Adaptation to Climate Change: Assessing the Costs

Investment and Financial Flows to Address Climate Change

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Several recent studies have reported the costs of adapting to climate change, including for developing countries. They have similar-sized estimates and have been influential in United Nations (UN) negotiations aimed at tackling climate change. Our reassessment of one of these studies, which reports the UN Framework Convention on Climate Change (UNFCCC) approximations for 2030, suggests that they are likely to be substantial underestimates, for several reasons. First, some sectors have not been included in an assessment of cost (for example, ecosystems, energy, manufacturing, retailing, and tourism). In addition, some of the sectors that have been included have been only partially covered. Finally, the additional costs of adaptation have sometimes been calculated as "climate markups" against low levels of assumed investment. In some parts of the world low levels of investment have led to a current adaptation deficit, and this deficit will need to be made up by full funding of development, without which the funding for adaptation will be insufficient. Residual damages also need to be evaluated and reported because not all damages can be avoided due to technical and economic constraints. There is an urgent need for more detailed assessments of these costs, including case studies of costs of adaptation in specific places and sectors.

Estimating the Cost of Adaptation

The UNFCCC estimates, published in a report in 2007,[1] are based on a set of commissioned studies that provided estimates of the cost of adaptation for the year 2030, usually assuming a climate scenario similar to the Intergovernmental Panel on Climate Change's (IPCC) Special Report on Emissions Scenarios A1B and B1. These cover the following sectors:

- Agriculture, forestry, and fisheries. The agriculture estimate consists of three distinct cost items: extra capital investment at farm level, the need for better extension services at country level, and the cost of additional global research (for example, on new cultivars).[2]
- Water supply. The water estimate considers the effect of additional water demand and changes on the supply side.[3] Investment decisions are made in anticipation of 2050 water needs.
- Human health. The health estimates are the extra prevention costs for three health issues: malnutrition, malaria and diarrhea.[4] The health impacts are based on the Global Burden of Disease study.[5]
- Coastal zones. Coastal protection costs are based on a model that considers a limited set of adaptation options that are applied globally.[6] Uniquely, the coastal estimate considers both adaptation costs and residual damages. For long-life defense infrastructure, investments are made in anticipation of sea-level rise in 2080.
- Infrastructure. The infrastructure estimate adopts World Bank methodology, using insurance data to determine the share of climate-sensitive investment and applying a percentage increase on current infrastructural investment to suggest additional costs for climate-proofing new infrastructure.[7]
- Ecosystems. An indication of adaptation costs for ecosystems was derived from the costs of increasing protected areas to at least 10 percent of the land area of each nation or ecosystem, although it was not possible to split this into baseline costs of meeting current deficits and incremental adaptation.[8]

The UNFCCC report concluded that total funding need for adaptation by 2030 could amount to US$49–171 billion per annum globally, of which $27–66 billion would accrue in developing countries (Table 1 on page 30). By far the largest-cost item is infrastructure investment, which for the upper-bound estimate accounts for three-quarters of total costs. Costs are over and above what would have to be invested in the baseline to renew the capital stock and accommodate income and population growth. Note that the total excludes the estimate for ecosystem adaptation, for reasons discussed below. The commissioned studies informing the report took place over a short period dictated by the timescale of the UNFCCC process and the need to report the results to the next Conference of the Parties, so there was no time for independent review of a draft of the report. It is important, therefore, to recall the objectives of the UNFCCC report and the caveats that the authors ascribed to its conclusions. The study was a preliminary look at the funding, especially the public funding, estimated to be needed in the year 2030 to meet the challenge of climate change. It is not a study of the full cost of avoiding all damage. It does not cover some important activities, and other activities are only partially covered. The authors suggest that their estimates are probably underestimates and that much more study is needed.

Robustness of the Estimates

The UNFCCC estimates of adaptation cost are broadly in line with preceding studies published by the World Bank, Oxfam, UN Development Programme, and in the Stern Report.[9] These have recently been summarized by the Organisation for Economic Cooperation and Development and are given in Table 2 on page 31.[10] Since these studies appear to support each other, the conclusion has sometimes been made that there exists a comforting convergence of evidence. However, none of these are substantive studies; they are not independent but rather borrow heavily from each other; and they have not been tested by peer review in the scientific or economics literature.

