Managing climate-induced risks on Indian infrastructure assets

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Infrastructure assets are exposed to natural weather conditions and face challenges due to increased frequency and variability of climate-induced natural disasters. Infrastructure has a pivotal role to play in development and therefore, the large investments planned for future have to be protected against climate-induced risks. These span beyond physical risks as strict mitigation regimes could jeopardize their profitability and even future existence. The integrated climate change risk management framework for infrastructures presented here includes market and policy-induced enforcements and adaptation strategies. The key to managing risks lies in identifying them and initiating appropriate risk management and adaptation initiatives.

Keywords: Adaptation, infrastructure assets, reverse impact matrix, risk management.

THE challenges associated with investment in infrastructure in developing countries go beyond financing and adequacy issues. While there is a need for aggressive investments in infrastructure, there have been ample instances of investments not yielding the desired results because of policy deficiencies, inappropriate implementation, poor institutional arrangements, etc. To add to these challenges are the additional stresses due to climate change.

Climate change in India represents an additional stress on socio-economic systems that are already facing multiple stresses from population growth, increased urbanization, resource use, and regionally imbalanced economic growth[1–3]. Even an optimistic future climate scenario projects a minimum increase of 2°C in the global mean temperature by the end of 2100, and its implications would be in the form of altered patterns of precipitation and temperature, sea-level rise, and extreme events[4].

Developing countries like India would be worst hit by climate-induced adverse impacts and disasters because of lack of capacity, vulnerability of people and weak resilience mechanisms[5]. Regions and populations inside India would also have uneven impacts on coastal infrastructure, Himalayan ecosystems, agriculture, transport systems, water resources, energy and industry, and other infrastructures[2]. India is projected to invest almost US$ 120 billion on infrastructure asset creation during 2011–2012, which would increase in subsequent years[6]. Increased frequency and variability of climate-induced natural disasters would pose a challenge to these investments and would therefore have a strong bearing on the growth trajectory of a resource constraint country.

The present article attempts to explore the climate change-induced risks that must be identified and managed, *ceteris paribus*, while investing in infrastructure in developing countries in a sustainability framework.

Infrastructure and its importance in India

For a developing country like India, infrastructure is crucial for economic growth for two reasons. First, investment in infrastructure is lumpy because of the long life of the assets and the magnitude of investment. Therefore, investments today will determine the development scenario and greenhouse gas (GHG) emission trajectories of the country in future because of these lock-ins. Second, since the resources are limited, every unit of a resource has an alternate use, making it essential to optimize the investment in infrastructure. Infrastructure is a prerequisite for development, and economic expansion is unlikely if infrastructure growth is retarded[7].

The Indian Eleventh Five Year plan (EFYP) target of a 9% GDP growth rate and the decadal population growth rate in the range 1.5–2%, pose many developmental challenges[6]. To meet these challenges, massive investment in physical infrastructure is being undertaken currently and in the foreseeable future (Table 1). Investment in infrastructure is likely to grow by over 20% per annum during 2006–2007 to 2011–2012.

Being a developing country, infrastructure investments are needed in every domain in India. The total investment planned for the EFYP is about US$ 500 billion and the figure is like to double in the next five-year plan[6]. Table 2 shows the planned investment for the period 2007–2012 in some infrastructure assets in India[8–12]. These figures just show the planned investments, but actual capacity requirements and the corresponding investment needs would be far greater.

In India, it is often seen that the poor state of infrastructure constrains private investments and overall

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Table 1. Infrastructure investment (in billion USD at 2004–2005 prices) as a percentage of GDP

	2006–2007		2011–2012	
	Investment	Percentage of GDP	Investment	Percentage of GDP
Public sector (Centre + State)	36.17	4.23	80.56	6.45
Private sector	10.26	1.20	36.10	2.89
Total	46.43	5.43	116.66	9.34

Source: Derived from Central Statistical Organization (for 2006–2007), RBI Statistics for Exchange Rate and GDP at constant prices, and computations by the Planning Commission (for 2011–2012).

