP or GNP
Pacific	OECD Pacific	Nicholls, 2007[1]	8.9–9.1 cm by 2030 (average); max 44.4–52.7 cm by 2080	N/A	0.39-1.08	N/A
	OECD Pacific	Tol, 2002	1 m	95%	0.63	N/A
	Pacific Ocean Large Island	Tol *et al.*, 1998	1 m	76%[2]	N/A	0.17% GNP[5]
	Pacific Ocean Small Island			88%[2]		0.77% GNP[5]
	Marshall Island			90%[2]		>7.04% GNP[5]
	Micronesia	Nicholls and Tol, 2006	20-35 cm by 2080s	85-99%	N/A	5-13.5% GDP[6]
	Palau			65-95%		3.9- 9.1% GDP[6]
	Tuvalu			75-98%		0.9-2.2% GDP[6]
	Marshall Islands			N/A		0.6-1.7% GDP[6]
	French Polynesia			83-99%		0.4-1.0% GDP[6]
	Nauru			N/A		0.2-0.6% GDP[6]
	New Caledonia			43-93%		0.2-0.4% GDP[6]
	Papua New Guinea			75-98%		0.2-0.4% GDP[6]
	Kiribati			0-75%		0-1.2% GDP[6]

Table 2.3. **Costs of coastal protection (cont.)**

Regions/countries		Reference	Sea level rise considered	Protection level (% of coastline protected, unless otherwise noted)	Annual protection costs (In USD billions, unless otherwise noted)	% GDP or GNP
Other	Transition economies	Nicholls, 2007[1]	8.9–9.1 cm by 2030 (average); max 44.4-52.7 cm by 2080	N/A	0.16-0.48	N/A

1. This study provides protection costs for mean sea level rise in 2030 and maximum sea level rise in 2080 under A1B and B1 scenarios. The cost range reported here is the minimum and maximum under both scenarios and time periods.

2. Percent decrease in the number of "people at risk" (population in the risk zone multiplied by the probability of flooding per year).

3. The number of people at risk increases because adaptation allows people to remain in areas that would otherwise be abandoned.

4. Percentage of 1990 GDP assumed to remain constant each year between 1990 and 2100. Values in 1990 USD.

5. Annual percentage undiscounted, assuming 100 years lifetime.

6. Protection costs as a percentage of current GDP under the four Special Report on Emission Scenarios (SRES) worlds (A1FI, A2, B1, B2) for 2080.

7. This protection level corresponds to the median protection level for the nine regions provided in the study (protection levels are given separately for each region).

Limitations of cost estimates

The studies reviewed above have divided the costs of sea level rise into three categories: capital costs of protective infrastructure, costs of dry land loss, and costs of wetland loss. This, however, is a relatively simplistic treatment of the impacts of climate change on coastal zones and of the costs and benefits associated with adaptation.

Specifically, the costing studies face four key limitations. First, they consider a very narrow scope of climate change impacts and adaptation within coastal zones. On the impacts side, typically only inundation of coastal zones and wetlands are considered in such costing studies. Not included are other impacts, such as saltwater intrusion which could affect surface and groundwater supply, increased disease risk, increased exposure to storm surge and flooding. Inclusion of such considerations may significantly alter the choice of optimal strategies and estimates of protection costs. For example, Kirshen *et al.* (2006) show that accounting for storm damages (in addition to mean sea level rise) may significantly alter the costs and benefits of various adaptation measures, and influence the choice of optimal adaptation strategies. The authors modelled the impacts of sea level rise and storm surges, and estimated the potential costs and benefits of different adaptation measures for the Boston metropolitan area. Thus, land use planning and flood-proofing were shown to be optimal for mean sea level rise, while coastal protection was the optimal response if storm surge was taken into account. Adaptation costing studies also typically do not consider costs of adapting to more extreme scenarios of sea level rise, as would be the case if there were to be rapid melting of the Greenland and West Antarctic ice sheets.

Only one study (Nicholls *et al.*, 2005) has examined the consequences for climate damages and protection costs associated with the collapse of the West Antarctic ice sheet, which could raise sea levels by up to five metres in the long term. A wide range of scenarios is examined ranging from an additional contribution of 0.5 metre per century to an extreme (and unlikely) additional five metres between 2030 and 2130. Under such extreme scenarios the costs of adaptation rise dramatically (by as much as a factor of 30) and the level of optimal protection declines from 85 to 50%. Conversely, the studies are also limited in terms of the scope of the adaptation responses that are costed. Costing is limited only to hard protection measures (such as dykes), and in some cases also includes beach nourishment. However, many other adaptation responses to sea level rise, such as land use planning and building codes, are very difficult to cost and have thus been excluded from such assessments.

Second, as noted previously, protection cost estimates are based on models that seek to minimise the total costs of climate change, *i.e.* the costs of protection and the residual (unprotected) damages that will be incurred through loss of valuable endowments, such as land. Clearly, assumptions about costs of protection investments and the economic value of endowments which are at risk are critical to the final results. Both these parameters are based on key assumptions – protection costs are typically extrapolated from specific local projects, while endowment values are often not accurately known or comprehensive enough. For example, according to one study the uncertainties surrounding endowment values can lead to a 17% difference in coastal protection, a 36% difference in the amount of land protected, and a 36% difference in direct cost globally (Darwin and Tol, 2001).

Further, endowment values are often assumed to be static and do not reflect dynamic market realities. For example, Yohe *et al.* (1996) note that in a situation where the real estate market firmly believes that coasts will not be protected by public authorities and that land should eventually be abandoned, the risk of sea level rise should be internalised and property should be depreciated in accordance with the evolving conditions and accruing information. Based on this reasoning, the authors demonstrate that a 30-year foresight, assumed to be sufficient to allow for efficient property market adaptation, would not only reduce optimal levels of protection but also the total cost of sea level rise (damages + protection costs) in unprotected areas by 22 to 70% for a one metre sea level rise for five coastal communities of the east coast of the United States. An additional study by Yohe and Schlesinger (1998) for the entire developed coastline of the United States found that the cost of sea level rise would be reduced by 25-33% on average if markets adjusted efficiently. Efficient market adaptation or perfect foresight, however, requires timely and complete information, which is unrealistic. The reality will lie between the no foresight and perfect foresight estimates.

Finally, most studies focus only on the direct protection costs to sea level rise and do not consider that the level of investment in protective structures will likely have an impact on capital markets and that the diminution of natural resources due to land losses may well negatively affect national economies. Therefore, sea level rise and the response measures implemented will likely have macro-economic effects, such as increases in price level and shifts in the demand for capital resources. A limited number of studies have used Computable General Equilibrium (CGE) models to assess the economy wide impact of land loss and increased protection investment in coastal zones (Darwin and Tol, 2001; Deke *et al.*, 2001; Bosello *et al.*, 2007). Although these studies are based on slightly different assumptions[2] and are subject to significant limitations (in particular the uncertainties associated with projections of trade patterns and economic growth several decades into the future), they all conclude that there might be very significant divergence between direct costs and welfare losses, as well as in the regional distribution of these costs.

Agriculture

Climate change will impact agriculture in multiple ways. Changes in temperature and precipitation will affect the timing and length of growing seasons, as well as yields. These climatic changes will also affect water availability for agriculture. Increasing carbon dioxide concentrations, meanwhile, will have a positive effect on water use efficiency leading to higher yields for certain crops. Changes in climate variability, in particular changes in the intensity and/or frequency of floods, drought and storms, are also expected to significantly affect agricultural production. Regional yields are projected to increase up to 3ºC of warming in mid to high latitudes, while they are expected to decline in low latitudes for any increase in temperature (IPCC, 2007b, Chapter 5). In Africa and especially in Sub-Saharan regions the agricultural production could decrease leading to a growing number of people at risk of hunger (Yates and Strzepek, 1998; Parry *et al.*, 2004; Winters *et al.*, 1998; Fischer *et al.,* 2002). Adaptation will, therefore, be of particular importance to dampen the adverse regional impacts, maintain food production and access in many developing countries.

Adaptation in agriculture

The agricultural sector has a long record of adapting to climate. To a large extent these measures will be implemented at the farm level through short-term production decisions including adjustments in planting dates, crop mixes, or in the intensity of input use such as fertiliser. However, these

2. The Deke *et al.* (2001) study is restricted to the costs of coastal protection, ignoring land losses and its wider economic consequences. In addition, both Deke *et al.*'s and Darwin and Tol's (2001) studies model investments in coastal protection as a general loss of productive capital and ignore the induced investment demand for coastal protection and, thus, overstate the negative impacts of sea level rise (Bosello *et al.*, 2007). By contrast, Bosello *et al.* (2007) model coastal protection explicitly as an additional investment (thus including its demand effects) and assume that investing in coastal protection crowds out consumption rather than other investment (Bosello *et al.*, 2007). Finally, it is worth noting that while Deke *et al.* (2001) use a dynamic CGE model, Darwin and Tol (2001) and Bosello *et al.* (2007) use a static CGE model.

decisions will be largely influenced by the economic environment including market conditions and public policies. Public intervention will be important in providing a proper environment for adaptation, in particular by stimulating research and development, diffusing information and making markets and policy conditions conducive for efficient and sustainable adaptation. Table 2.4 outlines key farm and public level adaptations.

Table 2.4. **Adaptation strategies in agriculture**

Farm level	**Public level**
Crop and farm income insurance	Invest in research and development (*e.g.* develop heat resistant cultivars)
Diversification of production	Promote adoption of new technologies and practices
Adjust the timing of operations	Provide institutional support to diffuse information on climate change and adaptation possibilities (*e.g.* extension services, early warning systems)
Migration (move to cities or other rural regions)	Promote efficient use of resources (*e.g.* ensure market efficiency)
Adjust intensity of input use (*e.g.* fertiliser, irrigation)	Review policies to create an environment which is conducive for efficient and sustainable adaptation (*e.g.* water rights, environmental policies, trade policies, domestic support)
Adopt new production practices (*e.g.* conservation tillage)	
	Enhance agricultural trade to spread the impact of regional supply shortages over the international market

Given the complexity of agriculture and the multitude of decisions and actors involved, estimation of the costs and benefits of adaptation is an extremely challenging task. Two broad sets of approaches have been used, one focusing on crop impact models and how changes in management might affect yields, and the other looking at spatial analogues to examine the relationship between climatic factors and agricultural production. In both cases the literature has primarily focused on the assessment of the benefits of what are assumed to be low or no-cost adjustments in farming behaviour. Such estimates have been made from farm level studies, all the way to the global level. However, these benefits are not translated equally to all regions, all crops, or all levels of climate change. Aggregate estimates of adaptation costs in agriculture are relatively rare, although there are now some preliminary estimates of the magnitude of public investments that might be required to facilitate adaptation in agriculture.