Importantly, most of the precursors of the UNFCCC study were based on the same method, first developed by the World Bank.[11] This takes a fraction of current investment that is climate sensitive and applies a "markup" to this fraction to reflect the cost of climate-proofing those investments. The weakness of this approach is considered below, along with several other issues that require more thorough treatment in future assessments.

The potential damages to be avoided by adaptation. The fourth assessment report of the IPCC gives a summary of some impacts likely to occur under varying amounts of global warming.[12] Mapping onto this the expected warming range for 2030, indicates the potential impacts that adaptation will need to address. Figure 1 on page 32 shows this for the A1B scenario assumed generally in the UNFCCC study, as well as for 2050 and 2080 (used respectively in the water and coastal analyses of that study, on the assumption that adaptation in 2030 will need to anticipate future warming due to the long-term nature of investment needs in those sectors). One emerging aspect is the substantial magnitude of impacts that could occur even within the next few decades and the scale of damages that could be expected if adaptation is not fully successful in avoiding them..

The scarcity of information on adaptation and its cost. Information is scarce about the scale of future potential impacts and is even more scant for the costs of avoiding them by adaptation, a point stressed in the UNFCCC report. Some sectors, such as mining and manufacturing, energy, retailing, and tourism, were not included in the UNFCCC report. Cost estimations for ecosystems, although made, were left out of the final table showing total costs (see Table 1), due to lack of sufficiently robust information. Within some examined sectors, the funding needs estimated were clearly only partial. In health for example, just three areas of impact, where there were sufficient estimates, were considered: the effect of climate change on diarrheal diseases, malaria, and malnutrition in low- and middle-income countries. Adaptation costs for health effects in high-income countries were not estimated.

A major problem is the absence of case studies to test the top-down form of UNFCCC analysis. The few national figures available tend to suggest costs in excess of the UNFCCC estimates. For example, agencies responsible for flood man-

Table 1. UNFCCC estimate of additional annual investment and financial flow needed by 2030 to cover costs of adaptation to climate change

SECTOR	GLOBAL COST (billion dollars per year in present-day values)	DEVELOPED COUNTRIES	DEVELOPING COUNTRIES
Agriculture	14	7	7
Water	11	2	9
Human health	5	Not estimated	5
Coastal zones	11	7	4
Infrastructure	8—130	6—88	2—41
Total	49—171	22—105	27—66

SOURCE: United Nations Framework Convention on Climate Change (UNFCCC), *Investment and Financial Flows to Address Climate Change* (Bonn, Germany: Climate Change Secretariat, 2007).

agement in England and Wales have estimated a need to spend (due to climate change) an additional $30 million annually in 2011, growing to $720 million by 2035.[13]

Applying a "climate markup" against future investment trends. In most cases, the UNFCCC authors derived the estimation of funding needs by applying an increase in cost to areas of investment deemed to be climate sensitive. In agriculture for example, 2 percent of investment on infrastructure is taken to be climate sensitive. In some sectors, particularly the built environment, the investment flows are so large that even small changes in this markup can change estimates significantly.

Investment needed to remove the adaptation deficit. In particular, applying a climate markup is not appropriate when current investment flows are well below what they should be. In several parts of the world, current levels of investment are considered far from adequate and lead to high current vulnerability to climate, including its variability and extremes, the latter case being termed a current "adaptation deficit."[14] This partly explains why impacts from climate change are expected to be greatest in low- and middle-income countries.[15] To avoid these impacts, the adaptation deficit (which is largely a development deficit) will need to be filled. One background paper for the UNFCCC study estimated the costs of damage from present-day extreme weather at $200 billion per year and took this as a reflection of the current scale of inadequate adaptation.[16] The Millennium Development Goals (MDGs) represent an attempt to fill some, but probably not all, of the adaptation deficit, and have been priced at about $200 billion by 2015.[17] Ending the full development deficit probably requires enhancing official development assistance to 0.7 percent of GDP of OECD countries. Hence the issues of development and adaptation costs are intimately linked, requiring further exploration.