Table 2. Initial capacity and planned investment in some infrastructure assets[6,8–12]

Infrastructure type/ category	Unit	Initial capacity (2007)	Planned capacity additions (2007–2012)	Planned investments (2007–2012) in billion USD (2006–2007 prices)
Energy infrastructure				
Thermal power plants	Megawatt	86,014.8	58,644	33.2
Nuclear	Megawatt	3,900	3,380	1.98
Hydro	Megawatt	34,653.7	16,553	9.9
Solar PV	Megawatt	2.7	50	
Wind	Megawatt	6,070	10,000	
Aviation				
Airports (passenger traffic)	Million	205	133	9.6 (public)
Airports (cargo traffic)	’000 tonnes	2,684	1,100	20.6 (private)
Water supply and irrigation				
Irrigation	Million hectare	102.8	16	9.1[z]
Drinking water access	Percentage	Urban-91 Rural-	100	9.2
Road network				
National highways	Kilometre	66,590	46,000	26.7[x]
State highways	Kilometre	137,000	71,000	17.7[x]
Major district roads	Kilometre	300,000		
Rural roads	Kilometre	27,00,000	146,185[y]	9.1
Communications				
Tele density (rural)	Percentage	2.8	25	50.9[x]
Tele density (urban)	Percentage	55.9	100	
Ports/inland water transport				
Ports (major) – 12	Million tonnes	504.7	708.09	16.3[x]
Ports (minor) – 189	Million tonnes	228.3	575	7.9[x]
Inland water transport	Million tonnes	504.1		
Health and housing				
Subcentres	Units	144,998	20,903	
Primary health centres (HCs)	Units	22,669	4,803	
Community HCs	Units	3,910	2,653	
Housing (pucca)	Million	41.2	15.0[#]	5.7
Railways				
Originating freight	Million tonnes	728	1,100	42.0
Freight	Billion tonne kilometre	475	702	
Originating passengers	Million	6,352	8,400	
Passenger km	Billion	692	942	
Urban transport (under metro head)				0.41
Metropolitan transport project				0.29

[#]To be provided as a part of the Indira Aavaas Yojana; [x]Inclusive of private investment; includes upgrading and capacity addition; [y]Bharat Nirman Programme; [z]Accelerated Irrigation Benefit Programme.

economic potential[13]. Complete public financing of infrastructure may not work in India because of the large fund requirements, which the state alone cannot provide, as well as inadequacy of public institutions to deliver the desired results at the required pace. An apt example is the case of SEZs, where private participation in investments is actively sought. Private investments, on the other hand, may also not be available if adequate risk pooling and transfer mechanisms are unavailable.

For a country on the path of development, climate-induced natural disasters can reverse the benefits accrued by economic development. Resources for rebuilding are also scarce and carry opportunity costs, and hence the need to curtail the risks posed by climate change. Since the benefits and opportunity costs of infrastructure investment are high in a developing country, there is a need to guard them against the various risks, including those posed by climate change. Climate proofing infrastructure does not imply completely removing all the adverse impacts, but to make systems resilient so as to reduce impacts (preventive) and also for quick post-impact restoration to normalcy (palliative)[14].

Climate change and infrastructure: what are the climate-induced risks?

Since the frequency and intensity of climate-induced natural disasters is projected to increase for India[2,15]; the national ability to reduce vulnerability and limit fiscal exposure is becoming a priority[16]. Complications arise primarily because it is a challenge to establish a one-to-one direct causal relationship between any anthropogenic activity and climate-induced natural disasters. It can only be said that the incidence of occurrence has increased. An appropriate analogy to this is when one throws a loaded die and '6' appears, one cannot say that the outcome is because of loading, but that the probability of throwing a '6' has increased[17].

