

Fay, Marianne; Iimi, Atsushi; Perrissin-Fabert, Baptiste

Article

Financing greener and climate-resilient infrastructure in developing countries - challenges and opportunities

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ABSTRACT

Developing countries are faced with a substantial and persistent infrastructure deficit. Climate change complicates this challenge, affecting the way we design and manage infrastructure (defined here as transport, power, water and sanitation) and increasing costs. But all is not negative: Climate change affects both the economic and financial analysis of infrastructure projects in a way that could help achieve long-pursued but elusive goals, such as better maintenance and greener, more efficient design. Further, climate finance could bring additional financing, although that will require increasing the scale of available resources and addressing the fact that climate finance tends to provide ex post financing, ill-suited to a sector characterized by a need for substantial ex ante funding.

Marianne Fay (MFay@worldbank.org) is Chief Economist of the Sustainable Development Network and the co-director of the World Bank's 2010 World Development Report on climate change. **Atsushi Iimi** (aiimi@worldbank.org) is Senior Economist at the World Bank, Washington, D.C. **Baptiste Perissin-Fabert** (bperrissinfabert@worldbank.org) is a PhD candidate at Centre international de Recherche sur l'Environnement et le Développement (Cired), Nogent-sur-Marne, France.

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Financing greener and climate-resilient infrastructure in developing countries – challenges and opportunities

1. Introduction

This study examines how climate change is affecting the way we design, manage and finance infrastructure (defined here as transport, power, water and sanitation). Unlike much of the literature on climate change and infrastructure, it examines issues from the point of view of infrastructure. That is, over and above the familiar question how infrastructure affects climate change, the study raises the question of how climate change affects infrastructure provision and financing. Climate change is shown to complicate the infrastructure agenda. But all is not negative: Climate change affects both the economic and financial analysis of infrastructure projects in a way that could help achieve long-pursued but elusive goals, such as better maintenance and greener, more efficient design. While some of the analysis applies to all countries, we focus specifically on developing countries that are characterized by a substantial and persistent infrastructure deficit.

Unlike much of the work on climate change, we do not neatly separate the discussions of adaptation to and mitigation of (or measures to reduce) climate change, although where needed we flag the different challenges they pose.

The next section discusses the impact climate change is likely to have on the demand for and design of infrastructure, noting that tackling climate change requires profound and immediate changes in the way infrastructure is planned, designed, managed and maintained. We note the importance of improved or at least modified cost-benefit analysis to incorporate the substantial uncertainty introduced by climate change. Section 3 looks at the implications of climate change for climate finance. While climate change will undoubtedly increase the cost of infrastructure, this impact is modest relative to the current infrastructure deficit. Climate finance is becoming available and could be used to reduce the financing gap, although efforts are needed to increase the flows and to address the fact that climate finance tends to be *ex post* financing that cannot help the substantial *ex ante* financing needs characteristic of infrastructure. Section 4 concludes.

2. Win some, lose some – what happens when we include climate change concerns

Infrastructure services directly contribute 42 percent of global greenhouse gases, and this share is likely to increase massively in the coming century under a business-as-usual scenario.¹ Infrastructure services are also very vulnerable to changing climatic conditions. Indeed, large storms paralyze economies usually by interrupting transport and/or bringing down electricity transmission. Droughts affect not only drinking and irrigation water supply but also power supply.² Heat waves result in melting pavements and strained power supply. In other words, infrastructure services are both culprits and victims of climate change.

So tackling climate change and its consequences requires profound and immediate transformations in how infrastructure is planned, designed, managed and maintained. Profound, because business-as-usual approaches will condemn us to unmanageable levels of climate change and to unreliable and



Marianne Fay



Atsushi Iimi



Baptiste Perrissin-Fabert

1 Based on sum of shares of GHGs contributions by power, transport, and waste and wastewater (IPCC 2007). It does not include residential and commercial buildings (8 percent) or industry (19 percent) although these emissions would likely not be possible without the underlying energy infrastructure. Under a business-as-usual scenario, total energy consumption is set to triple by the end of the century.

2 Note that this is not only valid for hydroelectricity but also for thermal and nuclear power plants that require water for cooling.

expensive infrastructure services. Immediate, because infrastructure is long-lived and triggers substantial inertia in socio-economic systems. The choices made now in what is built, where and how, determine future options and vulnerabilities. The complication, however, is that action is needed in a context of profound uncertainty about future vulnerabilities and costs.

This section first discusses how the planning and design of infrastructure needs to change as a result of the new uncertainties introduced by climate change. It then reviews how adaptation concerns affect the management of infrastructure, increasing the returns to good maintenance and possibly modifying the optimal ratio of capital to current expenditure. The section concludes with a review of how climate change concerns could tilt the balance in favour of greener infrastructure in a way that local benefits (such as reduced pollution and congestion) have not always been able to motivate. In both the adaptation and mitigation discussions we note that climate change will likely increase infrastructure spending needs, though by less than usually argued.

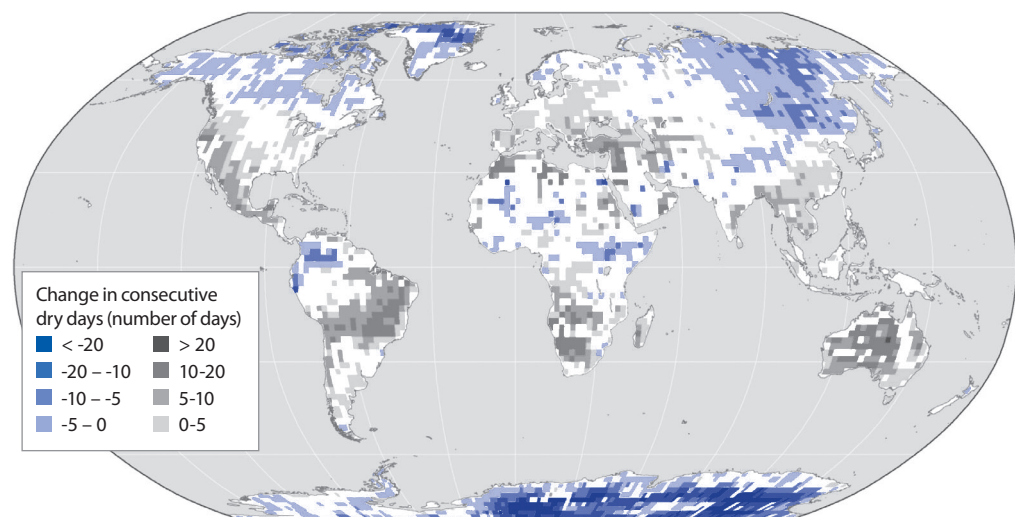
2.1 Climate change complicates the planning and design of infrastructure

Climate change introduces new uncertainties, greatly complicating investment decisions.

Climate change introduces three new sources of uncertainty that greatly complicate infrastructure design and management. These are uncertainties about climatic conditions, about carbon prices and about technologies able to tackle both a changing climate and higher carbon prices.

Climate uncertainty. There is general agreement that sea levels will rise, temperatures will continue rising and the world globally will become a wetter place with more frequent extreme weather events (IPCC 2007). However, the extent of likely change is highly uncertain, as are the timing and location of specific impacts. Map 1 illustrates the point, showing that for much of the world, models do not agree as to whether the climate will become drier or wetter. Further, the reliability of global and regional climate models decreases significantly when results of global models are downscaled to obtain projections at a smaller geographic scale.

Map 1. The future is uncertain – for much of the world models disagree about whether drought occurrence will increase or decrease



Source: World Bank 2009 based on data from The World Climate Research Program CMIP3 Multi-model Database (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php).

Note: The map shows the median change (based on eight climate models using SRES A1B) in annual values in 2030 – 2049, compared with 1980–1999. A “dry” day is defined as one with precipitation less than 1 millimetre whereas a “rainy” day has more than 1 millimetre. White areas show areas of high model disagreement (fewer than two-thirds of the models agree on the sign of change).