Adaptation costs in a world without an adaptation deficit. Should the climate markup be against investment levels that reflect current trends (which in many regions of Africa, for example, are insufficient to remove high levels of vulnerability to climate)? Or should the mark up be on elevated levels of investment that are needed to attain the MDGs? Or on even higher levels that would help achieve sustainable and equitable development. The UNFCCC takes the first approach, but this leads to estimations that are substantially lower than if one assumed a development pathway that protects the poor against vulnerability to climate change. Removing the housing and infrastructure deficit in low- and middle-income countries will cost around $315 billion per year (in today's figures) over 20 years, while adapting this upgraded infrastructure specifically to meet the challenge of climate change will cost an additional $16–63 billion per year.

How much impact is being avoided by adaptation? It is not clear what proportion of expected damage the proposed UNFCCC investment levels would avoid. Most impacts are projected to increase non-linearly with climate change, and adaptation costs similarly with impacts.[18] Therefore it will probably be very inexpensive to avoid some impacts but prohibitively expensive to avoid others; some impacts we cannot avoid even if funds were unlimited, because the technologies are not available (for instance, in connection with ocean acidification). A simple schema of a generalized adaptation cost curve is shown in Figure 2 on page 33. The curve is likely to vary greatly be-

Table 2. Estimates of adaptation costs in developing countries, for 2010–2015

SOURCE	US$ BILLION PER ANNUM	COMMENTS
World Bank, *Investment Framework for Clean Energy and Development* (World Bank, 2006)	9–41	Cost of climate-proofing foreign direct investment, gross domestic investment, and official development assistance flows
N. Stern, *Stern Review: Economics of Climate Change* (Cambridge University Press, 2006)	4–37	Update, with slight modification of World Bank estimates
Oxfam International, "Adapting to Climate Change: What Is Needed in Poor Countries and Who Should Pay?" Oxfam Briefing Paper 104 (Oxfam International Secretariat, 2007)	>50	Based on World Bank estimates plus extrapolation of costs from National Adaptation Programmes of Action and NGO projects
United Nations Development Programme, *Human Development Report 2007/08* (Palgrave McMillan, 2007)	86–109	World Bank estimates, plus costs of poverty reduction strategy targets and better disaster response

Source: S. Agrawala, and S. Fankhauser (eds.), *Economic Aspects of Adaptation to Climate Change. Costs, Benefits and Policy Instruments* (Paris: Organisation for Economic Co-operation and Development, 2008).