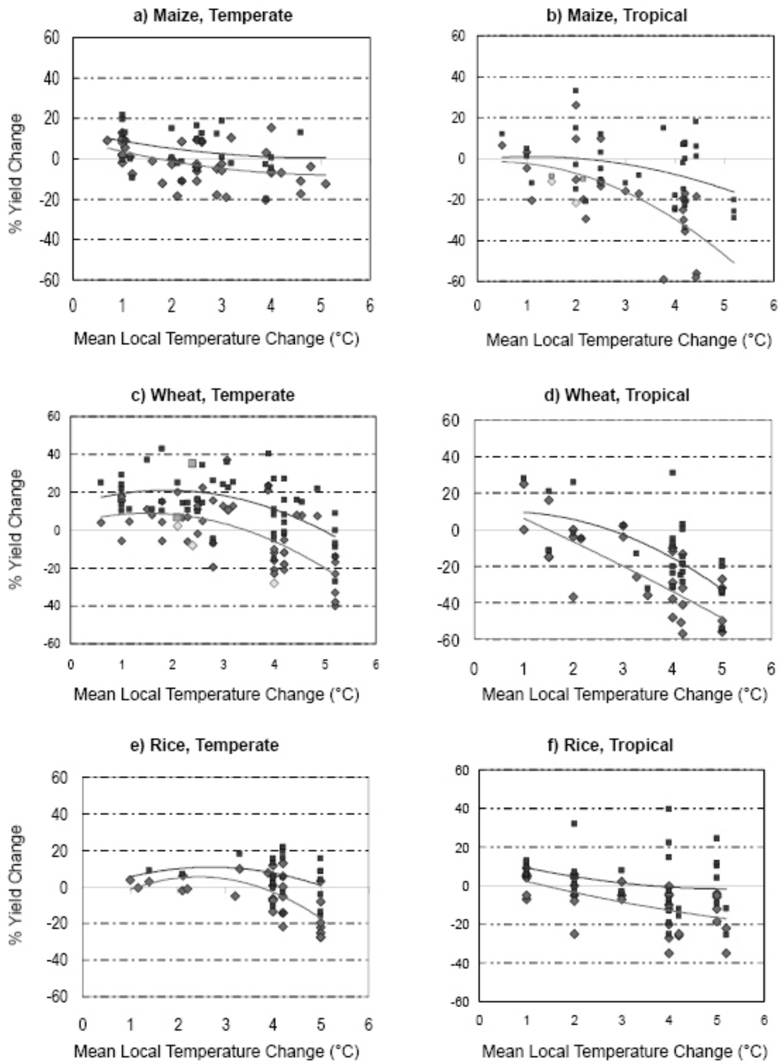
Benefits and costs of adaptation in agriculture

The agricultural sector has been fairly well covered by the climate change adaptation literature. Salient studies include Reilly *et al.* (1994) and

Darwin *et al.* (1995), which looked at climate change and adaptation impacts on world agriculture and economy, as well as a global assessment by Rosenzweig and Parry (1994), which reported the impacts and adaptation benefits in terms of increased cereal production and food security. A general finding from the global-level studies is that relatively modest adaptation measures can significantly offset declines in projected yield as a result of climate change. Rosenzweig and Parry (1994) using the crop impact modelling approach concluded that such adaptations could offset yield declines by anywhere from 37.5 to 200%. Using spatial analogues, Darwin *et al.* (1995) computed global adaptation benefits to range from 78-90% of the initial impacts. However, their assessment of adaptation was relatively simplistic, leaving large uncertainties with regard to its true potential. Recent studies provide a more comprehensive treatment of adaptation by relaxing the assumptions of smooth climatic change and perfect foresight by decision makers, or using higher spatial resolution climate change scenarios. Tan and Shibasaki (2003), using a geographical-information-system-based crop model and allowing for modelling of inter and intra-regional bioclimatic differences, computed global adaptation benefits of low cost adjustments in the range of 23-48%.

There are also a large number of studies that assess the benefits of adaptation for different crops and regions. Figure 2.1 presents a synthesis from 69 published studies on the impacts of climate change on crop yields for maize, wheat and rice (IPCC, 2007b, Chapter 5). The adaptation measures considered in these studies include changes in planting dates, changes in cultivars, and shifts from rain-fed to irrigated agriculture. "Best fit" curves are shown for crop yields without adaptation (light, lower curve), and with adaptation (dark, upper curve). The adaptation benefit, in this figure, then is the difference between these two curves. More specific results from a select number of studies are shown in Table 2.5. A key message from these various studies is that farm level adjustments do yield significant adaptation benefits. However, such benefits do not translate equally to all regions, crops or levels of climate change. Some studies also suggested that even in the absence of financial or environmental constraints potential benefits of climate change adaptation could be significantly reduced by climate variability and imperfect information and decision-making processes.

Figure 2.1. **Adaptation benefits for cereal crops in temperate and tropical regions**[1]



1. The adaptation benefits are shown as the difference between the lower (no adaptation) and upper (low cost adaptation) yield curves which are based on a synthesis of 69 published studies.

Source: Published with the permission of the Intergovernmental Panel on Climate Change; Easterling, W.E., *et al.* (2007), "Food, Fibre and Forest Products. Climate Change 2007: Impacts, Adaptation and Vulnerability", contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, in M.L. Parry *et al.* (eds.), *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, pp. 273-313.

Table 2.5. **Quantified adaptation benefits in agriculture from selected studies**

Study	Climate scenario	Area	Adaptation	Impacts: Without adaptation	Impacts: With adaptation	Adaptation benefits (% of impacts)
Tan and Shibasaki, 2003	CGCM1/ for 2050		Changes in planting dates	Yield changes		
		Asia		-12%	-8%	33%
		North America		-23%	-12%	48%
		South America		-29%	-18%	38%
		Europe		-23%	-13%	43%
		Australia		-26%	-19%	27%
		Africa		-35%	-27%	23%
Butt *et al.*, 2005	CGCM, HADCM /for 2030	Mali		Yield changes		
			Heat resistant variety	-8.8%	-3.2%	63%
				Welfare changes		
			Change in crop mix	N/A	N/A	29-33%
			Heat resistant variety			33-34%
			Market adaptation			58%
			Full adaptation			90-107%
				Risk of hunger (ROH) decreases		
			Change in crop mix	N/A	N/A	7-11%
			Heat resistant variety			0-1%
			Market adaptation			7-14%
			Full adaptation			30-35%
Njie *et al.*, 2006	HADCM3 /2010-39	The Gambia		Yield changes (kg/ha)		
			Changes in crop mix	1 141	1 294	13%
			Increased fertiliser use		1 517	33%
			Irrigation		1 563	37%
			Minimal/survival irrigation		1 247	9%

Table 2.5. **Quantified adaptation benefits in agriculture from selected studies (cont.)**

Study	Climate scenario	Area	Adaptation	Impacts		Adaptation benefits (% of impacts)
				Without adaptation	With adaptation	
Yates and Strzepek, 1998		Egypt	Extensive adaptation measures[1]	Welfare changes (%)		
	GDFL(600ppm/2060)			-4.25	2.85	167%
	UKMO(640ppm/2060)			-4.60	-0.70	115%
	GISSA(630ppm/2060)			0.50	4.50	800%
				Trade deficit changes		
	GDFL(600ppm/2060)			44.0	30.5	31%
	UKMO(640ppm/2060)			48.5	19.0	61%
	GISSA(630ppm/2060)			11.4	-5.7	150%
Reilly *et al.*, 2001	IS92a (HaDCM, CGCM)	United States	Changes in planting dates and cultivars	Yield changes (%)		
	2030	All crops		12.6	18.3	45%
		Irrigated crops		7.5	13.8	84%
		Grains rain-fed		20.9	32.0	46%
		Fruits and vegetables Rain-fed		22.4	62.7	1%
	2090	All crops		29.5	38.8	31%
		Irrigated crops		19.8	28.8	45%
		Grains rain-fed		32.0	53.8	68%
		Fruits and vegetables rain-fed		62.7	63.6	1%

Table 2.5. **Quantified adaptation benefits in agriculture from selected studies (cont.)**

Study	Climate scenario	Area	Adaptation	Impacts: Without adaptation	Impacts: With adaptation	Adaptation benefits (% of impacts)
Adams *et al.*, 2003	High resolution RegCM (540ppmCO2)	United States	Changes in planting dates and cultivars	Yield changes		
		Dry land crops		4.3%	15.4%	262%
		Irrigated crops		9.3%	11.6%	26%
				Welfare		
		Deterministic		.32	3.61	1061%
		Stochastic[2]		-2.05	2.65	229%
	Low resolution CSIRO (540ppmCO2)	United States		Yield changes		
		Dry land crops		8.8%	19%	117.1%
		Irrigated crops		8.6%	10.6%	23.2%
				Welfare		
		Deterministic		3.05	5.69	87%
		Stochastic		3.51	7.43	112%
Stuczyinski *et al.*, 2000	GISS and GDFL (2xCO2)	Poland	Changes in cultivars, crop mix, and management practices	Change in agricultural production		
				-5 to -25%	5%	20-100%

1. Includes large shifts in planting dates (>1 month), increased fertiliser applications, and new investments in irrigation (as defined by adaptation level II in Rosenzweig and Parry, 1994).