In the Indian context, the mean minimum and maximum temperatures may increase by 2–4°C as a result of climate change[18]. There are forecasts for a decrease in the number of rainy days over much of India, along with increased frequency of heavy rainfall during the monsoons. Sea-level rise, combined with an increased frequency and intensity of tropical cyclones will lead to an increase in extreme sea levels due to storm surge[19]. The vulnerability study of a coastal district points out that the growth of infrastructure index is very low with respect to the growth rate of the population[20]. Consequently, any occurrence of extreme events is experienced more because of the increased pressure on limited assets.

Overall, climate change stress is disproportionately affecting the developing countries, making proactive adoption of adaptation measures a priority. One can also understand this as a case of the prisoner's dilemma. A common property resource is being misused and can be protected only if collective efforts are taken. However, everyone sees an incentive in deviating by not contributing to overall mitigation efforts and taking up adaptation. Consequently, sub-optimal mitigation efforts are taken, as the incentives to mitigate at an individual level are not as high as incentives to deviate and adapt at an individual level. Ambitious mitigation efforts can lessen, but cannot eliminate the risks posed. The challenge for developing countries is to minimize the impact of climate change by an appropriate mix of resources towards mitigation, adaptation and impact management.

Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years (the classical period is 30 years)[21]. The effect of climate change will be seen distinctly in the form of four critical climate change (CCC) parameters, i.e. temperature change, precipitation variability, sea-level rise and other extreme events. CCC parameters are those components of climate which pose a potential threat to the normal operations and even existence of an infrastructure. For example, in the case of the Konkan railways, the critical climate parameter is the precipitation of more than 200 mm in 24 h (ref. 1). Being located in the windward side of the Western Ghats, its risk damage increases during the monsoons. Table 3 shows some infrastructure assets, associated CCC parameters and impacts.

Energy infrastructure such as thermal, hydroelectricity and renewable generation is susceptible to temperature change and extreme events. Extreme events are associated with physical damage to infrastructure. Temperature changes are likely to bring demand side variation in terms of space heating and cooling requirements. Variability in water availability and excessive siltation in river systems due to landslides in catchment areas will affect the hydropower potential. Brazil, where 85% of all electricity consumed comes from hydroelectricity, faced a major power crisis during the 2001 drought[22]. Similar impacts would be associated with water supply and infrastructure assets.

These four CCC parameters would create direct and indirect impacts on infrastructure. Enhanced landslides, vegetation cover, excessive siltation in river systems and soil erosion are the possible direct impacts, while groundwater table depletion, energy-demand changes and migratory traffic could be the possible indirect impacts. Additional risks could also be due to strict global regimes for GHG emission mitigation that could severely constrain operations of some existing infrastructures and could even jeopardize their future existence. For instance, a severe carbon constraint could alter the levelized cost of power production across various fuels and technologies, relatively increasing the production costs from carbon-intensive plants such as coal-based power plants[23].

A targeted approach towards risk reduction and management requires efforts over and above emission reductions. The systems now have to live with these adverse impacts by adequate preparation, i.e. by adapting to climate change. Adaptation will not only require responding to the physical effects, but also a review of the way we conceptualize, measure and manage risks. Climate change

Table 3. Associated critical climate change (CCC) parameters for some infrastructure assets

Sector	CCC parameters	Some direct impacts	Some indirect impacts
Energy infrastructure	Temperature, precipitation, extreme events	Space heating and cooling requirements, excessive siltation in dams	Supply-chain disruptions, carbon constraints
Aviation	Extreme events	Physical damages	Migratory traffic, tourism shifts, carbon constraints
Water supply and irrigation	Precipitation, temperature, extreme events	Enhanced evapotranspiration	Depleting groundwater table, water supply and demand changes
Roads	Precipitation, extreme events	Landslides, soil erosion	Migration pressures, modal shifts
Communications	Extreme events	Physical damages	Emergency requirements
Ports/inland waterways and transport	Sea-level rise, extreme events	Physical damages, excessive siltation	Modal shifts
Health and housing	Temperature, precipitation	Humidity, vector-borne diseases	Migrations, more space cooling/heating
Railways	Precipitation, extreme events	Landslides, soil erosion, vegetation cover	Carbon constraints, modal shifts

is creating new risks, altering the risks we already face, and importantly, affecting the interdependencies between these risks[24]. For example, more than the increase in averages, it is the extreme weather conditions (i.e. the fat tails of distributions), which have adverse impacts.