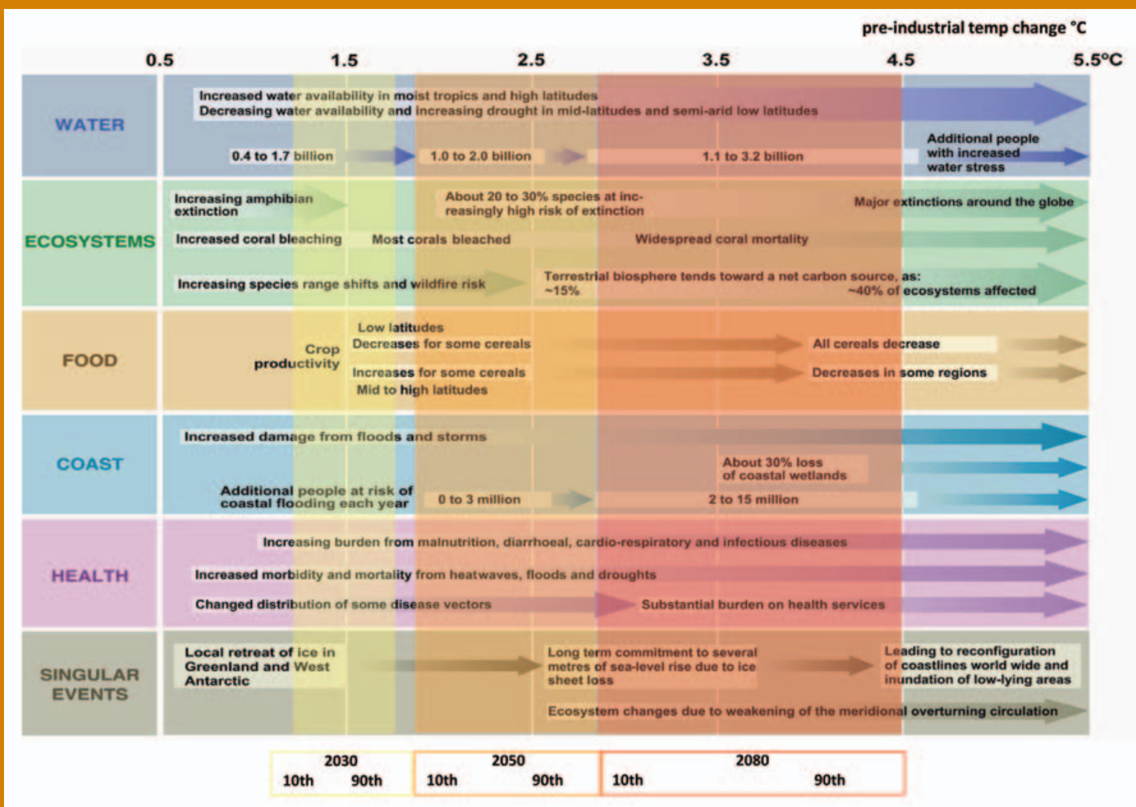
tween different sectors and places, but probably common to most cases will be that adaptation to (say) the first 10 percent of damage will be disproportionately cheaper than for 90 percent of damage. We need to be clear, then, about how much we are willing to pay for adaptation to avoid damages. To illustrate, we might aim (in a scale of reducing cost) to adapt to all those impacts that reduce human welfare, all those that are economically feasible (that is, cheaper to adapt to than to be borne), or all those that are affordable within a given budget constraint (for example, the size of the global Adaptation Fund).

The costs of damage not adapted to, or residual damage. Implicit in the above (and illustrated in Figure 2) is that nations will not adapt to much damage over the longer term because adaptation is either not economic or not feasible. This can be termed "residual damage." In the UNFCCC report, it is not clear how much residual damage might be expected. But it is very important that we start to consider this because the amount may be significant and is likely to increase over time. According to one evaluation, residual impacts are estimated at about a fifth of all impacts in agriculture in 2030[19] and, over the longer term, may account for up to two-thirds of all potential impacts across all sectors, depending on the amount of climate change not avoided by mitigation.[20]

Soft adaptation. The UNFCCC study may have given insufficient weight to the value of "soft" adaptation. It is easier analytically to cost out structural measures like the expansion of water supply systems, and the UNFCCC study focused on these. In reality, it will often be cheaper to apply measures to use water more efficiently, for example, which may obviate the need for expensive new infrastructure. Conversely, the human health costs do not include changes in infrastructure ("hard" adaptation), which may be considerable.[21]

How will adaptation costs change over time? The UNFCCC estimate of adaptation costs is a snapshot for 2030 at one point along the climate-impact curve, and its authors note the importance of the question, "While the adaptation cost curve seems quite gentle between now and 2030, how steeply will it grow thereafter?" Some believe it may rise steeply, possibly quadratically in some sectors.[22] It is very important that this be analyzed so we are sufficiently prepared for escalating adaptation costs beyond 2030.

Figure 1. Projected damages without adaptation



Note: The shaded columns show the 10th and 90th percentile uncertainty range for the scenarios assumed in the UNFCCC estimation of funding needs for adaptation. For most sectors the A1B scenario was taken. For water and coastal protection the scenarios were 2050 and 2080 respectively, due to the need for adaption to anticipate future climate change. Scenario data is from a simple Earth system model (M. L. Parry, J. A. Lowe, and C. Hanson, "Overshoot, Adapt and Recover," *Nature* 258, no. 7242 (30 April 2009): 1102–03).

Source: Intergovernmental Panel on Climate Change, *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson, eds. (Cambridge, UK: Cambridge University Press).