2. The stochastic version of the model accounted for climate variability.

In particular, adaptation measures are projected to have very limited benefits in many African contexts. A study of Malian agriculture shows that on-farm adjustments in planting dates do not offer significant benefits in terms of offsetting yield impacts (Butt *et al.*, 2005). A study in The Gambia, meanwhile, presents a more nuanced picture (Njie *et al.*, 2006). For the period 2010-39 climate change is projected to increase millet yields slightly. However, this increase can be amplified significantly through adaptation measures. Specifically, fertiliser use could increase yields by 33% and irrigation by 37%. Over the longer term (the period 2060-90) millet yields could decline (by almost 300%) if precipitation were to decline during the cropping season. This would require significant investments in irrigation. A benefit-cost analysis was then performed, which concluded that irrigation would not be an economically viable option at the farm level.

The literature on the cost side of the adaptation equation for agriculture, meanwhile, is almost entirely lacking. As noted earlier, this is in part because the focus has been on farm level adjustments, which are shown to significantly offset climate change impacts on yield, while assumed to themselves cost very little. However, agricultural production is influenced significantly by public policies and there is a need to ensure that these interventions provide a conducive environment for adaptation at the farm level. This may include the provision of public goods (*e.g.* research on drought resistant crop varieties, climate forecasts).

One recent study estimates that the scale of such additional investment needs for agriculture, forestry and fisheries will be USD 14.23 billion per year by the year 2030 (McCarl, 2007). Specifically, three types of investments are costed: in research (*e.g.* in drought resistant seed varieties), agricultural extension, and physical capital (such as irrigation infrastructure). The levels of investments in each of these three categories for the year 2000 are projected to the year 2030 based on assumptions about their growth under business as usual (*i.e.* in the absence of climate change). Next, fairly *ad hoc* assumptions are made on what additional percent increments might be needed to these investments by the year 2030 in the light of climate change. For example, it is assumed that research expenditures would need to increase by an additional 10% to address climate change, without explicit discussion of the precise impacts that such research investments would seek to offset or how such a costing estimate was made. Likewise, the investments in physical capital are assumed to increase by 2% globally (and investments in agricultural extension by 10% in developing countries) to respond to climate change, again with very limited justification. The costs of adaptation, therefore, are not calculated independently. Rather, they follow directly from these assumed percentages of incremental investments which are then multiplied to very large baseline investment flows. These shortcomings raise questions about the reliability of the results.

Water resources

Water supply will be affected by changes in temperature and shifts in precipitation patterns. The impacts of climate change on precipitation are quite uncertain and will differ significantly across regions. These changes will affect many sectors which depend on water supplies, including drinking water supplies, waste water treatment, and agriculture. Off stream uses, such as navigation and hydropower, will also be impacted. In addition, river water quality may also be affected due to lower streamflow, higher temperatures, and higher concentration of organic matter linked to more intense precipitation and erosion. Ecosystem health may be impacted by both poorer water quality and changes in flow regimes.

Adaptation in the water sector requires a combination of both supply and demand side measures. Supply side measures fall into two broad categories: *(i)* supply enhancement, by building new storage capacity, prospecting and extracting ground water, removing invasive species from water storage, rainwater harvesting and water transfers; and *(ii)* harnessing unviable water through desalinisation, wastewater reclamation and other measures. On the demand side, meanwhile, measures focus on reducing demand and promotion of more efficient water use through measures that include recycling, changing usage patterns, importing water-intensive products, increased use of rain-fed agriculture, greater use of water markets and other economic incentives.

While very limited, the literature on adaptation in the water sector covers a diversified set of impacts and adaptation measures. This section reviews the few studies looking at the costs and benefits of adaptation measures related to these impacts, followed by an evaluation of the only published costing of adaptation measures at the global level.

Regional and local cost/benefit estimates

Costs and benefits have been assessed for adaptation measures that offset the impacts of climate change on water availability, reliability of water supplies, as well as on water quality. In the United States, Kirshen *et al.* (2006) assessed the reliabilities of local and regional water supply systems in metropolitan Boston under climate change. To assess supply reliability, the authors derived water demand from projections of population and economic growth. These were then used in conjunction with water supply scenarios as determined by climate change impacts on precipitation and evapo-transpiration. Under the baseline scenario of no adaptation to climate change, it was found that the reliability of local water supply systems would decline from 100% currently to less than 80% by 2100. These declines, however, could be offset (modestly) by demand side management, while connecting local systems to the main regional water system could significantly boost the reliability to almost 100%. The costs of these measures were not evaluated. The same study, however, does examine the costs of adaptation measures to maintain water quality in the Assabet River near Boston. Here climate change primarily impacts water quality through increases in nonpoint source pollution and stream temperatures and lower low flows. The adaptation strategies studied included the additional cost related to extra treatment of wastewater in order to reduce the input of nutrients in the river and also the establishment of wetlands and infiltration basins to reduce non-point source inputs. Results indicate that climate change and population increase would lead to USD 30-39 million in capital cost and USD 300 000 to USD 600 000 in annual operating costs to maintain aquatic communities in the Assabet River. Without these changes, capital costs to meet water quality goals would be USD 22.5 million with operating costs of USD 210 000. Most of the changes are due to climate change as most of the region is close to full development.

Some estimates are also provided for adaptation costs related to water utilities in Canada. Dore and Burton (2001) looked at adaptation costs in response to impacts of climate change on the availability of drinking water supply and the capacity of treating wastewater. Water utilities are expected to be affected by climate change since the timing and regional patterns of precipitation may change. As precipitation is projected to increase in many regions, drinking water supply is not likely to be affected by climate change. However, many regions will face adaptation costs as rainfall increases beyond existing capacities for wastewater treatment and storage and, thus, such capacities will need to be expanded. The authors considered potential adaptation strategies, such as building new treatment plants, improved efficiency of actual plants, or increases in retention tanks. Results indicated that adaptation costs for Toronto could be as high as CAD 9 400 million if extreme events are considered.

A different approach was taken by Muller (2007) who estimated the costs of adapting urban water infrastructure in (Sub-Saharan) Africa to climate change to be USD 2-5 billion annually. This study relies on three assumptions: *(i)* reliable yields from dams will reduce at the same rate as stream flow: a 30% reduction in average stream flow will result in a 30% reduction in yield and the unit cost of water will increase by more than 40%; *(ii)* where waste is disposed into a stream if stream flow is reduced by 30%, the pollutant load must be reduced by 30% and as treatment costs to achieve lower pollution levels increase rapidly overall cost of wastewater treatment could double; and *(iii)* power generation reduces linearly with stream flow: a 30% reduction in stream flow will result in a 30% reduction in electricity production.[3] The cost estimates in this study were divided into costs of adapting existing water infrastructure, which ranged from USD 1 050 million to USD 2 650 million, and costs of new developments, which were estimated to rise by between USD 990 million and USD 2 550 million.[4]

At a more local level, Callaway *et al.* (2006) provide estimates of water management adaptation costs and benefits for the Berg River basin in South Africa. Adaptation measures investigated include the establishment of an efficient water market and an increase in water storage capacity through the construction of a dam. Accounting for climate change impacts on urban and farm demand, they provided cost and benefit estimates for storage and water market adaptation strategies. The discounted impact of climate change over the next 30 years was estimated to vary between ZAR 13.5 billion and ZAR 27.7 billion. The net welfare benefits of adapting water storage capacity under current allocation rights were estimated at about ZAR 0.2 billion, while adding water storage capacity in presence of efficient water markets would yield adaptation benefits between ZAR 5.8 billion and ZAR 7 billion. The authors assessed the robustness of adaptation responses and showed that under efficient water markets, the costs of not adapting to climate change that does occur outweigh the costs of adapting to climate change that does not occur.

Climate change is likely to lead to rapid glacier retreat, which will disrupt the water cycle in the many glacier-dependent basins, such as in the Andes, and thus affect water regulation and availability.

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3. The study uses unit costs derived from project experience to calculate the costs of adapting existing urban water infrastructure. For the costs of new developments, the study assumes that the costs of adapting to climate change for new developments will be similar to those for existing systems.

4. Breakdown of costs to adapt existing urban water infrastructure: USD 500-1 500 million capital costs for urban water storage (USD 50-150 million annual equivalent); USD 100-200 million annually for wastewater treatment; and USD 900-2 300 million annually for electricity generation. Breakdown of costs for new developments: USD 150-500 million capital costs for urban water storage (USD 15-50 million annual equivalent); USD 75-200 million annually for wastewater treatment assuming an additional 100 million people served; USD 900-2 300 million annually for electricity generation assuming installed capacity doubles.

Vergara *et al.* (2007) estimated potential adaptation costs to climate change for Quito, Ecuador. The authors suggest that the city will have to divert additional water and build new water infrastructure at an accelerated pace in order to cope with a reduction in water yields and supply from existing water sources due to glacier retreat. They estimated the incremental net present value of the accelerated investments required for the next 20 years to be around USD 100 million. This represents a 30% increase over the infrastructure required under the "no climate change" scenario.

Finally, climate change will also affect the management of river floods, through increases in precipitation and extreme events, which are likely to alter river discharges. A case study examining the impact of climate change on river flood management for the river Rhine was carried out by the European Environment Agency (EEA, 2007). Climate change is expected to have a significant effect on peak discharges of certain European rivers, such as the Rhine. Policies designed to manage river floods need to take into account not only the long-term natural and socio-economic developments but also the risks presented by climate change. The EEA study concluded that adaptation could reduce most of the climate change induced increases in river flooding risks at relatively modest costs. Optimal flood defence investments were estimated to cost around EUR 1.5 billion and to lead to significant benefits by reducing climate-induced flood damage from EUR 39.9 billion to EUR 1.1 billion over the 21st century.