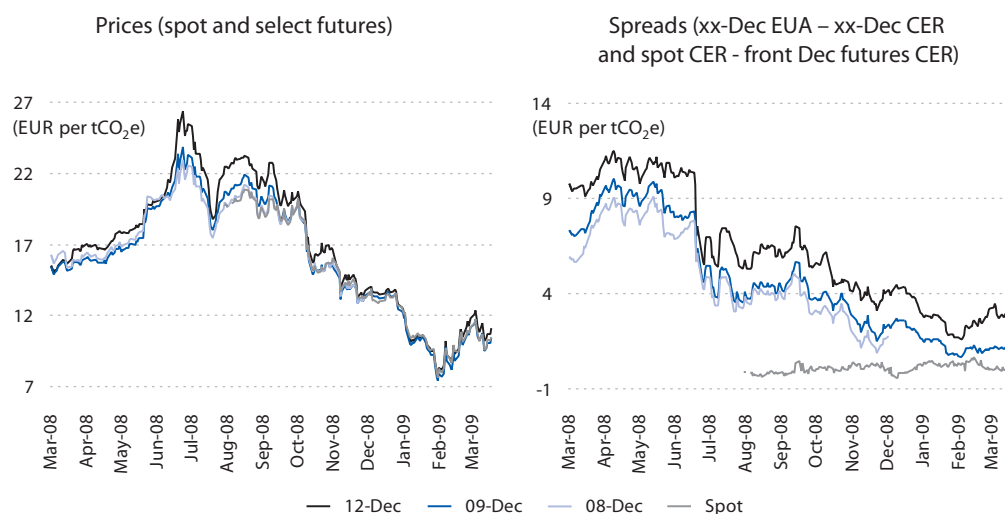
Increased climate uncertainty greatly complicates infrastructure design. In Kazakhstan, for example, truck transportation has already been restricted during the summer when the asphalt is softest due to extreme heat (Nakat 2008). Higher road standards may be necessary. However, it still depends on how the climate will change. In Ho Chi Minh City, more regular and extreme floods are expected because of increasing monsoonal rainfalls combined with tidal influences. The area inundated could increase by 3 to 7 percentage points (World Bank 2010a). More flood control measures, such as flood embankments, sea walls and pumped drainage, may be necessary. But to what extent these measures will be necessary is dependent on the future extent of climate change. Further, a misreading of future trends could result in building infrastructure that actually worsens vulnerability – as indeed has already happened in Ho Chi Minh City, where the construction of dikes resulted in worsened flooding in areas adjacent to the dikes.

Carbon price uncertainty. While it is very likely that carbon will be priced at some point in the future, it is highly uncertain when this will happen, or what the price will be. Carbon markets have been highly volatile with prices between USD 9 to USD 43 per tCO₂ (i.e. tons of carbon dioxide equivalent) because of the global financial crisis and lack of clarity as to what will happen when the Kyoto Protocol commitment period expires in 2012 (Figure 1). The published literature is far from providing a commonly accepted benchmark of the social cost of carbon. The last report by the Intergovernmental Panel on Climate Change (IPCC) estimates the social cost of carbon at USD 3 to USD 95 per tCO₂ (IPCC 2007). Tol (2005), surveying more than 100 estimates, shows that the distribution of estimates has a long tail: the median is USD 3.8 per tCO₂, the mean USD 25 and the 95th percentile USD 95. The UK government recommends a social cost of carbon of USD 28 per tCO₂ for public decisions, with a range from USD 14 to USD 57 (Watkiss 2005) similar to the United States’ central value of USD 21 per tCO₂ and range of USD 5 to USD 65 (US Department of Energy 2010, Appendix 15A). A committee tasked by the French Government to look into the question recommended USD 60 per tCO₂ in 2010, rising to USD 135/tCO₂ in 2030 (Quinet 2008).

There is so far no commonly accepted benchmark for the social cost of carbon, and estimates are in a wide range of USD 3-95.

The combination of historical volatility and uncertainty about future prices has led investors to urge decision makers to act swiftly in implementing policies that put a clear and effective price on carbon to allow businesses and investors to reassess investment values and redirect their investments (Institutional Investors Group on Climate Change 2009).

Figure 1. Secondary Certified Emission Reductions (CER) in the carbon market



Source: Capoor and Ambrosi (2009)

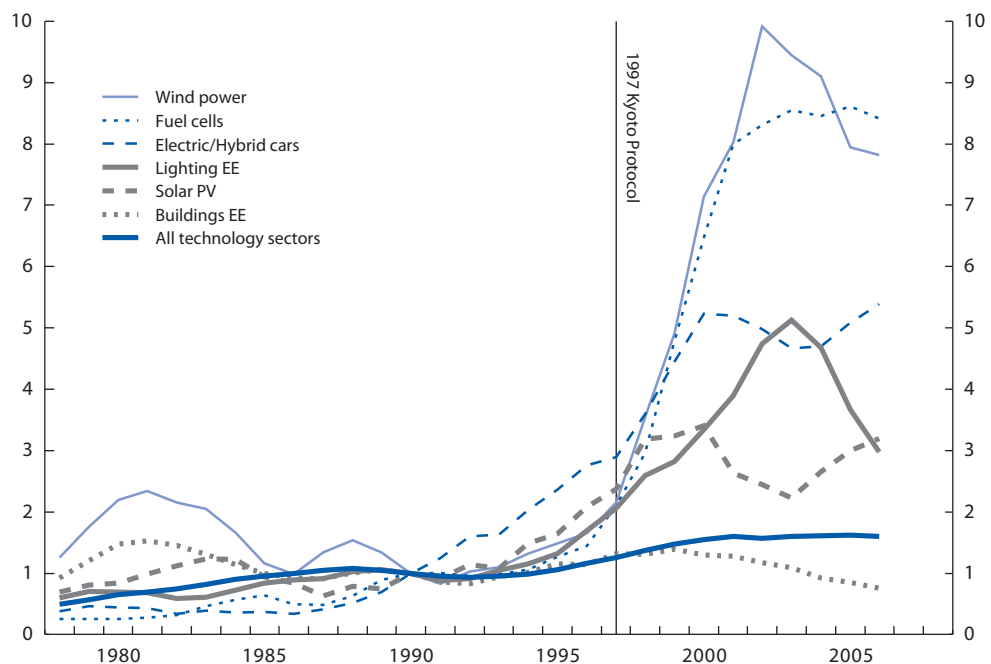
Technology uncertainty. Technology optimists argue that little adaptation and mitigation efforts are needed now, since better technology will make it easier and cheaper to adapt and mitigate later on. Technology pessimists would instead argue for substantial efforts now since new technologies may be far away. Uncertainty about technology also makes it difficult to decide what to build. For example, why invest massively in public transport or high-speed rail if inexpensive electric or hydrogen cars are around the corner? Should a city take a bet on electric cars and start building the associated infrastructure? What if electric cars remain very costly? But technological progress itself depends to a certain extent on estimates of future carbon prices, which motivates investments in R&D.

A number of new technologies have been developed in recent years. Patent applications for climate-related technologies increased since the late 1990s (Figure 2). Some energy-efficient or climate-resilient technologies are ready to use while others remain to be developed. There are also not-yet-proven advanced technologies, such as carbon capture and storage, fuel cell cars and second-generation biofuels. Which technology to bet on also depends on the uncertain future evolution of costs. While costs are generally expected to drop with higher scale of production, this has not always happened. Wind energy costs declined by 80 percent over the past 20 years largely due to economies of scale (World Bank 2009) but the price of the Toyota Prius – the best-selling hybrid car – barely changed over the last ten years (although fuel efficiency improved by about 20 percent).

Depending on technology availability, the sector distribution of climate change mitigation can look completely different.

Mitigation scenarios can look completely different depending on views on technology availability. This is particularly true for the transport sector. The IEA projects transport to contribute with a 30-percent reduction in transport-related emissions to the 50-50 scenario (50 percent reduction in emissions by 2050). By contrast, the Pacific Northwest National Laboratory (PNNL), an equally reputable energy modelling institution, projects a 47-percent increase in transport emissions in the same overall 50-50 scenario (Table 1). The main reason for this divergence of views is that the PNNL is more pessimistic about technology diffusion of advanced vehicle technologies, such as plug-in hybrids and electric vehicles.