The CCC parameters pose the following risks for infrastructure assets:

- Physical risks – Physical threats refer to the exposure risks. Increased frequency and variability of disasters can damage the tolerance of infrastructure and have the potential to disrupt the entire socio-economic system associated with it.
- Regulatory – These integrate mitigation and adaptation-related risks, mostly driven by higher mitigation costs for infrastructure systems. International mitigation regimes will have a bearing on the risks associated with assets. The European Union (EU), for example, will be forcing all EU airlines to participate in EU–ETS from 2012 (ref. 25). The financial implications for a large international carrier could be to the tune of €199–398 million annually[26]. Similarly, for energy-intensive power infrastructure, future regulations may make certain infrastructure assets redundant.
- Supply chain risks – These generally are the allied risks that physical risks and regulatory risks pose. A cyclone at ports such as Kandla and Jamanagar not only brings about damage to the port infrastructure, but brings about allied risks such as, shortage of essentials, fuel supply for refineries, coal supply for power plants. The direct impact can be seen in water supply and hydropower, where extreme events such as droughts can affect the supply of water and electricity. Similarly, stringent regulations may make existing infrastructure assets redundant or non-profitable.
- Product and technology risks – To meet newer regulations a continuous improvement in technology will be required, e.g. improved integrated gasification combined cycle (IGCC) can reduce emissions substantially. Physical challenges such as landslides as in the case of the Konkan railways, can be managed by safety nets and better communication. But in the long run, product and technology changes can make many infrastructure assets redundant.

Every infrastructure asset category will have some risks, which will play a dominant role based on the potential impact they can have on the asset category. For example, in the case of energy infrastructure, all the risks such as supply chain, physical, regulatory and product-technology play a dominant role. This is also because their malfunctioning can also have a ripple effect on other dependent infrastructures such as communications. However, the same effect may not be true for the aviation infrastructure. The central idea behind this is the identification of key high risks and moving from high to low risks, thereby reducing the potential impacts.

Managing climate change risks to infrastructure

Conventionally, it is the forward impact of infrastructure on environment that is studied. The reverse, i.e. the impact of the environment, mainly climate change here, on the infrastructure is generally not studied. For instance, a hydroelectric multipurpose dam could become a stranded economic asset if the future water inflows from its catchment areas dry up due to a changing climate. Such reverse impacts are estimated through a 'reverse impact matrix' that talks about the project-environment inter-linkages (Table 4)[7]. In Table 4, quadrant 1 represents the

Table 4. Reverse impact matrix

Forcing variables/dependent variables	Environmental variables	Project components
Environmental variables	*Quadrant 2:* Environmental impact inter-linkages	*Quadrant 3:* Reverse impact (impacts of environment on project)
Project components	*Quadrant 1:* Forward impact (impacts of project on environment)	*Quadrant 4:* Impact of project on other projects

Table 5. Managing climate change-induced risks for various infrastructure assets

Infrastructure category	Risk type	Likely impacts	Risk management
Energy infrastructure	S	Change in demand pattern Supply of conventional fuel Hydro-power dependent on water supply	Forward contracts Power purchase agreements Technology upgradation
	R	Strict emission reduction norms Efficiency norms	Energy efficiency Switch to renewable sources of supply
	PT P	Redundant assets due to technological change Physical damage due to extreme events	Insurance Catastrophe bonds Emissions trading
Aviation	S R	Fuel supply uncertainly Strict emission reduction norms	Technology upgradation Switch to efficient fuel Forward contracts Emissions trading
Water supply and irrigation	S	Variability in water supply	Dams Other water-conservation measures Tradable water rights
Roads	P	Physical damage due to extreme events	Insurance
Communications	P	Physical damage due to extreme events	Technology upgradation
Ports/inland waterways and transport	P	Physical damage due to extreme events	Insurance Better communication
Health and housing	P	Increased number of diseases Malaria/breathing disorders Sea-level rise to affect houses on the coast	Insurance More health services Dikes on the coast Better communication Official development assistance
Railways	P	Physical damage	Insurance Technology upgradation Safety nets Better communication