The Level of Underestimation for Each Sector

For a number of reasons discussed above, the UNFCCC estimate of investment needs is probably under by a factor of between 2 and 3 for the included sectors of agriculture, water, human health, coasts, infrastructure, and natural ecosystems

Agriculture. The UNFCCC estimated the cost of adaptation of agriculture to climate change at $11.3–12.6 billion for 2030. The basis for this is an assumption that the climate markup will amount to 10 percent of research and extension funding, and 2 percent of infrastructure funding. In the background paper informing the study, the authors state that these assumptions are uncertain and speculative given the limited basis from which they were formed, but the UNFCCC report does not repeat these caveats nor make clear the reasoning behind the markup levels that were adopted.

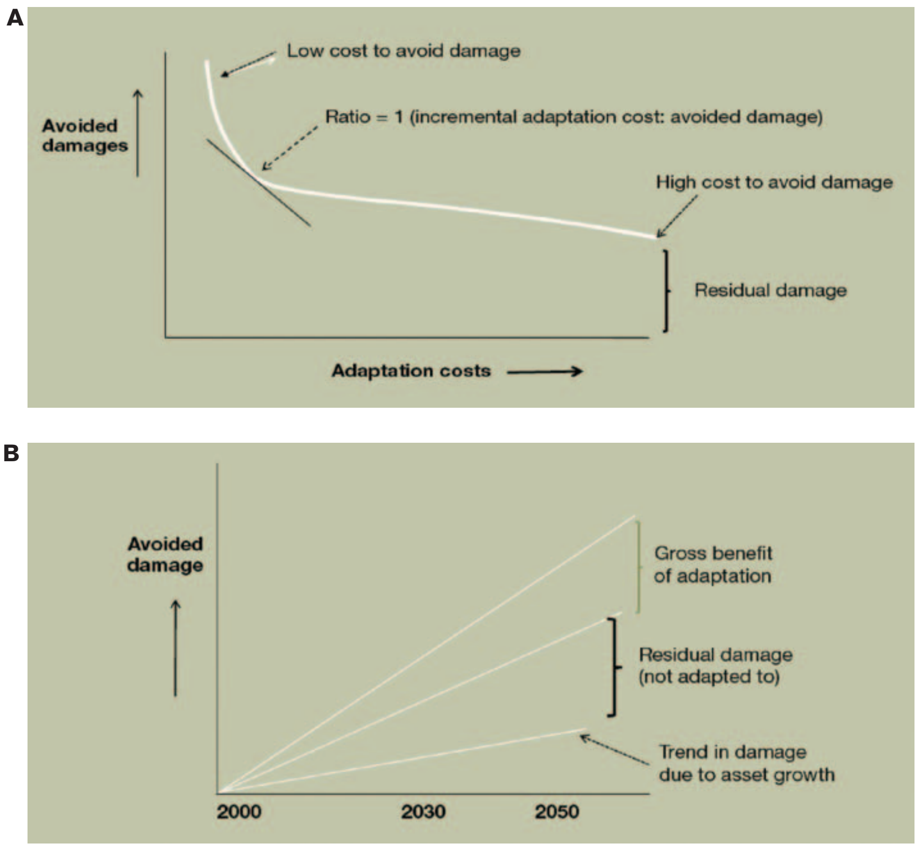
One outcome of the small climate markup is the UNFCCC conclusion that the cost of adapting to climate change will be one-fortieth the cost of adapting to population change (that is, meeting increased demand). This contrasts with estimations for the water sector where the ratio is given as 1:3. These are important differences that deserve analysis.

The current adaptation deficit in agriculture is high. The number of people at risk from hunger increased from around 300 million in 1990 to 700 million in 2007, and may exceed 1 billion in 2010.[23] A measure of the cost of making up this deficit is the cost of achieving the relevant MDG, estimated at $40–60 billion per year. Without this non-climate investment, the estimated levels of investment for adaptation to climate change will be insufficient to avoid serious damage.

A few bottom-up case studies indicate the magnitude of adaptation costs, and these suggest that UNFCCC may be on the low side of adaptation costs in this sector. For example, there is an estimate of $8 billion for adapting crop irrigation systems to climate change by 2030, and $14.5 billion for the year 2030 for the reduction in the value of global crop outputs due to climate change.