Overall, the literature on adapting water supply and demand in response to the impacts of climate change at the regional level is still too sparse and context specific to make a broad assessment with regard to the costs. Nevertheless, some messages do emerge from this limited literature. For regions where precipitation is expected to increase, issues such as flood management and waste water treatment may become problematic and impose substantial additional costs. On the other hand, in regions where precipitation will decline or where water availability might decline on account of glacier retreat, investments in enhanced storage, as well as enhancing the efficiency of water allocation becomes highly valuable. However, drawbacks in terms of market access for urban poor and related social impacts may need to be investigated. To ensure supplies of drinking water, a diversification of supply sources through the interconnection of supply systems can also prove to be beneficial. Maintaining river water quality may also be very costly for public authorities.

Global costs

There is only one assessment of the costs of adaptation in water resources at the global level (Kirshen, 2007). This study estimates the global costs of adaptation associated with additional water infrastructure needed by 2030,[5] given present and future total projected water demands for four sectors (urban domestic/commercial, irrigation, rural domestic and industrial), and water supplies in more than 200 countries. Four main water production utilities are costed: additional surface storage reservoirs and ground water wells to supplement existing reservoirs and wells, as well as desalination plants and water reclamation technologies in case of "water shortages". The study compares future projected water demands from different sectors to water supplies. Next, the need for additional production infrastructure is determined, based on an assumed international legislation that would limit 2050 water withdrawals to 40% of 2050 total available national water resources.[6] If one country has water withdrawal requirements that are largely covered by its internal water availability (and therefore is in line with the mentioned legislation), the additional reservoir storage and wells needed are determined and costed. It is assumed that water demands have to be covered in the following order of priority: domestic/commercial, industrial and agricultural irrigation needs. If instead, one nation cannot meet the international legislation because it faces "water shortage", *i.e.* withdrawal requirements exceed 40% of its mean annual flows (MAF), it has to resort (in order of priority) to desalination for domestic/commercial and to reclaimed water for irrigation needs. Implementation costs of these technologies are then evaluated and added to additional storage and wells required. Even using all these sources, some nations will still face water shortages and will have to rely upon virtual water to meet their needs.

The overall conclusion of this assessment is that adaptation costs in the water sector will amount to a total of about USD 531 billion for the period up to 2030. However, these costs include adaptation responses to both economic and climatic changes. The costs of adaptation to climate change alone are not isolated from other investments needed. While USD 80 billion, equivalent to 15% of total adaptation costs, are estimated to be needed in

5. The analysis period is 2030, but since water resource investments are typically made at least for 20 years in the future, the planning period is 2050. This assumes that nations are willing to plan ahead for climate change. Therefore, national water supply and demand estimates were obtained for 2050.

6. This study assumes that there will be an international requirement that in-stream flows must be at least 60% of mean annual flows (MAF), as presently many watersheds are over abstracted. This means that a maximum of 40% of MAF can be used for water withdrawals (off-stream use). The MAF is that of a nation's available water resources, which includes its internally generated water resources as well as reasonable upstream releases of surface water from countries with excess water.

North America and Europe jointly, USD 451 billion (85%) are estimated to be required in developing countries, mainly Asia and Africa.

The assessment by Kirshen (2007) was subsequently modified and published in UNFCCC (2007), which reports the total global adaptation costs to be USD 898 billion for the period up to 2030. These updated costs consider two factors which had not been costed in the Kirshen (2007) study: *(i)* the increase in reservoir and groundwater costs as the best located sites are developed; and *(ii)* unmet irrigation demands. The UNFCCC update also reports the costs of adapting specifically to climate change as 25% of the total costs, *i.e.* USD 225 billion for the period up to 2030, equivalent to approximately USD 11 billion per year (UNFCCC, 2007).

While the analytical approach in this assessment is fairly detailed, there are nevertheless some key limitations. First, the cost estimates do not include operation and maintenance costs. Second, the empirical numbers on costs of specific measures are typically taken from specific examples from the United States before being scaled up to various regions based upon the regional differences of costs.[7] Third, and perhaps most importantly, although the study accounts for improvement in water-use efficiency the study only costs supply side adaptation options (such as investments in new storage) without explicitly estimating the costs of demand side measures, such as promotion of indigenous practices for sustainable water use, increased use of rain-fed agriculture or expanded use of water markets and other economic incentives. Inclusion of such demand side measures could significantly lower the adaptation costs.

Energy demand

The literature on adaptation costs in the energy sector is limited to the costs associated with increases in energy demand for cooling in the summer and reduced heating in the winter. In terms of geographical coverage the literature is largely limited to the United States. The cooling demand (which will increase) is met entirely by electricity, while the offset due to reduced heating demand in the winter will be distributed amongst multiple energy sources. Whether there will be net adaptation costs or benefits is also dependent upon assumptions that are made about the future evolution of building stocks.

Rosenthal *et al.* (1995) used an engineering "bottom-up" model and found net benefits, that is a net reduction in energy consumption, of

7. While all costs were scaled, the scale factor used was only taken from irrigation data, as this data was readily available.

5.3 billion (1990 USD), for the US economy under the assumption of a one degree temperature rise by 2010. Meanwhile, Morrison and Mendelsohn (1999) used a "top-down" approach, and looked at the climate change impacts on US energy demand, disaggregating by sectors and fuel/energy types. The authors report net adaptation costs (*i.e.* increased energy expenditures) ranging from 1.93 billion (1990 USD) to 12.79 billion (1990 USD) for the 2060 horizon. The difference between these results and the net benefits computed by Rosenthal *et al.* (1995) is partly explained by the different time horizons considered in the two studies, and partly because the bottom-up study had more optimistic assumptions about the potential for energy savings.

The estimates of the net adaptation costs or benefits in energy demands are also sensitive to the assumptions that are made about the future evolution of building stocks. Morrison and Mendelsohn (1999) and Mendelsohn (2003) differentiated between scenarios with and without changes in climate sensitive building characteristics.[8] The two studies conclude that including evolution in building characteristics significantly increases the cost of adaptation, as future buildings will have greater cooling capacity. For the 2060 time horizon, the studies estimate that changes in building stocks and characteristics raised the cost of adaptation by 2.98 billion (1990 USD) to 8.57 billion (1990 USD) depending on the underlying economic scenario. Sailor and Pavlova (2003) reach similar conclusions. For the city of Buffalo (United States) the authors report that up to two-thirds of estimated energy consumption rise was induced by the growth in the cooling market. A more recent study, by Mansur *et al.* (2005) examines the impact of climate change not only on energy demand, but also on the choices between energy types. The authors conclude that climate change leads towards a shift in favour of electricity consumption relative to other energy sources since it is the primary source of cooling energy. Taking this shift in energy mix into account, the authors estimate a net increase in US energy expenditures ranging from 4-9 billion (1990 USD) for 2050 and from 16-39.8 billion (1990 USD) for 2100, depending on the severity of climate change.

A few general conclusions can be drawn from the literature on energy costs. First, at least for the United States, the majority of studies conclude that the adaptation costs of increased cooling will be greater than the

8. Morrison and Mendelsohn (1999, p. 218), included climate sensitive building characteristics such as "building material, conservation efforts, the choice of heating and cooling equipment, and energy-consuming appliances as well as some aspects of building structure such as the number of rooms, doors, and windows."

benefits associated with reduced heating demands. Second, the studies are yet to systematically assess the effects of changes in climate variability, and also how market forces might mediate the shifts in energy demand through changes in prices. Finally, the trade-offs between increased cooling versus reduced heating will be different for other regions and countries. With the exception of Cartalis *et al.* (2001) who provided estimates for the southeast Mediterranean region, assessments of the adaptation costs in the energy sector outside of the United States are scarce. One recent study, however, has examined the investment costs that might be needed in additional energy generation capacity to meet the additional demand for air conditioning in the Paris region (Hallegatte *et al.*, 2007). New work is also currently underway to examine the effects of hotter summers and milder winters on a global basis but there are no empirical estimates yet on the costs of adaptation (Di Cian *et al.*, 2007).

Other sectors: infrastructure, tourism and public health

Beyond coastal zones, agriculture, water resources, and energy demand that have been reviewed in preceding sections, there are only three areas where a few isolated estimates exist for adaptation costs and benefits. These are infrastructure, (winter) tourism, and public health.

Infrastructure

Infrastructure is part of the adaptation solution in many climate sensitive sectors. It is also a high value asset which is particularly vulnerable to climate change on account of its long lifetime, over which climate change impacts will become progressively more pronounced. Adaptation costs for infrastructure, therefore, could have two interlinked but different meanings: *(i)* the costs of infrastructural solutions that serve as adaptations in many climate sensitive sectors or regions; and *(ii)* the costs of "climate-proofing" infrastructure itself to the impacts of climate change. With regard to the former perspective, many of the cost estimates for adaptation in coastal zones, water resources, energy, and (to some extent) agriculture are, in fact, infrastructure costs. This includes costs of protective structures in coastal zones, storage or irrigation infrastructure for agriculture and water supply, as well as energy supply infrastructure – that have been discussed already.

Taking the latter perspective, meanwhile, there are some cost estimates that are available for specific local contexts – for example the costs of building the Confederation Bridge in Canada one metre higher than currently anticipated to accommodate sea level rise, or raising the sewage treatment facility on deer island in the Boston harbour, again to take sea level rise into account (IPCC, 2007b, Chapter 17). In such cases, the precise cost numbers, while extremely relevant from a project planning perspective, do not really offer any insights that might be of broader policy relevance.

Beyond that, only very few studies exist which have attempted to provide more aggregate information. One study, for Canada, costs two infrastructure related adaptations: the replacement of the Canadian winter/ice road network by "all weather roads" in response to rising temperatures; and investment in enhanced rainwater storage and wastewater treatment facilities (Dore and Burton, 2001). The total costs of these measures are estimated to be in the range of CAD 3.5-12 billion for the year 2100. A more recent study examines the cost of adapting public infrastructure in Alaska to five impacts associated with climate change: permafrost melt, sea level rise, accelerated coastal erosion, increased flooding, and increased fire risk. The study estimates that the repair and replacement cost for 16 000 pieces of public infrastructure in Alaska to adapt to these impacts by the year 2030 will be as much as USD 6.1 billion, which is a 20% increase from baseline investment levels (Larsen *et al.*, 2007). In contrast to these two bottom-up studies, which aggregate micro-level data, the third study is more top-down and estimates the worldwide costs of adapting infrastructure to range from USD 7.8-130 billion by the year 2030 (Satterthwaite, 2007).