Figure 2. Trend of number of patent applications for mitigation technologies (Index 1990 = 1)



Source: OECD (2010)

Table 1. Sector contributions to a 50 percent reduction of energy-related 2005 emissions by 2050

Sector	Estimated percentage of carbon that must be removed by sector	
	IEA	MiniCam
Power	-71	-87
Building	-41	-50
Transport	-30	47
Industry	-21	-71
Total	-50	-50

Source: World Bank (2009)

Note: MiniCam is the model of the Pacific Northwest National Laboratory.

Uncertainty about impacts, prices and technology would not be so problematic if infrastructure could be quickly adjusted to respond to new information. However, infrastructure exhibits significant inertia: infrastructure investment creates long-lived capital stocks which cannot be removed overnight and therefore induce lock-in effects in terms of technology used and GHG emissions during their lifespan (e.g. 40-50 years for power plants; up to 75 years or more for road and rail networks or power distribution networks). Further, infrastructure investments are “lumpy”, implying a concentration in time of aggregate investment in major networks of long-lived capital. As a result, the window of opportunity during which to influence what is built is quite narrow (Shalizi and Lecocq 2009): developing countries (particularly fast-growing ones such as China and India) will install the bulk of their infrastructure in the coming decade.

China offers a striking quantitative illustration of the magnitude of the issue. Although its emissions are currently on par with those of the US, its “committed emissions” (computed on the basis of its existing installed infrastructure and the world average of infrastructure lifetime) already account for 37 percent of global emission commitments (Davis *et al.* 2010). This is due to the massive and very recent expansion in its infrastructure and the fact that coal accounts for most of its power generation capacity.

Infrastructure choices generate further downstream socio-economic inertia. The US interstate highway program launched during the 1960s caused particular patterns of settlement (sprawl) to emerge, making it very difficult to develop cost-effective public transportation (Shalizi and Lecocq 2009). Network effects create incentives to densify existing grids (Economides 1996). The comparative value of having a fuel car rather than an electric car increases when everybody has a fuel car and a dense network of fuel stations is already set up. Then, the dominant technology tends to crowd out the market at the expense of newer technologies. Further, oil refineries, auto manufactures, and power generator producers usually exhibit internal economies of scale and are accompanied by a number of downstream industries (Shalizi and Lecocq 2009; Davis *et al.* 2010).

Many of the likely climate impacts will not look new for engineers, policy makers and project designers. In choosing how high to build the clearance below a bridge, how securely the decks must be attached to the substructure to withstand high winds, how often its surface ought to be repaved, whether riprap or extensive gabions are needed to protect abutments from scour, decision makers consult building and maintenance standards that provide guidance on these choices in relation to climate, hydrological, geological, and usage data. Probabilities and risks are always weighed against costs, and locally appropriate choices are made based on the combination of physical factors with risk tolerance and budget constraints. So why can't investments continue to be made as they have always been?

The fundamental problem is the deep uncertainty about climate change and future technology. Past climate data have, until now, provided reasonable summary statistics to guide infrastructure investment

Substantial inertia in infrastructure and associated socio-economic systems complicates the management of uncertainty.

decisions, based on probabilities and averages. Infrastructure design and planning, insurance pricing, and many other decisions have long assumed stationarity in climate events. However, with climate change, “stationarity is dead” (Milly *et al.*, p. 573). Decision-making based on past averages and probability distributions for various climate phenomena are no longer valid. And new underlying probability distributions are unknown. Given recent extreme events, such as floods, heat waves and massive snow, we may not have yet figured out whether they were realizations of the past probability distribution or whether the whole underlying probability distribution has shifted.

New ways of thinking to facilitate robust decision-making are required to limit the possible adverse impacts of deep uncertainty on infrastructure (see discussion in Sub-section 2.4 below). Communication between infrastructure planners and climate specialists must be promoted to determine the full range of relevant climate information that could affect a specific project and then get planners the relevant data. Further, local decision makers will need to decide what variables are most important for them. In some instances this will be quite obvious – land-locked countries do not need to consider sea-level rise, and changes in freeze/thaw cycles are not a concern in low-elevation, low-latitude areas. In others, it will not be so clear, so an initial general understanding of possible climate impacts might be needed to determine which variables need to be monitored.

2.2 Improved infrastructure management is a key part of any adaptation strategy

A key consequence of climate change will be an increase in both intra-annual and inter-annual variability in temperature and precipitation as well as greater frequency of extreme weather events. The greater intra-annual variability means that, even though total annual rainfall in a location may be unchanged, under an altered climate regime, rainfall is likely to occur in more concentrated downpours so that many regions will experience both more floods and more droughts. Thus, infrastructure and operational procedures will need to be adapted to deal not just with drier or wetter conditions, but with both. This will very likely mean an increase in costs. For even if it were no more or less costly to build, maintain, and operate transport infrastructure in either a dry climate or a wet climate, it is more costly to build, maintain, and operate assets to withstand both.

Yet, World Bank estimates of the investments required for developing countries to adapt their infrastructure to a changing climate are relatively modest at USD 14-30 billion a year (Table 2). The cost of adaptation only includes the incremental cost of constructing as well as operating and maintaining the baseline level of infrastructure under new climatic conditions (Annex). Estimates from other studies range from USD 2 billion to USD 63 billion, with infrastructure generally one of the largest sources of total adaptation costs.

Estimates of the infrastructure adaptation gap are relatively modest...

Table 2. Average annual incremental adaptation cost by 2050

Source	Total	Infrastructure	
	USD billion	USD billion	Percent of total
UNFCCC (2007)	28-67	2-41	
Parry <i>et al.</i> (2009)		16-63	
World Bank (2010b)			
NCAR scenario	90	30	33
CSIRO scenario	78	14	17

Notes: Estimates by Parry *et al.* (2009) include housing and infrastructure. Estimate by World Bank (2010b): Delta-p estimate only. See Annex for a discussion of the methodologies used by the various studies.

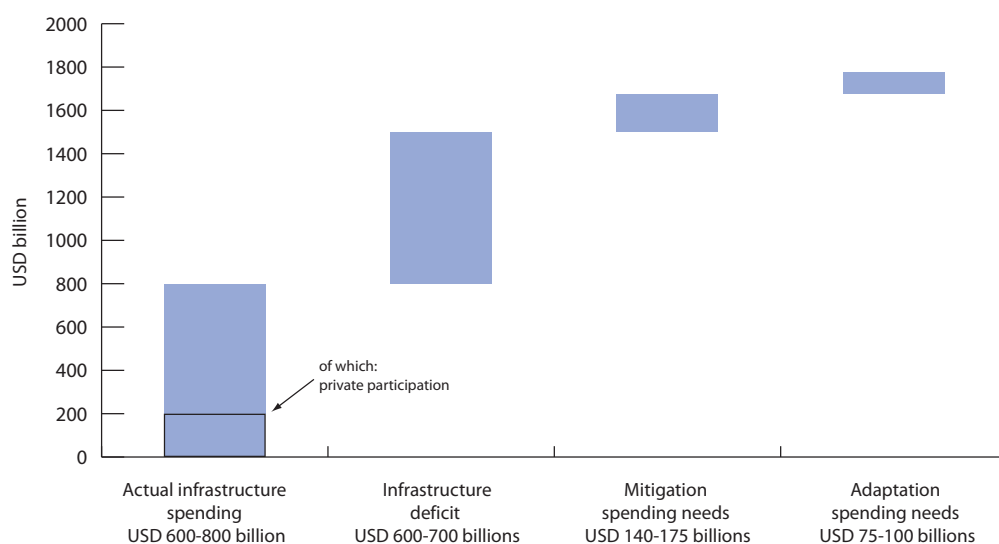
The methodologies used to estimate adaptation costs estimate the incremental cost of adapting to climate change rather than the cost of reducing vulnerability. The latter would require addressing the significant infrastructure deficits that exist in most developing countries. This approach is theoretically correct given

the fact that adaptation costs are usually being calculated to estimate the assistance that high-income countries should provide given their responsibility for a disproportionate share of past emissions.

But in most developing countries vulnerability arises mostly from a lack of infrastructure or from poorly maintained assets. Developing countries are generally estimated to need some USD 1.2-1.5 billion in annual infrastructure investment to close the development gap – of which only about half is actually invested every year. This is supported by the result of country level studies conducted across Africa that show that most countries are investing only 30 to 60 percent of what would be needed to close the development gap (Briceno-Garmendia *et al.* 2008). Thus, adaptation costs pale in comparison to the USD 600-700 billion in additional annual investment in infrastructure that would be needed to close the development gap (Figure 3 and Table 3).