S, Supply chain risk; R, Regulatory risk; PT, Product-technology; P, Physical risk.

conventional form of impact of infrastructure on environment. Quadrant 2 represents the environmental impact inter-linkages and quadrant 3 represents the impact of infrastructure on other such infrastructure projects. Quadrant 4 is the reverse impact and focus of this section.

The risk that any climate-induced disaster poses is a product of hazard and vulnerability[27]. While hazard in simple terms may refer to the physical exposure, vulnerability is far more complex. This is because prevailing socio-economic conditions contribute to vulnerability and impacts on human activities within a given society[6]. Therefore, vulnerability and hazard, both have to be managed for risk management. Table 5 shows the management of various climate change-induced risks (and their impact).

Lack of understanding of adverse impacts of climate change and vulnerability of infrastructure assets is a challenge for risk management[28]. Disaster and emergency risk management in a climate change context could be a restrictive approach towards a mechanism that has inter-linkages with almost every component of a system and extends onto a longer time horizon. Developing a comprehensive risk management and adaptation framework therefore requires an integrated approach by incorporating issues concerning urban development and growth, vulnerability, risk unbundling, the redirection of

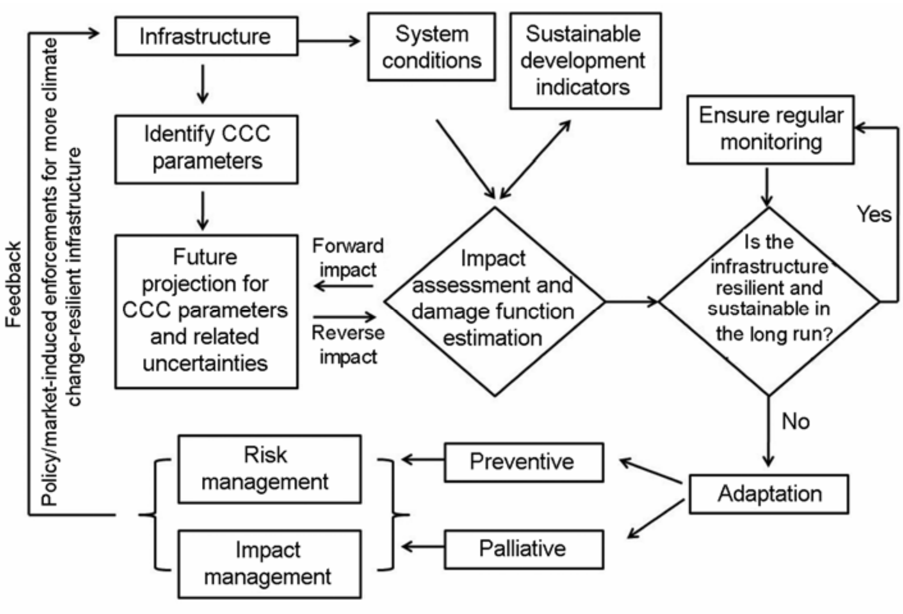

Figure 1. Integrated risk management framework.

ongoing investments and micro and macro interventions (Figure 1)[29].