(Winter) tourism

Studies investigating costs of adaptation to climate change in the tourism sector have mainly focused on winter tourism and the ski industry. Winter tourism is likely to be most hit, as it could become effectively impracticable in some regions. Agrawala (2007) and Bosello *et al.* (2007) assess adaptation measures in the winter tourism sector/industry and some of the costs provided for technological adaptations. The range of adaptation practices found among ski area operators can be divided into two main categories: technological and behavioural. Technological adaptations appear so far to be the main types of adaptation strategies adopted by tourism stakeholders in the European Alps. There are four main types of technological adaptations: landscaping and slope development; a move to higher altitudes and north facing slopes; glacier skiing; and artificial snow making. Behavioural adaptations range from operational practices and financial tools to new business models and a move towards the diversification of activities. Few cost estimates exist, but there are *ad hoc* numbers for some technological adaptations, especially for artificial snow making. Costs for behavioural adaptations are not provided, as these measures are complex and difficult to cost.

While some adaptation strategies, such as the protection of glaciers with white sheets, can be relatively cheap (cost of EUR $3/m^2$), other strategies, such as extending ski areas to high elevations and artificial snow-making, can be expensive. For example, Mathis *et al.* (2003), who carried out a survey of projected ski area developments in Switzerland, found that the high mountain extensions would cost between EUR 25-30 million. In France, for the 2003-04 winter season, investment costs for snow-making material reached EUR 60 million. However, the investment in new snow-making equipment rarely represents the development of completely new installations but an extension to or improvement in current equipment. Operational costs for that same season in France reached EUR 9.4 million.

Costs of snow making are divided into investment costs, operational costs and maintenance costs. Different figures are available with regards to the production of one cubic metre of snow. For example, the Association of Austrian Cableways estimates the costs to be between EUR 1-5, while another study estimates the costs to be between EUR 3-5 per cubic metre (CIPRA, 2004). This latter study also estimates that it costs on average EUR 136 000 to cover one hectare with artificial snow. The annual operating costs in Switzerland vary between EUR 19 000 and 32 000 per kilometre. For example, in the canton of Valais/Wallis in Switzerland the operational costs of a snow-making system were estimated at EUR 33 000 per kilometre. However, there is only a small difference of about EUR 2 000 between normal and snow-deficient winters.

However, these adaptations are not necessarily sustainable in the long term and may also generate negative externalities. For example, glacier skiing may not be sustainable, as it is estimated that by 2050 about 75% of glaciers in the Swiss Alps will have disappeared and that by 2100 the whole of the Alps could lose almost their entire glacier cover. Other adaptations are likely to have detrimental environmental impacts. Interventions of bulldozers and excavators, the installation of ski transportation facilities, the implantation of artificial snow pumps and increase in artificial snow making can be very destructive on the environment, lead to “scars” on the Alpine landscape, impact water supplies, and increase energy consumption with consequent impact on greenhouse gas emissions (Abegg *et al.*, 2007). These environmental externalities have not been considered in the costing studies, and their inclusion may increase costs significantly.

Public health

While there is extensive literature on the implications of climate change on public health[9] on the one hand and on the costs and benefits of delivering health services on the other, specific information on adaptation costs and benefits in this sector is still embryonic. Only one study provides global adaptation costs to climate change in the health sector (Ebi, 2007). It estimates direct adaptation costs in a bottom-up approach by investigating treatment costs of additional number of cases limited to three health outcomes: diarrhoeal diseases, malnutrition and malaria. Globally, the study estimates these costs to amount to a total of USD 4-5 billion by 2030,[10] primarily in developing countries.[11] The study also presents a high cost estimate of USD 11-12.6 billion although no further explanation is provided.

While the above mentioned study explicitly isolates adaptation costs induced by climate change it does have some important limitations. It does not, for example, include costs of setting up new infrastructure needed, which may be important especially in developing countries.

More generally, costing the component of investments in public health infrastructure that might be needed to address climate change as opposed to those required on account of social and demographic trends is not straightforward. Further, the boundary between what constitutes climate change impacts and what might be an adaptation is not entirely clear in the case of public health. Specifically, the costs of treatment of climate sensitive diseases could equally be included under the impacts of climate change and

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9. See for example, the PESETA Project co-ordinated by the Institute for Prospective Technological Studies, one of the European Commission's Joint Research Centres, http://peseta.jrc.es/index.html.

10. To provide these numbers, first, year 2002 current annual incidences of diarrhoeal disease, malnutrition and malaria are taken from the World Health Organization (WHO) for 14 sub-regions of the world. Climate-change-related health outcomes were then isolated from health outcomes due to other factors using relative risk associated with climate change by 2030. Assuming that current incidence cases would remain constant by 2030, these were multiplied by the climate change risk factors to yield additional incidence cases of each health outcome due to climate change. Finally, additional incidence cases are multiplied by the unit cost required by each disease treatment.

11. All malnutrition and malaria cases are assumed to concern developing countries only. Developed countries are affected by 1-5% of the diarrhoeal disease cases, which would amount to total adaptation costs of USD 22-111 million (UNFCCC, 2007).

under costs of (reactive) adaptation. What assumptions are made would therefore critically affect the final estimates of adaptation costs and benefits.

Multi-sectoral estimates at the national level

While sectoral assessments of adaptation costs and benefits have the advantage of offering greater insight into the adaptation process, they might only be of limited relevance to planners at the macro level who might need more information on more aggregate "price tags" for adapting to climate change. This is a rapidly developing area of analysis on two fronts: at the national level, where a number of Least Developed Countries (LDCs) have produced cost estimates of priority adaptation actions; and at the global level, where international agencies have produced estimates of the global costs of adaptation. This section evaluates the emerging results from the national level multi-sectoral estimates of adaptation costs. The global results are evaluated in the next section.

At the national level, a number of costings of adaptation needs have recently been undertaken through a stakeholder driven process as part of the National Adaptation Programmes of Action (NAPAs). NAPAs are being prepared by the LDCs under the United Nations Framework Convention on Climate Change (UNFCCC) in order to identify priority activities, which address their urgent and immediate needs with regard to adaptation to climate change. They are developed based on a bottom-up process, which gives prominence to community-level input as an important source of information. The development of NAPAs is based on the recognition that LDCs have a limited ability to adapt to the adverse effects of climate change. In order to address the urgent adaptation needs of LDCs, NAPAs follow an approach that focuses on enhancing adaptive capacity to current climate variability and extremes, as this will in turn help address the adverse effects of climate change. A key output required from the NAPAs is a list of priority adaptation activities, whose further delay could lead to increased vulnerability or increased costs at a later stage. The analysis of costs in the following sections covers the 23 NAPAs that had been submitted by end 2007.[12]

12. Bangladesh, Bhutan, Burundi, Cambodia, Comoros, Democratic Republic of Congo, Djibouti, Eritrea, Guinea, Haiti, Kiribati, Lesotho, Madagascar, Malawi, Mauritania, Niger, Rwanda, Samoa, Senegal, Sudan, Tuvalu, Tanzania, Zambia. Cost information is reported in all NAPAs except that of Niger.

Cost estimates of priority projects

Clearly there are a number of elements to both the NAPA process and the final output. Many of these elements have been reviewed elsewhere (see for example Osman-Elasha and Downing, 2007). The focus here is on the information on the costs of priority adaptations, which the NAPAs are required to report. For the purposes of this analysis, the priority projects that are costed have been broken down into eight categories: agriculture, water, extreme events, coastal zones, health, infrastructure, ecosystems, and cross-sectoral measures (Box 2.1).

Box 2.1. **Description of the eight sectors/categories chosen**

Agriculture

This includes projects relating to food security, irrigation, crop and livestock production, agro forestry and to a lesser extent aquaculture and fisheries. Projects addressing soil erosion and reforestation activities in order to increase soil productivity were also included.

Water

This includes projects that address water supply and sanitation problems; promote integrated water resource management (IWRM); improve water use efficiency and water storage; reduce pressure on water resources; develop water infrastructure, drainage, rainwater harvesting techniques and water treatment and desalinisation techniques for coastal areas; and provide better access to water resources to sedentary and pastoral populations.

Extreme events

This includes projects which involve developing early warning systems, constructing dykes to address flooding issues and measures aiming to strengthen community disaster preparedness and response capacity.

Coastal zones

This sector includes projects that aim to protect coastal zones through the construction and upgrading of coastal defences and causeways, development of an integrated management of coastal zones and plantation of mangroves.

Health

This includes projects that aim to increase awareness of diseases, such as malaria, improve medical facilities and the control of vector borne diseases (*e.g.* spraying vector breeding areas), especially in rural areas, and improve water quality and sanitation facilities in order to reduce the extent of water borne diseases.

Infrastructure

This sector includes projects that aim to extend communication and telecommunication infrastructures, enhance stability of buildings and impose construction norms to address potential impacts of extreme events.

Cross-sectoral

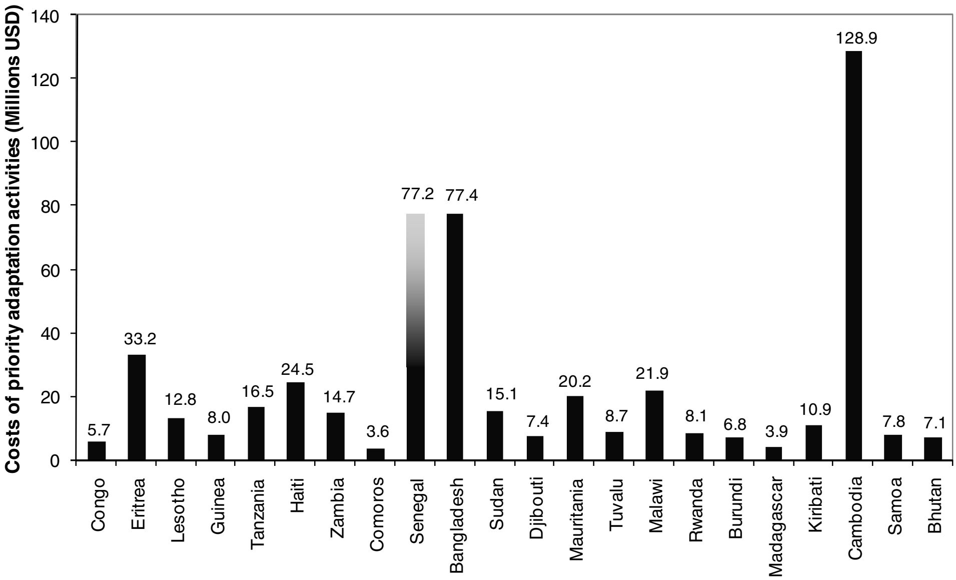
This includes projects that are broadly defined and/or have multi sectoral objectives and benefits. An example of such a project is one that aims to increase crop productivity, improve water quality and reduce health risks.