...but resilience to climate change requires addressing the development gap.

Figure 3. The adaptation and mitigation gaps, while important, are a fraction of the overall infrastructure “development” gap



Source: Own elaboration based on data from Fay *et al.* (2010) and World Bank (2009)

Note: Total infrastructure investment needs are estimated at USD 1.2-1.5 billion per annum, of which only about half is actually invested.

Table 3. Comparison between annual development and adaptation deficits (USD billion)

Source	Parry <i>et al.</i> (2009)		World Bank (2010c)	
	Infrastructure deficits	Adaptation costs	Baseline spending	Adaptation costs
Asia	218	11–44	956	18
Latin America and the Caribbean	37	2–7	283	4
Africa	62	3–12	130	3
Others			531	5
Total	316	16–63	1900	30

Notes: Parry *et al.* (2009): includes housing and infrastructure and calculates the infrastructure deficit as the investment needed to address the Millennium Development Goals. World Bank (2010c): Based on the National Center for Atmospheric Research (NCAR) climate scenario; estimates include health, education, power and wire, road, urban, water and sewage, and other transport infrastructure; baseline spending is estimated as amounts of investments needed to address the overall development deficit.

But in addition of addressing the development deficits, reducing vulnerability will require better maintenance infrastructure assets. Returns to maintenance are well known to be very high, with assets decaying at a much faster rate when improperly maintained. Climate change will only increase the importance of good maintenance. Poorly maintained roads are very vulnerable to climate change, particularly increased precipitation, as water infiltrates through cracks and joints, resulting in pavement faulting and increases in the roughness of roads. A detailed study of the road sector in Ethiopia found that much of what was needed to adapt to the changing climate was in fact better maintenance (COWI 2010). Unsurprisingly, the study found that aggressively improving maintenance of roads would pay off even with the current climate as potential benefits from better maintained culverts, bridges and riverside roads are estimated to be already greater than costs (Table 4).

Table 4. Cost of climate-related incidents in 2009 and climate change adaptation in Ethiopia (USD thousand, constant 2009 prices)

	Culverts	Bridges	Roads	Drainage ditches
Expected road user costs in 2010 due to climate-related incidents	3.2	9.8	5.3	0.003
Annual adaptation cost	0.1–0.3	4.3–14.0	0.1–0.4	0.02–0.2

Source: COWI (2010)

Notes: "Roads" refers to roads located next to river banks. Cost is per km.

While proper maintenance contributes to climate-proofing existing infrastructure, the most vulnerable populations are those without any access to basic infrastructure.

Lack of proper maintenance of rail assets is already affecting rail operations in developing countries. In Africa, nearly half of the assets of railways are estimated to be in urgent need of rehabilitation (Briceno-Garmendia *et al.* 2008). In Azerbaijan, 62 percent of the track on the East-West corridor is operating under speed restrictions. Nearly two thirds of the mainline locomotives are well beyond their design service lives and in need of urgent replacement. Accordingly, Azerbaijan Railway cannot operate at full capacity (World Bank 2008). Climate change may add to these difficulties, because increased intensity of precipitation may damage rail beds and more frequent heat waves may strain tracks. But increasing resilience will require addressing the development deficits.

In many developing countries, proper airport infrastructure and facilities are also missing. This tends to result in poor regulatory aviation oversight and compliance with international safety and security standards (World Bank 2010d). One third of developing countries have not yet satisfied the international standards and practices for aircraft operations and maintenance (Table 5). And many flight cancellations are attributable to weather conditions.³ Without addressing the infrastructure deficit, it will be impossible for the air transport sector to accommodate more severe weather conditions in the future.

In the electricity sector, many developing countries are wasting a significant amount of energy in technical and non-technical losses (Figure 4). In addition to reducing emissions, improving efficiency would make it easier to expand services and tackle the challenge of providing electricity to the 1.5 billion people who still do not have access. It might also help reduce climate vulnerability. In Albania, which derives more than 95 percent of its energy from hydroelectricity and is likely to experience reduced precipitation as a result of climate change, significant efforts to improve energy efficiency in production and consumption are now being made as part of efforts to adapt to climate change (ESMAP 2009).

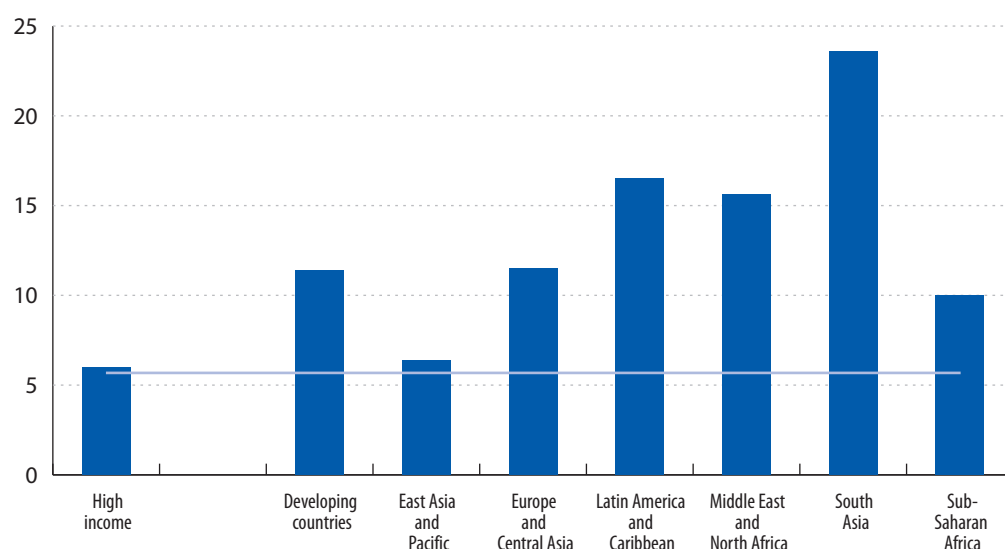
³ According to the Research and Innovative Technology Administration, Bureau of Transportation Statistics, about 40 percent of flights cancelled were attributed to weather in the United States.

Table 5. US civil aviation safety assessment 2008

	Number of countries assessed	Percent of countries meeting ICAO standards
High-income countries	45	96
Developing countries	62	68
Upper middle-income countries	27	89
Lower middle-income countries	27	59
Low-income countries	8	25

Source: US Federal Aviation Administration

Figure 4. Electricity transmission and distribution losses, latest available year (percent of total)



Source: World Development Indicators (accessed November 2010)

2.3 Mitigation benefits further tilt the balance in favour of greener infrastructure

Mitigation costs in developing countries could reach USD 139-175 billion a year by 2030 with associated financing needs of USD 264-563 billion (Table 6). The difference between upfront costs and financing needs is due to the fact that many efforts concern energy efficiency or renewable-energy projects that have higher upfront costs, but eventually pay for themselves or have lower operation costs.

Annual financing needs for mitigation in developing countries could reach USD 264-563bn by 2030, more than half of it concerning infrastructure.

Table 6. Annual net cost and financing needs to limit warming to 2°C in 2030

	Net cost		Financing need	
	USD billion	Total USD billion	Infrastructure USD billion	Percent
IEA		565	324	57.3
IIASA		264		
MiniCam	139			
McKinsey & Co.	175	563		
PNNL		384		

Source: World Bank (2009) and IEA (2009)

Yet not all is negative. Factoring in the benefits of mitigation could significantly alter the economics of investment in infrastructure in favour of greener investments. These usually carry a host of local co-benefits, such as improved environmental health or a reduction in congestion and local pollution, which are often not fully taken into account in project appraisal. This internalization could encourage policy makers to allocate more resources to greener and cleaner investment.

Taking the case of transport, externalities such as congestion and local pollution are estimated at 11 cents per mile (Table 7). This is approximately the same amount as the fuel cost spent on a standard passenger car in the United States, meaning that the monetary cost of driving a car is only half its social cost. In total, these external costs amount to 10-11 percent of GDP in OECD member countries (Banister 1998 cited in OECD 2002b). The potential benefits from removing these externalities therefore cannot be ignored when implementing policy interventions.