The first step towards risk management of any infrastructure asset is to identify the CCC parameters that affect it. Since infrastructure is a long-term asset, management of risk should also have a long-term focus. Therefore, future projections for the CCC parameters and their related uncertainties have to be identified. This would be the reverse impact assessment for the infrastructure. It would allow creation of damage functions, which capture the aggregate economic losses that can occur given variables such as location, sector, climate parameters affecting it and their relative weights for a given time period. The damage function is a dynamic concept and helps identify whether the system can cope with the changing climate stresses or not, i.e. system resilience. If the asset is not resilient, then one has to map its alignment with the sustainable development goals and explore the adaptation needs. If some risks are beyond acceptable adaptation costs, then palliative adaptation measures have to be taken.

This inherently implies that the probability of excessive losses due to a future climate change event is low enough so as to let the infrastructure be exposed to some uncovered risks today and manage the losses later in case the uncovered risk does manifest. Extreme events involve a stochastic negative shock, the severity of which can be affected through a process of prevention and relief. The probability and intensity of a shock cannot be controlled, but the impact of the shock can be controlled. Stochastic shocks are non-deterministic in nature, where the future state of a system is dependent upon its present state, predictable actions that the system would take to incorporate information about shocks, and a random element. Preventive adaptation would cover the first and second components, which would mitigate the adverse impact probability due to randomness of the extreme event, therefore reducing the need for palliative action. While palliative measures depend upon randomness of the event and are thus independent, preventive adaptation measures take an independent view of risk management. Therefore, for palliative adaptation to be more effective in resource utilization and reducing the impacts of the shock, appropriate preventive measures would have to be taken. For example, in the case of the Konkan Railway Corporation Limited (KRCL), preventive measures of installing safety nets, better communication technology, technology for travel during heavy rainfall, etc. have to be taken before palliative measures of relief work, rebuilding, etc. are required post-calamity[1].

The essential part of this framework is the policy and market-oriented cues that these risk management practices can provide. As is the case with KRCL, if insurance is taken for potential losses in future, a feedback loop in the form of market demand for risk pooling emerges[1,10]. An insurance company would want KRCL to take certain precautions or preventive measures to minimize possible future payouts (palliative measures) by the insurance company for any loss due extreme events. The premium determination between KRCL and the insurer will be negotiated based on their costs and benefits, with their own perceptions on probability distribution of damage function in future. The choice of KRCL would understandably be the one where it gets higher compensation for climatic damages by paying minimum annual premiums or marginal costs. The insurance company would however aim to get maximum preventive measures taken and paid for by KRCL, so as to reduce damage risks in future and thus reduce palliative payouts. The systematic losses, combined for both KRCL and insurance company (internal payments between the two would not be included in the economic framework as they balance out), will be a function of three categories of variables, namely the relevant critical climate change variables (CCCV), the relevant sustainable development variables (SDV) and the system condition variables (SCV).

$$\text{Economic loss} = fn\,(\text{SDV}_i, \text{CCCV}_j, \text{SCV}_k).$$

Here *i* could be technology, economic instruments (e.g. insurance, ODA, etc.) and other policies (e.g. forestation, community participation, etc.); CCCV, Projections for critical climate change variables as discussed before with *j* representing temperature, rainfall, sea-level rise, extreme events, etc.; SCV, Projections for relevant system condition variables where *k* represents physical life of the asset, maintenance levels, usage patterns, soil type, etc. *i*, *j*, *k* would depend on the system under study[1].

Similarly, the insurance market will also have to decide what level of risk is acceptable. All over the world, over the past decade the premium for catastrophe insurance has been high and cyclical, ranging from double to 18 times the actuarially fair premium, although there have been periods where the price actually fell below pure premium. Thus, the insurance instruments appear to be costly; however, this may change as investors gain more experience[30]. Studies have pointed out that in some cases catastrophe insurance premiums have exceeded the average estimated GDP losses[31]. Based on recent market data, the average XL (excess of loss) rates[32] for different levels of catastrophe coverage based on probability of occurrence are shown in Table 6. The index shows the 'risk load' added to the pure probability premium[33]. This indicates an option for deciding whether to go for preventive adaptation or take the risk for the incident to occur with subsequently higher palliative efforts.