Ecosystems

This includes projects to protect natural resources, such as coral reefs and forests, in order to maintain natural habitats and biodiversity.

The total costs of all priority projects identified in the 22 NAPAs amount to approximately USD 472 million. While nearly all projects only report point estimates of costs, one coastal zone project in Senegal reports costs ranging from USD 16-64 million. If the upper end of this range is considered, then the total costs of all priority projects in the 22 NAPAs would be USD 520.2 million. The highest national costs of priority projects has been identified in Cambodia (USD 128.9 million), followed by Bangladesh and Senegal (USD 77.4 million and USD 77.2 million respectively). Most NAPAs, however, report cost estimates between USD 5-20 million, as shown in Figure 2.2.

Figure 2.2. **Summary of total costs for priority adaptation activities identified in NAPAs**

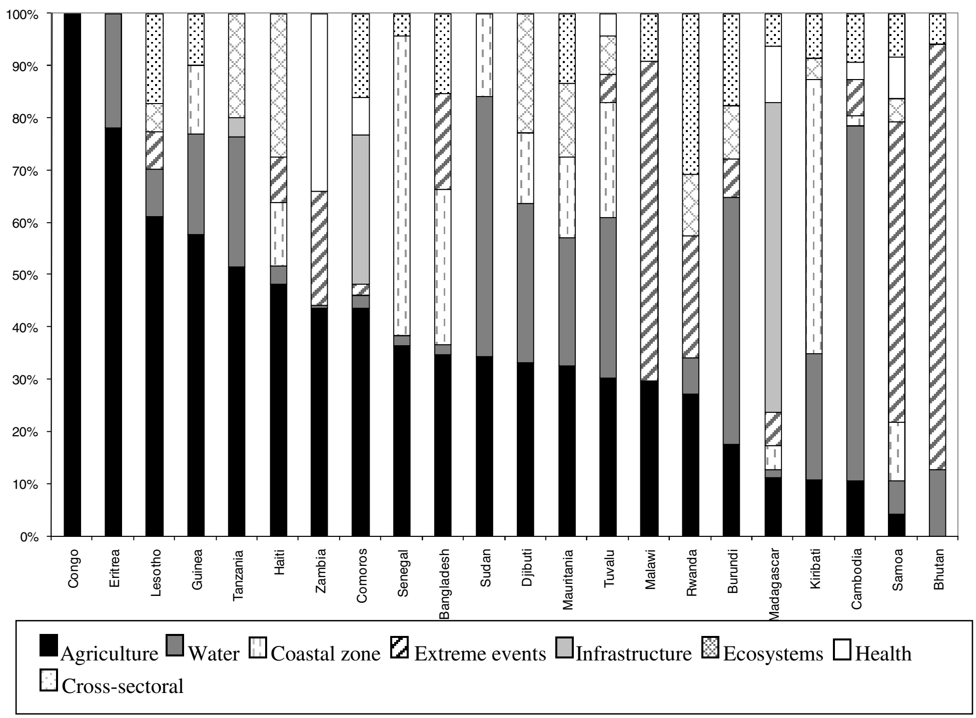


Further insights can be obtained by examining the breakdown of adaptation costs, according to the sectoral classification described in Box 2.1. These results are presented in Figure 2.3.[13] The highest costs are in agriculture for a majority of the countries. For 14 of the 22 countries that have submitted NAPAs, adaptation costs in the agricultural sector represent at least 30% of the total adaptation costs. Another priority sector is water, and together agriculture and water account for approximately 60% of total adaptation costs identified in the NAPAs. Many countries also ascribe high costs with regard to priority projects to deal with extreme events, with these costs constituting over half of the total costs of priority projects for countries like Samoa and Malawi. At the level of individual projects, meanwhile,

13. Since the presentations/descriptions of projects and the definition of project costs vary from country to country, it had to be assumed that project costs, funds or budgets estimated represent total project costs. In addition only a few countries identify which sector each project is attributed to, in other cases the projects were classified into particular categories based on the subjective judgment of the authors. Yet, a certain amount of uncertainty is still associated with this classification, as certain projects could fall into one or more sectors. The difficulty in defining clear sectoral boundaries for each project may have significant impacts on total sectoral costs and the relative weight of each sector in total cost estimates.

costs range from USD 32 500 for a project in Madagascar aiming to restore coastal habitats to USD 45 million for a project in Cambodia aiming to enhance food security by increasing water availability and reducing risk of crop failures.

Figure 2.3. **Distribution of adaptation costs by sector for each country**



Discussion

Despite their diverse geophysical and social contexts, the countries that have developed NAPAs identify many common adaptation priorities. These include general capacity building and awareness raising, studies to establish baselines for climate change impacts and adaptation, improved dissemination of information, such as disaster early warning, that could facilitate adaptation, developing alternatives to activities that might be particularly vulnerable to climate change, upgrading existing infrastructure such as civil defences, as well as developing new infrastructure, for example water reservoirs (Njie, 2008).

In principle, a potential strength of the NAPAs is that they are based on concrete project proposals and activities developed during a process adopting a bottom-up approach and engaging a wide variety of stakeholders. The adaptation priorities and projects should, therefore, be more realistic and better reflect priorities on the ground than the stylised abstract assumptions of adaptation that are embedded in top-down studies. Indeed, a reading of the NAPAs reveals many "atypical" adaptation priorities that can only be identified through stakeholder driven processes. For example, the NAPA of Comoros highlights as one of the priority projects "Short conservation of fish under ice to reduce losses after catches, due to high temperature". The project is justified by the deterioration and reduction of catches due to temperature increase and the lack of conservation techniques. These may affect the fish market as well as ill health incidences of diarrhoeal diseases due to consumption of rotting fish. Such adaptation priorities would be typically overlooked in more theoretical analyses.

One striking contrast between the sectoral estimates reviewed earlier and the NAPAs is the high cost ascribed to priority adaptations in agriculture. By contrast, most modelling studies in agriculture conclude (or assume) that significant yield benefits can be obtained from adaptation measures that will cost very little. The priority actions identified in the NAPAs concentrate mainly on rural livelihoods and how to adapt the livelihoods of rural farmers relying on agriculture. In addition, NAPAs identify several activities relating to soil erosion reduction and improving soil fertility. These activities differ considerably from those identified in the theoretical farm level studies described earlier in the sectoral section. This may suggest that farm level modelling studies may only be looking at adaptation in the agricultural sector from a narrow perspective. Adaptation in the agricultural sector for rural households will not simply be about small adjustments and better adapted crop varieties but will require wider changes in the economy and diversification of their livelihoods. These changes will require financial support from governments. Soil erosion, soil fertility and natural resource management measures to adapt the agricultural sector will also require significant financial outlay.

There are clearly important strengths to the NAPA process and the insights they reveal about adaptation needs. However, with regard to the specific issue of adaptation costs, there are considerable limitations to the information presented in the NAPAs. This is because generally no justification or sourcing of underlying analyses of the cost estimates is provided within these documents. For example, 9[14] of the 22 NAPAs do not provide any explanation for total project costs given. In other cases, the

14. Bangladesh, Cambodia, Comoros, Haiti, Kiribati, Guinea, Mauritania, Rwanda and Zambia.

NAPAs only note that costs are based on historical and/or ongoing projects, but the underlying analysis is not available. In addition there are a number of factors that can also result in the under- or over-estimation of adaptation costs in the NAPAs. These include, simplified assumptions regarding the geographical distribution of project input prices and omission or inadequate consideration of the costs of contingencies as well as the delay in implementation (Njie, 2008). Therefore, while such estimates might be indicative of relative priorities placed by stakeholders, they may not necessarily be a reliable guide to the actual costs of implementing such measures.

Global multi-sectoral estimates

Following a long period of total absence of any empirical estimates of the global costs of adaptation across multiple sectors, there have been six assessments which have explicitly confronted this issue within the short period of one year between mid-2006 and late 2007.

Multiple factors have contributed to this growing interest in the global costs of adaptation. First, such estimates can serve an agenda setting role and help raise the profile of adaptation. Second, they can serve as a guide to international donors seeking to enhance the climate resilience (or "climate-proof") of development projects and activities. Finally, they can help shape the discussion on financing adaptation needs in developing countries within the context of the international climate change negotiations.

In chronological sequence they include the Investment Framework for Clean Energy and Development of the World Bank, the Stern Review, the Intergovernmental Panel for Climate Change (IPCC) Working Group II Fourth Assessment Report, studies on adaptation financing by the Oxfam and the UNFCCC, and the UNDP Human Development Report. All, with the exception of the IPCC, provide specific numerical estimates for the costs of adaptation (Table 2.6).