Table 7. Estimated external costs in the United States

	US Cent/gallon	US Cents/mile
Central values of marginal external costs		
Greenhouse warming	6	0.3
Oil dependency	12	0.6
Local pollution	42	2.0
Congestion, cents/mile	105	5.0
Accidents	63	3.0
Total	228	10.9

Source: Parry *et al.* (2007)

Note: It is assumed that vehicle fuel economy is 30 miles per gallon and gasoline price is USD 3 per gallon.

In transport, greenhouse gas abatement requires infrastructure improvements but demand side measures might be needed, too.

Policy interventions to reduce emissions can carry significant local co-benefits. For instance, traffic congestion clearly increases emissions as cars tend to emit more CO₂ when traffic speeds are too low (Davis and Diegel 2004; Anas and Timilsina 2009). But congestion and idling also increase local pollutants and noise. Optimization of traffic signals can not only alleviate congestion and save travel time but also reduce CO₂ emissions. In Tokyo, for instance, an improvement of the intersection of rail tracks and trunk roads resulted in a doubling of traffic speed, thereby reducing emissions by 12,000 tons of CO₂ per year (OECD 2002a). Complementary measures might be needed, however, so that people do not respond to reduced congestion by driving more.⁴ Fuel taxation, road user pricing, parking policies, congestion charges and high vehicle-related charges help discourage people from using cars, resulting in both lower traffic congestion and emissions.

And while public transportation helps reduce emissions, it also results in reduced road traffic injury and fatality. Speed limits and car inspection regulations also help with both safety and emissions. In Rio de Janeiro, the state light-vehicle inspection and maintenance program is expected to reduce carbon monoxide by 16-44 percent and hydrocarbon by 9-37 percent as a co-benefit (Ribeiro and Abreu 2008).

Potential health benefits from local pollution prevention policies that help reduce emissions, such as diesel particulate filter regulation, are also significant. Particulate exposure affects the pulmonary

⁴ In Niort, France, a traffic signal synchronization project improved the average speeds. But at the same time, the traffic volume also increased by 7 percent. People seem to have been induced to travel more because of the increased speeds. As a result, emissions rose by 6 percent (OECD 2002a).

function in children and asthmatics and causes mortality (Schwartz 1994). Individuals in lower middle-income and low-income countries are exposed to 50 percent higher particulate matter air pollution than people in high-income countries. For instance, converting diesel to CNG buses is one of the common measures to control pollution from vehicles. In Mumbai this could reduce particulates by 662 tons of PM10 per year while also reducing CO2 emissions (Takeuchi *et al.* 2007).

Another positive side-effect of the pressure to mitigate is the increased emphasis on energy efficiency. Energy modellers expect energy efficiency to account for a significant share of emission reduction relative to the business-as-usual scenario and evidence abounds that the potential is very large (World Bank 2009). Furthermore, it is cost effective: a dollar invested in energy efficiency is estimated to avoid more than two dollars in investment in energy supply capacity (World Bank 2009). This is particularly true for buildings, which consume about 40 percent of the world's final energy, and manufacturing. Pricing is critical to motivate energy consumers to use energy more wisely. If energy consumption is properly priced, the energy efficiency markets, such as energy supply companies (ESCO) can be part of the solution. In Brazil, the National Electrical Energy Conservation Program aims to retrofit government buildings and save 140 GWh of energy per year (UNEP 2010).

2.4 Better cost-benefit analysis is needed to help with both adaptation and mitigation concerns

New externalities and increased uncertainty call for revisiting cost-benefit analysis (CBA) approaches. To perform sound project appraisals, the full spectrum of the consequences of investment decisions has to be examined. Still, as desirable as expanded CBA may be, they are constrained in practice by data availability, reliability, cost of collection, and accuracy. Decision makers may therefore be confronted with a trade-off between accuracy and relevance for action.

New externalities and increased uncertainty call for revisiting cost-benefit analysis.

With this caveat in mind, it may be desirable to expand CBA to better take into account the following broader set of factors.

- **Indirect and induced effects.** Shalizi and Lecocq (2009), drawing on the input/output literature, give a new definition to these concepts. "Indirect effects" refer to effects that occur outside the boundary of the project but within its system. They are not taken into account in traditional project appraisal but can be related to the project because they belong to the same system. Example: an indirect effect of the US interstate highway network was to foster the building of new roads since it was the easiest way to plug in new transport infrastructure with the existing transport grid. "Induced effects" are those that occur beyond the boundary of the project's system and later in time. The sprawling pattern of US cities which does not belong to the road transport system can then be analyzed as an "induced effect" of building an efficient interstate highway network. Tracking those effects may be critical to assess projects' CO2 emissions and very relevant for mitigation concerns.
- **Externalities or intangibles.** The transport literature is already familiar with the pricing of certain externalities such as congestion (through the opportunity cost of time). Though they are still controversial, methodologies to price eco-system services are already available (Costanza *et al.* 1987, Chevassus 2009). And as discussed earlier, there are also attempts to integrate a social cost of carbon in project appraisals to rebalance the competition between high and low carbon investments (*e.g.* AFD 2008, Awerbuch and Yang 2007).
- **Integrating uncertainty: real option value** (Scandizzo and Paolantonio 2010). Real options do not measure the values of the investments already made, but the contingent values that these investments would have if they were to be undertaken under alternative degrees of uncertainty. Within that framework, the extended form of the Net Present Value (NPV) calculation could be written in the following simplified form: $ENPV = E[B] - E[C] + [OVc - Ovd]$; where OVc denotes the "option values

created” and OVD the “option values destroyed” by the project. Then, when $OVC - OVD > 0$, the option value framework discloses additional benefits which increase the rate of return of some projects that would have failed traditional NPV tests. This improves the accuracy and relevance of the economic analysis of projects. It can help make the case for climate adaptation projects, for instance, which rarely pass traditional CBA because of their present excess costs (compared to business-as-usual projects), whereas they may get profitable when the option values they create are taken into account.

Yet, as accurate as an expanded CBA could be, a simple one-size-fits-all framework cannot encompass all the relevant dimensions of investment decisions. In some cases, monetary valuation (aggregation into only one commensurate dimension) of some decisive effects becomes meaningless because it is too reductive. Then CBA may be just one component of the decision process while narrative arguments can complement quantitative analysis. These arguments would be usefully based on the following techniques.

- **Multi-criteria analysis.** This approach aims at capturing a broader scope of dimensions of the decision (especially the moral dimension of decisions and human behaviour). Such framework acknowledges that decisions are fundamentally driven by political or normative choices, as reflected in the weight attributed to each criterion of the decision.
- **Technological-scenario analysis** along a decision tree. This consists of an *ex ante* mental experiment which describes sequences of investments. The framework assumes that one can attribute evolving subjective probabilities to alternative technical options all along the sequence of investments (*i.e.* along the branches of the decision tree). In a context of uncertainty, let us assume that all technical options are equally probable before the first round of investment. Then, after the first investment in, say, an interstate highway network, probabilities attached to alternative technical options for the second round of investment may have changed and become unequal among possible options. From now on, new investments in local road extension plugged into the interstate highway network, or densification of the existing network, are more probable than the construction of a parallel railway system. The new bias in favour of this type on transport infrastructure arises from a number of reasons: (i) path dependency; (ii) network effects; (iii) knowledge lock-in; and (iv) institutional lock-in.
- **Robust decision-making (RDM).** In the framework proposed by Lempert (2000), decisions are not based on optimizing for the most likely future but on optimizing given an unknown future, assessing vulnerabilities of different strategies. The aim is not to select the only “optimal” strategy, but the one best suited to generate a consensus among stakeholders and/or to minimize the impacts of a bad surprise. Thus, RDM does not help decision makers predict what will happen but to design better choices and improve the ability to cope with low-probability, undesirable events. In fact, the RDM approach offers a hedge, which consists of both reducing policy vulnerability and increasing policy flexibility if the unexpected occurs. RDM prepares decision makers to face the remaining uncertainty and help them to make inevitable trade-offs between the costs of coverage and levels of acceptable risks. RDM is particularly adequate to guide long-lived capital investments when decision makers are confronted with both deep uncertainty and a rich set of controversial options.