For these reasons, the UNFCCC estimate of $11.3–12.6 billion is a reasonable first approximation of adaptation costs in this sector, but the estimate of adaptation costs for agriculture,

Figure 2. Schematic of adaptation costs, avoided damages and residual damage compared A) at a point in time, and B) over time



forestry, and fisheries will likely increase as more detailed studies of specific adaptation actions become available. Finally, with such levels of adaptation, about 80 percent of the cost of potential impacts might be avoided but about 20 percent might not.

Water. The UNFCCC estimated national water resource availability in relation to large-area projections of national rainfall and then compared availability with expected demand. It assumed that a quarter of the total cost of adaptation due to changes in demand and supply would be due to changes in supply resulting from climate change ($11 billion per year). This 1:3 ratio contrasts with 1:40 given by the UNFCCC for agriculture.

The study worked at the national level only, assuming that water resources could be transferred within a country from areas of surplus to areas of deficit. For small countries this would not be a problem, but for large ones it is unrealistic and probably a source of underestimation of true cost. To illustrate, for a single basin in China (Huang Ho), the annual costs of adapting to climate change could be $0.5 billion per year.[24] Unfortunately, few such studies are currently available and are insufficient for drawing reliable conclusions.[25]

The UNFCCC costs include that of water provision, but not of adapting to altered flood risk in river basins. These altered flood management costs may be very substantial (potentially $0.1–0.2 billion annually in the Sacramento Basin in California alone), but there have been no consistent comparisons of costs in different parts of the water sector. The use of an average climate change scenario rather than an ensemble that describes the range of possible impacts has probably led the UNFCCC to underestimate the costs of providing for the full range water-storage need. In all, these costs omitted from the UNFCCC could be very substantial.

Human health. The UNFCCC estimates of costs of adaptation to adverse human health effects of climate change are the costs of the intervention set to prevent the additional burden of disease for three health outcomes in low- and middle-income countries: diarrheal diseases, malaria, and malnutrition. The estimates are in the range of $4–12 billion per year in 2030.

These three outcomes are not the total projected burden on human health from climate change. That total has yet to be assessed accurately, but authors of a World Health Organization study of the global disease burden estimate that these outcomes amount to 30–50 percent of the probable future total burden in 2030 in low-and middle-income countries.

A potential source of underestimation is that the UNFCCC considers a narrow range of development futures. It takes a single median population projection in which population numbers increase and cases of diarrhea, malaria, and malnutrition remain constant—optimistically assuming a steep relative decline in incidence.

Coasts. The costs reported by the UNFCCC study for coastal adaptation appear reasonable as a snapshot cost for IPCC sea-level rise projections in 2030 and are more reliable than those for other sectors because they are based on a model assessment rather than top-down assumptions. However, some post-2007 IPCC assessments suggest significantly higher observed and projected rises in sea levels than reported in the 2007 IPCC assessment. If these newer projections are assumed, then adaptation costs would be roughly doubled.

If the need to protect coastal landscapes for amenity or ecological reasons is taken into account, then the adaptation approach might change, and protection costs could increase significantly in most cases. Another deficiency of the UNFCCC study is the lack of consideration of other aspects of climate change such as more intense storms. No detailed estimates are available, but in the worst case, the necessary adaptation costs (and residual damage costs) could match those of adapting to sea-level rise.

When combined with the uncertainties about sea-level rise, adaptation costs three times those reported in the UNFCCC study are not implausible. One model suggests that UNFCCC estimations for residual damages are overly conservative and should be roughly doubled (to $2–3billion per year).[26]

Infrastructure. To estimate adaptation costs for infrastructure, the UNFCCC took three steps. First, it estimated global investment in gross fixed capital formation in 2030 (around three times the global investment in 2000), as $22.2 trillion. It then multiplied this number by the proportion that is vulnerable to the impact of climate change, based on data for losses from weather disasters estimated at 0.7 percent (Munich Re data) or 2.7 percent (ABI data), resulting in $153–650 billion a year. Finally, it assumed 5–20 percent of this total as the increase in capital costs needed for adaptation, giving $8–31 billion or $33–130 billion.