Table 2.6. **Estimates of costs of adaptation on a global scale**

Assessment	Cost of adaptation	Time frame	Countries included	Sectors	Comments on methods/sources
World Bank (2006)	USD 9-41 billion per year	Present	Developing countries	Unspecified (presumably all sectors where ODA, FDI, and GDI are directed)	Estimate based on OECD and World Bank (WB) analyses of official flows exposed to climate risk. Costs of "climate-proofing" are assumed in the analysis.
Stern Review (2006)	USD 4-37 billion per year	Present	Developing countries	Unspecified (presumably all sectors where ODA, FDI, and GDI are directed)	Update, with slight modifications, of WB study.
Oxfam (2007)	At least USD 50 billion per year	Present	Developing countries	Unspecified (presumably all sectors where ODA, FDI, GDI, and NGO interventions are directed)	WB study, plus extrapolation of cost estimates from NAPAs and NGO projects.
UNDP (2007)	USD 86-109 billion per year	2015	Developing countries	Unspecified (presumably all sectors where ODA, FDI, and GDI are directed)	WB study, plus costing of targets for adapting poverty reduction programmes and strengthening disaster response systems

Table 2.6. **Estimates of costs of adaptation on a global scale (cont.)**

Assessment	Cost of adaptation	Time frame	Countries included	Sectors	Comments on methods/sources
UNFCCC (2007)	USD 28–67 billion per year	2030	Developing countries	Agriculture, forestry and fisheries; water supply; human health; coastal zones; infrastructure	In-depth costing of specific adaptations in water, health and coastal zones. Less detailed costing for agriculture, infrastructure, and ecosystems. Infrastructure more abstract.
UNFCCC (2007)	USD 44-166 billion per year	2030	Global	Agriculture, forestry and fisheries; water supply; human health; coastal zones; infrastructure	Infrastructure adaptation costs overlap with costing in coastal zones and water resources.

Even though five different studies have reported on the costs of adaptation at the global level, there are only two quasi-independent estimates. The first estimate is by the World Bank as part of the "Investment Framework for Clean Energy and Development" (2006), which was modified subsequently in the Stern Review (2006) and also served as the principal input to the assessments by Oxfam (2007) and the UNDP (2007). The second estimate is by the UNFCCC as part of its "Analysis of Existing and Planned Investment and Financial Flows Relevant to the Development of Effective and Appropriate International Response to Climate Change" (2007).[15] As such, most of the cost estimates are linked to each other, rather than fully independent. Further, there has been a trend towards escalation of adaptation costs with successive estimates.

The World Bank (2006) and derivative assessments of adaptation costs

The World Bank study looks at the current magnitudes of three sets of financial flows in developing countries: Official Development Assistance (ODA) and concessional finance, estimated at USD 100 billion per year; Foreign Direct Investment (FDI), estimated at USD 160 billion per year; and Gross Domestic Investment (GDI), estimated at USD 1 500 billion per year.

In this study, 40% of ODA, 10 % of FDI and 2-10% of GDI are taken to be "climate sensitive". The climate exposure of ODA draws upon previous studies by the World Bank and the OECD.[16] The climate exposure of FDI and GDI, meanwhile, has been assumed and is not sourced to any underlying analyses. This is particularly critical, as the sheer magnitude of GDI (USD 1 500 billion per year, or 15 times the ODA) dwarfs other investments. Hence any modification on how much of GDI is exposed to

15. While the UNFCC cost estimates for other sectors largely follow an independent approach, its estimation of the adaptation costs for infrastructure does draw upon the cost assumptions made in the World Bank analysis.

16. The climate sensitivity of ODA draws in part on the analysis conducted by the OECD which concluded that anywhere from 12-26% to 50-65% of official flows in Bangladesh, Egypt, Tanzania, Uruguay, Nepal, and Fiji could be potentially affected by climate risks. The OECD analysis, however, is only for these six countries, and scaling up to all ODA recipients is problematic. Further, being "climate sensitive" under this very broad definition does not automatically imply that investments would be required for adaptation. As the OECD report cautions "if an activity falls within the climate sensitive cluster that does not necessarily mean that it needs to be redesigned in the light of climate change" (van Aalst and Agrawala, 2005, p. 66).

climate risks would significantly alter the final estimate of total costs of adaptation. Next, the costs of "climate-proofing" these exposed investments are assumed to be between 10-20% of the financial exposure in each of these cases. Any change in these assumptions would significantly alter the overall costs of adaptation. This then yields the range of USD 9-41 billion per year for adaptation costs. The study does not quantify the benefits (in terms of reduced damages) of the adaptation investments.

The Stern Review (2006) does not develop new estimates of adaptation costs, but it does provide an update of the World Bank estimates. Following the same methodology, the Stern Review assumes that 20% of ODA, 10% of FDI, and 2-10% of GDI are climate sensitive. Likewise, with regard to costs, while the World Bank Investment Framework assumed that adaptation would cost 10-20% of the financial exposure, this range is updated to be between 5-20% in the Stern Review. These assumptions consequently yield a range of USD 4–37 billion per year for adaptation costs. The Review does not discuss the basis of the percentages chosen for the exposure of different financial flows to climate risks. There is also no discussion of the assumptions underlying the estimate that adaptation investments would cost between 5-20% of financial flows exposed to climate risks.

The adaptation cost numbers in the World Bank Investment Framework also serve as the primary input for the costing assessment by Oxfam (2007). In addition, the Oxfam assessment adds three elements: scaled-up costs of community level projects by non-governmental organisations (NGOs); scaled-up costs of immediate adaptation needs of developing country governments; and considerations of adaptation costs which are excluded from the World Bank study (as well as the above elements). These additions yield Oxfam's estimate of adaptation costs of "at least USD 50 billion per year" for developing countries.

Some of the costs in the Oxfam assessment might be double counted. It is not clear whether community level interventions are not (at least partially) captured in ODA and GDI, which are both already accounted for separately. For example, at least one of the three examples of community level interventions that are provided in the report was financed by a bilateral donor (in other words should be covered under ODA). Second, the report extrapolates costs from a small number of point estimates to the global scale. For example, cost estimates for three local community level projects are normalised to per capita terms and then scaled up to the 2.8 billion of the world's poor who live on less than USD 2 per day, assuming that 40% of them are in need of such interventions at any given time. Likewise, cost estimates of immediate adaptation needs in 13 NAPAs are first normalised (in terms of population, GDP, or land area) and then scaled up, first to all LDCs, and then to all developing countries. This scaling up is even more problematic, as the underlying costs which are being scaled up have not been well substantiated in the first place (see the previous section on national estimates).

The World Bank study and approach also serves as a primary input for the costing assessment by the UNDP (2007), which sets annual investment targets required for adaptation for 2015. The calculation of adaptation costs is based on three elements: costs of "climate-proofing" development investments, costs of adapting poverty reduction strategies to climate change and increased costs of strengthening disaster responses. The cost of climate-proofing investments in developing countries until 2015 is based on an update of the World Bank study using 2007 data on ODA,[17] FDI,[18] and GDI.[19] The proportion of climate sensitive ODA is lowered from the initial 40% used by the World Bank to 17-33%, while the climate sensitive parts of FDI and GDI remain the same as those provided by the World Bank. Likewise to the Stern Review, the UNDP assume that adaptation will cost between 5-20% of total financial flows exposed to climate risks.

Overall costs for climate-proofing investments are estimated by UNDP (2007) to range between USD 5-67 billion per year, with a mid range of USD 30 billion per year. Finally, a target of "at least USD 44 billion per year" is set for climate-proofing development investments.[20] The study also accounts for costs that are needed to "strengthen social protection programmes and scale up aid in other key areas" for which a target of "at least USD 40 billion per year" by 2015 is set.[21] Finally, to strengthen the disaster response system, an increase in climate-related disaster response of USD 2 billion per year in bilateral and multilateral assistance by 2015 is assumed. Adding these cost numbers, the report suggests a lower bound ballpark estimation of adaptation costs of USD 86 billion per year. However, this figure limits the lower bound estimate of costs of "climate-proofing" development at USD 44 billion per year, instead of the actual low range estimate of USD 5 billion per year (provided in the same report). If the USD 5 billion per year figure was taken as the lower bound estimate for

17. Estimated at USD 107 billion per year.

18. Estimated at USD 281 billion per year.

19. Estimated at USD 2 724 billion per year.

20. This figure is based on the assumption that adaptation financing requirements in developing countries will represent around 0.1% of developed country GDP (the approximate level in 2005 based on World Bank methodology).

21. This would amount to 0.5% GDP for low and lower-middle income countries.

"climate-proofing" development investments, then the total lower bound estimate for adaptation costs would be of USD 47 billion per year.

Adaptation costing in UNFCCC analysis of investment and financial flows (2007)

The UNFCCC analysis examines investment and financial flows for adaptation to climate change in five sectors: agriculture, forestry and fisheries; water supply; human health; coastal zones; and infrastructure. The results were examined for the year 2030, under a reference and a "mitigation" scenario, both on a global basis and for developing countries.[22] The total annual costs for adaptation by the year 2030 for these five sectors are calculated to be in the range of USD 49-171 billion per year globally, of which USD 28–67 billion per year will be in non-Annex I countries (UNFCCC, 2007). Overall, this corresponds to 0.2-0.8% of global investment flows or 0.06-0.21% of projected GDP in 2030 (Smith, 2007).

The UNFCCC analysis is more in depth than the estimates reviewed in the preceding section. In particular, in most sections of this analysis there is a clearer representation of the specific adaptation activities that are being costed. The sectoral cost analyses follow different methodologies, both because of the specific nature of adaptations in particular sectors and due to the characteristics of the underlying literature that they draw upon. These analyses have been reviewed in greater detail in the section on sectoral estimates. The underlying cost analysis for certain sectors (particularly coastal zones and water resources) is more in depth and better substantiated than for other sectors.