Infrastructure delivering even in the face of extreme yet uncertain climate events may be preferable to one with maximum net benefits in the baseline scenario.

3. Implications for the design and use of climate finance

Even if adaptation and mitigation costs are a fraction of overall infrastructure investment needs, they do add to the stresses of an already underfinanced sector. Climate finance could help although remains too modest. This section reviews the limitation of current adaptation and mitigation finance and looks at possible solutions. A first step is to “get prices right”, or at least move in that direction, by eliminating

distorting subsidies. A second involves looking at means to develop public-finance schemes to increase available finance. In the absence of carbon prices or firm commitment to reduce emissions, the challenge remains substantial.

3.1 The limitations of current adaptation and mitigation finance

Current flows of mitigation and adaptation finance pale in comparison to needs (World Bank 2009). As discussed earlier, overall mitigation financing needs in developing countries are estimated at USD 265-565 billion per year. At the same time USD 75-100 billion are needed for adaptation. In contrast, the various funds available amount to a fraction of these needs. The Global Environment Facility (GEF) established in 1991 commits about USD 250 million per year largely in the form of grants to developing (non-Annex I) countries who are parties to the UNFCCC, in support of energy efficiency, renewable energy, new clean energy technology, and sustainable transport projects. The Clean Technology Fund (CTF) established in 2008 also provides grants, concessional loans and partial risk guarantees to help countries scale up clean technology initiatives. Including private and public co-financing, the CTF allowed for some USD 37 billion in green investments over the last two years. It demonstrated that the combination of funding instruments can leverage substantial resources, as in the case of Mexico City (World Bank 2010b).

Currently available resources are a fraction of the adaptation and mitigation gaps.

The funding gap remains huge even if other official and nongovernmental financial resources are taken into account. Private capital will not shift from regular projects to climate projects unless the latter are viewed as lower-risk options. Indeed, redirecting private finance is fundamentally an issue of lowering the risk premium on carbon-saving investments. This reduction depends upon: (i) the credibility of some form of carbon pricing in the future (carbon markets, carbon tax, social cost of carbon, shadow cost of regulatory standards); and (ii) the deployment of national mitigation efforts that facilitate the effectiveness and acceptability of measures leading to this carbon value.

In addition to their inadequate amounts, both adaptation and mitigation funding suffer from drawbacks that reduce their ability to effectively contribute to infrastructure finance. Adaptation projects are constantly confronted with the problem of additionality. If the goal of the financing is to reduce vulnerability, the financing might wisely be used to remediate a development deficit (*e.g.* clean up the road culverts and maintain the roads more regularly) rather than a net incremental project (enlarge the culverts).

In fact, many developing countries reject conditionality on adaptation funding, invoking the (very valid) need to use adaptation funding as a new source of development assistance. Indeed, limiting adaptation funds to the financing of incremental costs due to adaptation to climate change bears the risk of providing only a small share of total cost, insufficient to leverage other funding sources, and of making it impossible to implement most-needed development projects. Drawing an interesting parallel between the EU enlargement funds and adaptation finance through the notion of additionality, Przyluski and Hallegatte (2010) suggest that adaptation funds should finance more than the incremental cost, as was done for EU projects in accession countries. The authors propose to set the level of funding at the level necessary to trigger other funding sources to reduce the development.

As to mitigation finance, it suffers from four main limitations – despite commendable achievements, such as creating a large market with a single price for carbon and catalyzing and implementing Clean Development Mechanism (CDM) projects:⁵

⁵ See de Gouvello and Zelenko (2010) for a discussion.

Carbon finance tends to be project based and ex post.

- It is only a limited means to overcome the upfront-financing barrier faced by many low-carbon projects since it provides *ex post* funding only once emission reductions are effectively observed;
- It is project based, making it largely irrelevant for sectors such as transport which require sector-wide combinations of demand and supply-side measures to truly affect emissions.⁶
- It only provides incentives to generate carbon offsets; consequently, emission reductions achieved in non-Annex 1 countries can only compensate for insufficient reduction efforts in Annex 1 countries (*i.e.* the buyers of carbon offsets);
- Future demand for CDM carbon offsets by Annex 1 countries will decrease as these countries limit the share of emission reduction that can be achieved through offsets (already the case for the EU emission trading system).

From an immediate infrastructure finance point of view, the first two of these four limitations are the most problematic. Many “climate-smart” projects – projects that efficiently incorporate relevant adaptation or mitigation concerns – still suffer from a lack of upfront funding necessary to launch the project. And the impact of the CDM on infrastructure will remain limited as long as it is project-based.

3.2 Mobilizing more available internal resources – getting the price right

The removal of climate-damaging subsidies (implicit or explicit) is an essential first step before attempts are made to tap outside resources. This will not only encourage people to use energy more wisely but also free up scarce fiscal resources. The IEA estimates that fossil-fuel-related consumption subsidies in developing countries amounted to USD 312 billion in 2009, a significant drop from USD 558 billion in 2008, which is mainly due to the decline in fossil-fuel prices. Consumption of oil products and natural gas received subsidies of USD 126 and USD 85 billion, respectively. The rest went to coal. A complete phase-out of these subsidies by 2020 would result in a reduction in global primary-energy demand of 5 percent and a fall in energy-related carbon-dioxide emissions of 5.8 percent, compared with a baseline in which subsidy rates remain unchanged (IEA 2010). Ten countries spent more than USD 10 billion subsidizing fossil fuels; nine countries allocated 5 percent or more of their GDP on such subsidies (Figure 5). These figures underestimate global fossil-fuel subsidies since they do not include producer subsidies that are believed to exist notably in high-income countries.

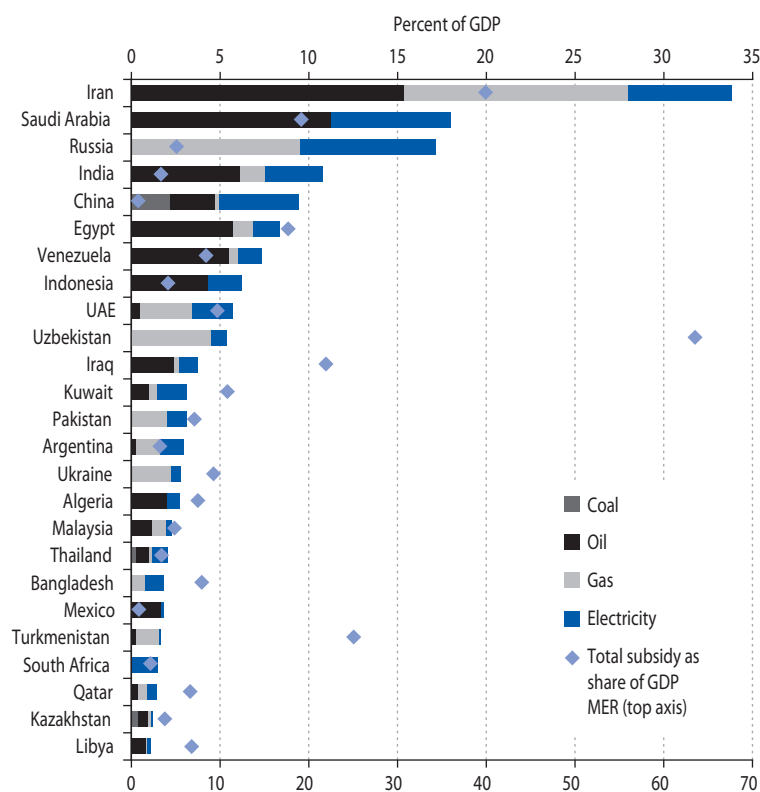
Another internal resource that can finance mitigation and adaptation in infrastructure is user charges. In many developing countries, utility services and roads are explicitly or implicitly subsidized to a greater or lesser extent. In the electricity sector, excess technical losses, non-payment or under-pricing, averages 0.84 percent of GDP in Africa (Briceno-Garmendia *et al.* 2008). Improving technical reliability of the network, strengthened tariff collection and/or rationalization of the prices, could generate substantial financial resources while promoting more efficient consumer behaviour.