At a policy level, the government may decide some mandatory levels of risk pooling for public infrastructure. Events like the sub-prime crisis may also lead to a regulatory base for comprehensive risk management strategies without compromising on pooling effect and proactive risk reduction strategies.

In practice, studying this phenomenon at a national level is far more complicated. This is because there is uncertainty at various levels, viz. uncertainty in climate change projections, uncertainty in assessment of impacts thereof, and uncertainty in estimating damage functions for economic losses. Cumulative uncertainty may be magnified or nullified based on the interaction of factors. Assessing the benefits of adaptation is complicated compared to mitigation. As a country, many infrastructure assets that are crucial for development are under threat from climate change. Each category of asset will have specific characteristics that make it vulnerable to climate change shocks. The relationship of that asset with peer assets, non-peer assets and other components of the system constitutes the system-generated stresses. This creates uncertainties in understanding the impacts. Finally, the degree to which the damage should be assessed is also debatable. Many interconnected primary, secondary and tertiary damages can be considered.

Also, adaptation does not come cheap. The World Bank has estimated that the incremental costs of adapting towards climate change impacts in developing countries could be the tune of US$ 9–41 billion per year[34]. As far as risk mapping is concerned, there will always be a probability of type I (α) and type II (β) errors, which may lead to over and under-adaptation respectively. While type I error may lead to adaptation expenditures when the risk is manageable, i.e. the system is resilient; type II error may lead to under-adaptation assuming certain risks to be manageable. Given the costs involved, both over and under-adaptation can be an expensive deal, as ultimately adaptation is not reducing the emissions stock. There are also temporal issues in mapping risk profiles as the pace of change is rapid, which one may be able to quantify, but because not all these inter-linkages may be fully explored resulting in a magnified effect. Therefore, this assessment may be needed at every linkage within a system, making it a complicated exercise.

Infrastructure adaptation in developed countries

Climate change affects all human societies and economic activities in some way or the other and most adaptation literature focuses on developing countries. India's annual and Five-Year Plans focus on promoting sustainable development and inclusive growth. Many programmes and schemes of the Government of India introduced in the last 60 years after independence with these objectives are also helping people adapt to the changing climate. Some of the prominent schemes for rural areas include green revolution, watershed development, integrated rural energy

Table 6. Excess of loss (XL) rates by event probability[32]

Event probability (%)	XL rate (%)	Index rate/probability
15.0	17.0	1.1
5.3	8.3	1.6
3.5	6.6	1.9
2.5	5.8	2.3
1.5	4.9	3.3
1.2	4.2	3.5
0.8	3.9	5.2
0.7	3.8	5.4
0.4	3.5	10.0
0.2	3.4	18.9

development, National Rural Employment Guarantee Act (NREGA), Bharat Nirman, agriculture insurance, etc. These programmes require and lead to additional consumption of resources, including energy and thus would result in increased GHG emissions. They, however, also enhance the adaptive capacity of the vast Indian population. The challenge lies in aligning low emission pathways with high adaptation policies and programmes in the long run.

This does not imply that there is no need for adaptation in developed countries. A study on the need for adaptation in Boston, USA in the domain of energy, health, transport and water supply infrastructure has suggested anticipatory adaptation actions in these domains to reduce the overall system risk management costs and longevity of infrastructure[35]. Adaptation becomes an international issue in the case of developing nations because they want their risks to be financed by those creating the risks, while in case of the developed nations it is more of an internal issue[36]. With high incomes in developed countries like the US, safety mechanisms can also be purchased. For example, it has been estimated that before hurricane Katrina, consumers were willing to pay only 0.01% of the price of a house for an additional one-foot elevation[37]. This figure has now increased tenfold. There have been several proposals to finance adaptation in developing nations through Official Development Assistance (ODA) and many such funds (The Environmental Transformation Fund of the United Kingdom; Cool Earth Partnership of Japan) have already been created[36].