With regard to the overall multi-sectoral estimates from the UNFCCC analysis, the costs of adapting infrastructure stand out as they have the widest range and their upper bound is an order of magnitude (or more) higher than costs in other sectors. Out of the upper bound of USD 171 billion that adaptation is estimated to cost annually on a global scale in the year 2030, USD 130 billion is attributed to infrastructure (Smith, 2007). Likewise, for developing countries, infrastructure costs contribute USD 41 billion out of the estimated upper bound of USD 67 billion in adaptation costs, again for 2030. The costs for infrastructure, however, are not derived in the study (Satterthwaite, 2007). Rather, the study relies on the

22. "Developing countries" here are defined as non-Annex I parties to the UNFCCC. The World Bank study analysis of costs of climate proofing in developing countries (reviewed earlier) was based on ODA recipients. The two categories overlap, but there are nevertheless some differences.

same percentage that adaptation is going to cost between 5-20% of the total infrastructure investment, which was assumed in the World Bank study. Other segments of the UNFCCC assessment (*e.g.* agriculture and water resources) are also based on assumed percentages of what adaptation might cost, which are then applied to very large numbers of baseline investments to yield dollar amounts of adaptation costs. There are also issues of both undercounting, due to the narrow scope of impacts and adaptations that have been considered, as well as potentially double-counting investments. For example, infrastructure is costed separately, and is an integral component of coastal, water sector, and agricultural adaptations as well.

Overall evaluation of global, multi-sectoral estimates

While potentially relevant for the global discussion on adaptation and its financing, existing multi-sectoral estimates face serious limitations. There has been a premature and very rapid convergence around initial estimates that are quite sensitive to the assumptions made. Two particular assumptions stand out: *(i)* the percentage value of assets/flows that might be exposed to climate risk; and *(ii)* the percentage incremental costs of "climate-proofing" such exposed assets. Very little or no analytical information is currently available on either of these parameters and, therefore, the assumptions that are made become particularly critical, given the very large magnitude of baseline investments to which these percentages are applied.

Further, in most cases the global adaptation cost estimates do not have a direct attribution to specific adaptation activities, nor are the benefits of adaptation investments articulated. There are also issues of double counting, and scaling up to global levels from a very limited (and often very local) evidence base. At the same time, many sectors and adaptations have not been included in such estimates. Existing global adaptation cost studies have also tended to stack upon the assumptions made in preceding studies, and are not really based upon independent analysis. Therefore, the "consensus" on global adaptation costs, even in order of magnitude terms, may be premature and not a useful guide to shape international decisions on adaptation financing.

This analysis, therefore, supports the more cautious view taken by the IPCC Fourth Assessment report that "comprehensive, multi-sectoral estimates of the global costs and benefits of adaptation are currently lacking" (IPCC, 2007b, Chapter 17, p. 719).

Concluding remarks

This chapter provides a critical assessment of adaptation costs and benefits in key climate sensitive sectors, as well as across sectors at the local/regional, national and global levels. There is a relatively large amount of information available about adaptation costs at the sectoral level. In particular, there is a significant body of literature on the costs and benefits of adaptation measures in coastal zones. In the agricultural sector, more work has been done on quantifying the benefits of adaptation strategies with limited information available on the costs of such measures. In terms of coverage, there is fairly comprehensive geographical coverage in the case of coastal zones and agriculture. However, for the other sectors covered in this report, the information on costs of adaptation was more limited and piecemeal. The discussion on energy has been largely limited to the United States, while only sporadic and largely local level information on adaptation costs and benefits is available for the water resources, public health, tourism and infrastructure sectors.

The studies on adaptation costs for coastal zones show that while significant investment will be needed for coastal protection, total costs of protection represent a small percentage of national GDP, frequently less than 0.1% of GDP. However, there are significant regional differences and the share of protection costs as a percentage of GDP might be significantly higher for certain small island states. In the agricultural sector, a general finding from global-level studies is that relatively modest adaptation measures can significantly offset any declines in projected yield as a result of climate change. While farm level adjustments have been found to yield significant benefits, these benefits are not translated equally to all regions. In the water sector, research seems to indicate that in regions where rainfall is expected to increase, it is waste water treatment that may become problematic and impose substantial cost in order to adapt public infrastructure. In contrast, in regions where there will be less rainfall or where water availability will decline due to glacier retreat, investments in enhanced storage, as well as increasing the efficiency of water allocation will become highly valuable. In the energy sector, the majority of studies carried out for the United States conclude that adaptation costs of increased cooling will be greater than the benefits associated with reduced heating demands. For the other sectors there are only a few isolated estimates of adaptation costs and benefits.

Aggregate, multi-sectoral studies on costs of adaptation are relatively new. National costing of adaptation can be found in the NAPAs of the Least Developed Countries. The NAPAs identified adaptation activities based on a bottom-up approach engaging a wide variety of stakeholders and are, therefore, likely to better represent/reflect priorities on the ground. In addition, the NAPAs identified some "atypical" adaptation priorities, which are missed in more theoretical studies. However, the NAPAs focus only on priority adaptation activities and do not provide guidance as to the type of adaptation actions that will be required over the long term. The type of priority activity identified may also be influenced by the group of stakeholders present during the NAPA process, and may, therefore, not necessarily reflect all priority actions required. Furthermore, the link between the adaptation action and the extent to which the damages are offset is not specified with any detail in the NAPAs. Finally, there is a concern about whether the priority actions identified will necessarily facilitate long-term adaptation to climate change.

Global, multi-sectoral estimates of adaptation costs are very recent. They suggest that adaptation to climate change at the global level will cost several billions of dollars per year. While potentially relevant for the global discussion on adaptation and its financing, existing multi-sectoral estimates face serious limitations. There has been a premature and very rapid convergence around initial estimates that are quite sensitive to the assumptions made. In most cases the estimates do not have a direct attribution to specific adaptation activities, nor are the benefits of adaptation investments articulated. There are also issues of double counting, and scaling up to global levels from a very limited (and often very local) evidence base. At the same time, however, many sectors and adaptations have not been included in such estimates. For all these reasons "headline" global adaptation cost numbers can be seriously misleading if adequate attention is not paid to the assumptions that underlie particular empirical estimates.

The analysis of adaptation costs and benefits at the sectoral, national, and global levels also raises some more fundamental issues. Adaptation is a rather nebulous concept, whose boundaries have not yet been clearly defined. What does or does not fall within the purview of adaptation remains ambiguous and could significantly affect the calculation of costs. For example, should adaptation only consider actions that reduce climate risks or should it also consider actions that enhance a system's capacity to respond to climate risks? If adaptation actions need to reduce risk and enhance capacity then the costs are likely to increase significantly, as a much broader set of actions will be included.

In addition, it is difficult to separate between adaptation to climatic stimuli only and adaptation to all risks. For example, farming practices, land use planning, infrastructure design might all reflect some considerations of current or anticipated climate but it might not be feasible to cost the climate component as such decisions are also simultaneously conditioned by a whole range of other (and often more influential) factors. In the water sector, costs often reflect adaptation responses to demographic and economic changes as well as to climatic changes. Meanwhile, separating the costs of adapting to climate variability and climate change adds a further layer of complexity because few examples of adaptation are as cut and dry as building the next increment of a sea wall to protect against climate change induced sea level rise.

Most studies only consider a very narrow scope of climate change impacts. For example, studies assessing adaptation in the coastal zones tend to focus only on inundation of coastal zones and wetlands and ignore other impacts such as saltwater intrusion, increased disease risk and increased exposure to storm surge and flooding. Furthermore, many studies do not consider the whole spectrum of risks, and only focus on changes in means without consideration of extremes. For example, most studies assessing protection costs for coastal zones focus on impacts of gradual sea level rise and do not consider storm surges or extreme scenarios of sea level rise. The types of impacts considered will not only affect the costs of adaptation but also the choice of optimal adaptation strategies. The consideration of extreme events in addition to changes in means is likely to significantly increase the costs of adaptation.

At the same time adaptation cost estimates are also extremely sensitive to the choice of adaptation measures. Most of the costing studies reviewed in this report focus on hard measures, as these measures are more easily costed than soft measures. For example, coastal zones studies focus on hard protection measures, such as dykes and sea walls, and ignore potential ‘soft’ adaptation responses, such as land use planning and building codes. In the water sector, costing studies focus mainly on supply side measures, such as adapting and/or building storage reservoirs, dams and waste water treatment facilities, and less on demand side measures, such as promoting efficient water use through recycling, changing usage patterns, greater use of water markets and other financial and economic incentives. Such behavioural adaptations, in fact, might go a long way in lowering the overall cost of adaptation. They might also induce decisions and choices that internalise both current and anticipated climate risks. Policy instruments, including both market and regulatory mechanisms, have a very important role to play in this regard and are, therefore, investigated in further detail in Chapter 3.

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List of Abbreviations

ADB	Asian Development Bank
CDM	Clean Development Mechanism
CEE	Central and Eastern Europe
CGE	Computable General Equilibrium
EBRD	European Bank for Reconstruction and Development
EC	European Commission
EEA	European Environment Agency
ENSO	El Niño Southern Oscillation
FDI	Foreign Direct Investment
FONDEN	*Fondo para Desastres Naturales*
fSU	former Soviet Union
GDI	Gross Domestic Investment
GDP	Gross Domestic Product
GHG	Greenhouse gas
GNP	Gross National Product
IMF	International Monetary Fund
IPCC	Intergovernmental Panel for Climate Change
LDCs	Least Developed Countries
MAF	Mean annual flow
MDB	Murray Darling Basin
MENA	Middle East and North Africa
MPCI	Multi-peril crop insurance
NAPA	National Adaptation Programmes of Action
NASFAM	National Smallholder Farmers' Association of Malawi
NGO	Non-governmental organisation
NOAA	National Oceanic and Atmospheric Administration (United States)
ODA	Official Development Assistance
PES	Payment for ecosystem or environmental services
PPP	Public Private Partnership
PFI	Private Finance Initiative
R&D	Research and development
ROH	Risk of hunger
SRES	Special Report on Emission Scenarios (of IPCC)
SSA	Sub-Saharan Africa

UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey
WB	World Bank
WFP	World Food Programme
WHO	World Health Organization
WUAs	Water user associations
WWF	World Wildlife Fund

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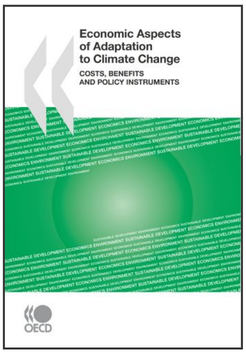

Economic Aspects of Adaptation to Climate Change

Costs, Benefits and Policy Instruments

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