Similarly, roads are largely publicly funded, hence *de facto* subsidized by public resources in most countries. In the United States, there are 277 toll roads, bridges and tunnels, totalling about 5,000 miles. But this accounts for only 0.2 percent of total roads or 0.5 percent of federal-aid highways. The share of toll revenue is less than 10 percent of total highway funding resources (NSTIFC 2009). Road pricing – both toll roads and cordon pricing – has proven highly effective to reduce congestion and emissions from traffic in urban areas since the pioneer experience in Singapore (World Bank 1978; OECD 2002a). Recently, more comprehensive road user pricing, such as cordon pricing, has been implemented in

⁶ Transport only accounted for three out of more than 2,200 registered CDM projects as of mid-2010.

several urban areas. In London and Stockholm, cordon pricing brought about USD 237 million and USD 116 million of congestion charges a year, respectively. These approaches are, however, only suited to high-density areas.

Figure 5. Economic value of fossil fuel consumption subsidies by country and type 2009



Source: IEA (2010)

Note: MER = market exchange rates.

3.3 Reforming external public financing schemes

Most economists share the view that the global economy is not confronted with a problem of capital shortage. Huge amounts of capital are held by sovereign funds, pension funds and more broadly by institutional investors. The available capital could be reoriented toward climate-smart projects if private investors could earn adequate risk-adjusted returns. Indeed, climate change presents both significant risks and significant opportunities for investment portfolios.

The challenge for public action consists in attracting the vast amount of private capital needed to scale up private investment in climate solutions. Public-Finance Mechanisms (PFMs) must be designed to maximize the leverage of additional private finance and to minimize the cost of public action (Ward *et al.* 2009). One assessment of experience with a number of different models of PFMs suggests typical leverage ratios of private investment in the USD 3–15 range for every USD 1 of public money⁷ (Maclean *et al.* 2008). A more conservative assessment estimates leverage ratios of 2 to 4 (AGF 2010). Either way, concerted programs of PFMs are key to raise needed private funds.

⁷ Such estimates are rather conservative in that they do not take into account the whole array of positive externalities generated by the PFMs, which support multiple generations of investments and help create markets that continue to grow after the public funds are expended. Public funds here are taken to include official development aid (ODA) and resources made available through multilateral development banks.

A reform of external public financing schemes should enhance the attractiveness of 'climate-smart' infrastructure projects...

However, the emerging proposals for developing climate finance are at risk of fragmentation. This is a source of inefficiency denounced in the Paris Declaration on Aid Effectiveness and discussed in the Bali action plan. It is also a cause of distrust inhibiting the increase in climate finance.

Assessments and reviews of experience of existing mechanisms are still very few.⁸ Table 8 lists all the PFM's used so far to back up climate-smart projects.

Table 8. Examples of public-finance mechanisms provided by different institutions

...and address the 'instrument gap' between climate-smart and traditional development projects.

	Public-finance mechanisms	Direct support		Indirect support	
		<i>International to project</i>	<i>International to national</i>	<i>National to project</i>	
Contribution to investment and operation	Up-front grant - Standard technical-assistance grants - 'Smart' grants	GEF grants Other bilateral and multilateral DFIs	ODA		Investment support
	Funding during operation	Offset mechanisms (CDM) World Bank support	Grant linked to continuous delivery (finance <i>plus</i> regulatory stability)		- Incremental payment to renewable - Removal of energy subsidies - Carbon tax/cap-and-trade scheme
Facilitating access to finance	Provision of equity - Private equity - Venture capital (VC) - Long-term investment	ADB Clean Energy PE fund EIB/EBRD Sovereign Wealth Funds	EIB/EBRD support for VC fund setup costs, and co-investment in funds		Carbon Trust VC fund Transition economy VCs
	Provision of debt and equity - Loans (usually with governance conditions) - Credit lines - Equity (large projects, alongside foreign investors)	IFIs e.g. EBRD, IFC	IMF and World Bank loans		
	Risk coverage - Full or partial guarantee - Policy to cover all or specific causes of non performance - Other financial products	MIGA political risk insurance	World Bank/IFC Partial Credit and Partial Risk Guarantees		Export credit agency guarantees

Source: Neuhoff *et al.* (2009)

⁸ The World Bank is launching a study to address this gap and evaluate its own instruments as well as those that have been used by Regional Development Banks.

The table distinguishes two types of PFMs:

- Those which aim at removing the excess financial and institutional barriers against climate-smart investments. Up-front grants and technical-assistance grants during the planning phase address directly the excess cost of such projects, which usually arises from the specific expertise and the more costly technologies they require. Then, CDM projects are explicitly dedicated to climate-smart projects enhancing project revenue during the operation phase when business as usual would have lead to less climate-friendly investments. Lastly, the suppression of distortive subsidies to dirty energies and the implementation of a carbon tax or a carbon market restore the truth on relative energy prices, thereby facilitating low-carbon investments.
- Those which are less focused on climate issues but commonly used to finance development projects. Public loans or public equity can be used to complement private funding of up-front capital (public funds intervene as “lenders of last resort”) or to maximize the leverage effect of additional private capital participation in the project. Regarding the risk coverage of building costs or production costs, the public sector can play the role of “insurer of last resort” through well-defined guarantees when private insurers are not ready to cover the risks or require too high premiums.

Public-finance mechanisms fall into those removing financial and institutional barriers against climate-smart investment and those commonly used to finance development projects.

As inventive as existing PFMs can be, they are not sufficient to leverage the overall amount of capital required to fund climate-smart projects. Therefore, they should be complemented by a more comprehensive and sophisticated financial architecture, which would offer low-cost access to capital and manage to channel enough private funds toward green infrastructure projects.

The scope of public intervention has to be defined consistently with an appropriate risk allocation between the private and public sectors. The private sector will invest to the extent that it expects a competitive risk-adjusted return. The role of the public sector thus should be limited to reducing risks associated with market failures, policy credibility and equity considerations. To go beyond this goal would be inefficient, stretching the financing capacity of governments and causing deadweight loss.

Given the risks of underlying projects and low familiarity with carbon finance, there have been few attempts by financial institutions to monetize forward carbon revenue streams to provide (part of) the investment capital required. The World Bank Group has been exploring structures to convert anticipated carbon revenues into finance flows or piloting innovative structures, such as revolving funds where accruing carbon finance revenues can support the next tranche of investments. Such initiative clearly aims at designing smart PFMs and shaping a financial architecture grounded on an effective carbon value. Further possible PFMs are explored in Box 1.

New proposals include, first, the IMF’s “Green Fund” (Bredenkamp and Patillo 2010), which suggests using an initial capital injection by developed countries in the form of reserve assets such as Special Drawing Rights (SDRs). The equity stakes could be scaled in proportion to countries’ IMF quota shares that define the respective contribution of countries to the IMF. The equity stakes would thus be disconnected from countries’ CO₂ emissions since they depend on countries’ weights in the world economy.⁹

⁹ Although, in general, rich countries emit more than poor countries, there is substantial variation among high-income countries and hence, less-than-perfect correlation between *per capita* income and emissions.

Box 1. Examples of possible new PFMs

An intermediary and more sophisticated option is to combine financial devices of uncertainty hedging and public commitment to secure part of the risk. In this case, public intervention focuses on a very restricted part of the risk: the excess risk perceived by private investors relative to other competitive more carbon-intensive projects. Such perception of an excess risk may arise from a lack of credible information on future carbon prices, biased expectations of risk-adjusted returns of carbon-intensive projects or an excessively high rate of pure time preference. Therefore, the high risk premium required prevents private investors from adopting the socially optimal project design. Thus, the government, consistent with an optimal control framework which aims at minimizing the cost of climate policy (the optimum is reached when for each point in time marginal abatement cost equals marginal damage), selects among a pool of projects those which deserve to be funded to reach the optimal aggregate path. Then public action aims at backing those projects by lowering their risk premium to a competitive level through appropriate financial instruments.