The estimates based on the Munich Re data are likely to be substantial underestimates of damages from climate because only data from large events are included. As the UNFCCC study notes, this leaves out the cost of a high proportion of all extreme-weather disasters. The authors of the background papers to the UNFCCC report recognized the climate-cost fraction of 0.7–2.7 percent was low, and in earlier work, they adopted climate-cost fractions of 2–10 percent for domestic investment and up to 40 percent for overseas development assistance.

Applying a climate markup to levels of infrastructure provision that are currently very low (for example, in most countries in Africa, many in Asia, and considerable parts of Latin America and the Caribbean) yields low estimations of future cost. Infrastructure provision needs substantial improvement to meet present-day needs, and these are partly embraced in the MDGs. Removing the housing and infrastructure deficit in low and middle-income countries will cost around $315 billion per year (in today's figures) over 20 years. Adapting this upgraded infrastructure specifically to meet the challenge of climate change will cost an additional $16–63 billion per year.

Investment in adaptation will not avoid all damages to infrastructure. The annual economic damage caused by large extreme-weather disasters in1996–2005 was more than $50 billion a year. This gives an indication of weather impacts that are currently not avoided by adaptation—even in countries where the population is served by protective infrastructure and good-quality buildings.

A potential source of underestimation is that the UNFCCC considers a narrow range of development futures.

Ecosystems. The UNFCCC methodology for ecosystems consisted of estimating the current global expenditure on conservation in the form of protected areas (PAs), the shortfall in the PA network (PAN), the level of additional expenditure needed for PAs to be adequate for climate-change adaptation, and pricing adaptation outside the PAN. An estimate of $12–22 billion was given by UNFCCC for the cost of expanding and protecting terrestrial PAN areas so that they represent 10 percent of each country, but this was excluded from the ultimate list of needed investment.

The conclusion of the background paper for the UNFCCC is more likely correct, estimating that $65–80 billion reflects the range of probable adaptation costs for PAN areas, including both terrestrial and marine environments. Additionally, the paper argues that adaptation costs for non-protected areas should be included and could amount to about $290 billion, although these involve key assumptions and have a higher degree of uncertainty than estimates for some of the other fields.[27] The UNFCCC report on global costs of adaptation omitted the costs of protecting ecosystems and the services they can provide for human society, an important source of underestimation.

It is important to note that the cost of adaptation could be much more if other sectors are considered. Including ecosystems protection could add a further $65–$300 billion per year in costs. Furthermore, estimates are not made for sectors such as mining and manufacturing, energy, the retail and financial sectors, and tourism. This probably explains why the investment levels proposed by the UNFCCC appear so small, roughly the annual cost of running two or three Olympic games. That this represents a doubling of current official development assistance only highlights the very low current level of development assistance.

Recommendations for Future Studies

It is important that robust future studies of adaptation costs are based upon case studies that cover a wide range of places and sectors and support top-down analyses. The World Bank and McKinsey will be reporting on this shortly.[28] The time period and expected climate changes need specifying (as they were in the UNFCCC study) and results for multiple timeframes would be useful. Non-climate trends need careful portrayal, especially the future levels of non-climate investment. Costs of adapting to varying amounts of impact should be analyzed, thus providing a choice range for preparedness to pay; and there needs to be some analysis of the residual impact that adaptation is not likely to avoid and the resulting damage costs that we need to anticipate.

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NOTES

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22. IPCC, note 12.
23. Food and Agricultural Organization of the United Nations, "1.02 Billion People Hungry," news release 2009, available at www.fao.org/news/story/en/item/20568/icode/; and FAO, *The State of Food Insecurity in the World* (Rome, forthcoming, 2009)
24. N. Arnell, "Costs of Adaptation in the Water Sector," in IPCC, note 12.
25. Anthony McMichael, professor, National Center for Population and Heath, The Australian National University; and Roberto Bertollini, director, Special Programme on Health and Environment, WHO Regional Office for Europe, European Centre for Environment and Health, personal communication, 2009.
26. Nicholls, note 6.
27. Berry, note 8.
28. World Bank, *The Economics of Adaptation to Climate Change* (forthcoming, 2009); and McKinsey & Company, *The Economics of Adaptation* (forthcoming, 2009).