Besides the existing PFMs mentioned above, innovative financial instruments such as long-term put option contracts (*i.e.* purchase promise of carbon credit at a defined future date and level of price) issued by governments could be examined (Ismer and Neuhoff 2006). Maintaining the carbon price at or above a certain level needs from their part a credible commitment both towards investors in low-carbon technology and towards foreign governments. Such commitment assumes the achievement of an international agreement on future targets of emission reduction protected from free-riding. In fact, this financial device provides two virtuous incentives. First, towards investors who can rely on credible future carbon prices; second, towards governments, since, to avoid potentially huge public loss, *i.e.*, if the carbon price falls below the strike price of the options, a rational government would better comply with its international commitment in terms of emission reduction. Indeed, only the actual implementation of more stringent policies can make carbon prices follow an increasing trend. Moreover, with sufficient outstanding contracts, the commitment is sufficiently strong, the likelihood of low carbon prices is low and thus, the price of contracts is close to zero, which makes the contracts easily accessible as a risk-hedging device under many circumstances. Indeed, public intervention can be very cheap and even free as long as the government's expectations over the true risk of the projects are right, that is, if the excess risk was not grounded or endogenized by the government's own behaviour and only rested on a lack of information among private investors.

Proposals to increase climate finance include IMF issuance of green bonds...

The basic idea is to give to the transferred SDRs the character of a genuine reserve asset, so that it just consists of an exchange of assets and does not require upfront budgetary cost for contributors. However, to be considered as a reserve, the asset must be perfectly liquid so that a contributor can withdraw all or part of its reserve to face a specific temporary funding need. Rules to ensure that equity in the Green Fund is perfectly liquid remain to be defined. Further, for the operation to be the neutral swap described by the IMF, the dividends offered to shareholders would need to be equivalent to the interests provided by their reserves expressed in SDRs.¹⁰ The SDRs would then be used as the counterpart to the issuance of low-cost "green bonds" sold to private or public investors and hence, to mobilize a multiple of its paid-in-capital. Basically, the Green Fund set up by the IMF is a financial device to reduce the cost of issuing Green Bonds. Its advantage over existing funds depends on whether compared to other institutions, IMF (or SDR) credibility is greater, allowing for issuance of bonds at lower cost.

¹⁰ The proposal acknowledges that additional funding would likely need to be mobilized since much of the financing would be provided as grants or concessional loans.

Green-Bond revenues would be used to provide loan resources to mitigation projects, with investors remunerated with the interests on those loans and the dividends that accrue to the shareholders of the Fund. The Green Fund therefore borrows at low price and lends at a higher price to pay back the interests of the bonds as well as the induced transaction costs. It essentially amounts to earmarking a share of IMF lending for climate-smart investments. Note that the IMF proposal does not envisage a role for the IMF in allocating the resources, which would be left to institutions better suited to this role.

A second proposal is that of the Low Carbon Development Facility proposed by de Gouvello and Zelenko (2010). It assumes that future negotiations can generate an agreement among countries to set up a green fund able to emit USD 100 billion in AAA green bonds per year whose revenue would be used to lend to climate projects globally rated BBB. Given the operation costs and the default and recovery rates attributed to BBB investments, the financial model shows that an initial capital of USD 68 billion would be necessary to sustain the AAA of the green bonds. These USD 68 billion represent the short-term one-shot effort that countries have to agree on to make it work.

...a facility ensuring an annual USD 100bn in AAA bond revenues and an international agreement on the social cost of carbon.

Finally, a third alternative consists in relying on a social cost of carbon to measure the value created by projects. Existing climate financing schemes implicitly assume that climate-smart projects will eventually create a valuable asset based on the value of avoided emissions. But in the absence of a global framework to price carbon externality, they face regulatory uncertainty that entails financial risks. In this context, existing initiatives are necessarily of limited scale and unlikely to generate the funding needed to reach ambitious climatic goals.

A global agreement on an estimate of the social cost of carbon would help scale up climate finance. The social cost of carbon is basically a notional value of the carbon externality that may allow disconnecting the price signal effect from an actual carbon price. Contrary to a carbon tax or a carbon market, the social cost of carbon does not imply an up-front budgetary cost for countries and may therefore be more acceptable politically. Specifically, the international agreement would be on the allocation of a certain amount of social-cost-of-carbon units (the values and time profiles of which would be conventionally defined) to different types of climate-smart projects. In practice, such allocation would lower the cost of capital for climate-smart projects because those social-cost-of-carbon units could be converted into international reserve.

4. Conclusion

This article represents a first attempt at looking at how climate change affects the management and provision of infrastructure services in developing countries. It reviews how uncertainty associated with local climate impacts, technology and future carbon prices complicates the design of infrastructure. It also argues that both mitigation and adaptation concerns will increase the costs of infrastructure. Estimates of the additional costs associated with adaptation are modest but this is due to the way they are calculated: as the incremental costs of adapting new infrastructure rather than the costs of improving resilience. The latter would require first and foremost addressing the large infrastructure deficit that characterizes most developing countries. In fact, adaptation and mitigation costs pale in comparison to the unmet infrastructure funding needs.

Climate finance for developing countries, if modest relative to needs, is expected to make a net addition to domestic and concessional resources for infrastructure funding.

All is not negative however. One positive side effect of climate change might be that it helps bring attention to the need to better address environmental issues in infrastructure design at the same time as it increases the value of environmental co-benefits. Further, high-income countries have pledged resources to assist developing countries both in adapting to and in mitigating climate change. It is reasonable to expect that a share of these resources will constitute a net addition to domestic and concessional resources available for infrastructure funding.

Unfortunately, climate finance for developing countries remains modest relative to needs. Adaptation funding needs to increase at the same time as it moves away from a narrow focus on incremental costs. The experience of the EU accession funds, which also had to tackle the question of additionality, offers some useful lessons. Mitigation funds suffer from the absence of agreement that could generate more certainty and stability around a carbon price and around the potential size of the offset markets. Several ideas are offered that could help raise additional funding but these require some commitments by high-income countries.

One issue that is not tackled in this study and requires further research is the extent to which climate change may affect private participation in infrastructure – currently the source of some 15-20 percent of developing-country infrastructure finance. As climate change increases uncertainty, it should increase the cost of capital and hence, make private finance more costly and possibly more difficult to attract, at least in the most affected countries. We can also expect that climate change and the need for new environmental regulations will affect the optimal regulatory regimes that govern PPPs.

Annex. Estimating infrastructure adaptation needs¹¹

As Parry *et al.* (2007) explain, the UNFCCC (2007) follows the traditional approach to estimate the adaptation investment needs. It does not take into account incremental operation and maintenance costs generated from the existing levels of infrastructure services. It first estimates the gross fixed infrastructure capital formation in 2030 at USD 22.27 trillion, which would be three times the investment in 2000 and corresponding to an average annual investment growth rate of 5-6 percent. Then the estimate of the proportion of the new investment that is vulnerable to climate change is assumed based on insurance data on losses from weather disasters. Munich Re considers 0.7 percent of total infrastructure as vulnerable while the Association of British Insurers (ABI) assumes 2.7 percent. This leads to estimates of vulnerable new investments of USD 153–600 billion for 2030. As climate-proofing infrastructure is assumed to cost 5 to 20 percent of total vulnerable investments according to the UNFCCC study, this leads to incremental financial cost for adaptation of USD 8–31 billion (with the vulnerability share of Munich Re) or USD 33–130 billion (based on the ABI data).

A different approach is taken in the World Bank's Economics of Adaptation to Climate Change (EACC) Study. It projects stocks of major types of infrastructure over 2010 to 2050. The transport infrastructure includes roads, rail and ports. The cost of adaptation is computed as the incremental cost of constructing as well as operating and maintaining the baseline levels of infrastructure services under the climate conditions projected by the climate models of the National Center for Atmospheric Research (NCAR) and the Commonwealth Scientific and Industrial Research Organization (CSIRO).

The study focuses on price and cost changes for fixed quantities of infrastructure (referred to as a delta-P component) but also calculates costs resulting from the impact of climate change on demand for infrastructure services (delta-Q component), including operating and maintenance costs. The parameters of the price and cost change estimates are obtained from dose response engineering studies on the effects of climate change on the construction of new infrastructure. Based on the NCAR model both the additional cost and the maintenance expenditures for all sectors would amount to USD 36.8 billion annually. On the basis of the CSIRO model, it would be USD 28.6 billion annually.

¹¹ This Annex draws on Parry *et al.* (2009) and World Bank (2010c).

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