The way developing and developed countries deal with climate change and its associated risks is different. For instance, insurance penetration and use of other risk-pooling mechanisms are far higher in developed countries compared to developing countries. This is illustrated by some examples below:

- After the severe floods and precipitation in 2002 in Austria, the insurance industry and public authorities developed a public risk-zoning tool for floods and earthquakes. The public authorities provided GIS basis data, and the insurance and reinsurance industry contributed modelling and development[38].
- About 70% of properties in The Netherlands lie below sea level or below river-water level and the flood risk increases in winter when it rains in the Alps. A majority of the population living in flood-risk areas are willing to take measures to guard themselves against flood, such as installing water-resistant floors, etc. to get small discounts in premiums[37]. Yet, there is a consensus that the government is also responsible due to insufficient investment in dikes.
- The United Kingdom is working towards risk reduction of extreme events by influencing government building design and choice of construction materials. European insurance industry supports land-use planning and risk awareness by developing improved risk mapping and zoning tools[38]. Private insurance companies cover disaster risks and the government does not provide compensation in case damage occurs. A drawback of the British system is that public investments for issues like flood protection are considered to be too low as there is a moral hazard on part of the government to not make investments[39].

Insurance, risk pooling, etc. are interim methods of risk management. Developed countries have already reached a stage where through appropriate risk-management strategies they are bringing about policy and market-induced enforcements for resilient infrastructure. For example, hurricane Andrew prompted the Florida state legislature to work with insurers and regulators to create a hurricane catastrophe system designed to mitigate losses for the insurance industry, thereby preventing the insurance companies from withdrawing from the state. The Florida Hurricane Catastrophe Fund was also created as a buffer with a purpose to act as a reinsurance-like entity. A part of it was funded by insurance premiums and managed by the Florida State Board of Administration[40].

Insurance as a risk mechanism can backfire in two ways. One is that of moral hazard. The insured party may not take sufficient preventive measures to reduce the risks or the state may not invest adequately in risk management as in the British case discussed above. The other is when leeways are found to vent policy decisions. For instance, hurricane Katrina is one the biggest natural disasters faced by the US with monetary losses to the tune of US$ 200 billion[39], of which a significant amount was not insured. Although it is mandatory in Louisiana to have flood insurance for being eligible for loans, many residents in flood-prone areas did not have insurance because it is difficult to track and keep the coverage in force[40]. Post Katrina, the reconstruction of the damage caused to urban infrastructure itself may take 8–11 years[41]. There are, of course, many other reasons, for the disaster in New Orleans.

These are some aspects that developing countries also need to think through. Although many developed countries have reached infrastructure lockins, better and integrated planning and foresightedness continue for both the existing infrastructure and the ones that are being planned. The larger objective has to be risk reduction, which must ideally be embedded into the activities of all countries. Insurance is not the only solution. Many times state-sponsoring of insurance schemes has the objective of providing insurance to all and in this pursuit, the fundamentals of actuarial science are sidelined exposing the funds to huge risks. Public compensation for damages also reduces risk management measures taken at individual levels. Prevention measures at an individual level may prove to be expensive; hence, loss-reducing incentives have to be provided.

Conclusion

Climate change-induced natural disasters represent an additional stress on a country's infrastructure. In India, investments of US$ 120 billion have been planned for infrastructure asset creation during 2011–2012. Given these huge investments, the limited existing capacity and the fact that the actual requirement of infrastructure is large, it is essential to protect infrastructure assets and related investments against climate change risks. Conventionally only the impacts of projects on the environment are studied. This article highlights some crucial reverse impacts of environment on the energy, aviation, water supply and irrigation, road, communications, posts, health and housing, and railway infrastructure assets. The critical climate parameters of temperature, precipitation, sea-level rise and extreme events pose direct and indirect impacts on infrastructure assets. The risks could be physical, technological change, supply chain and regulatory in nature. The risk management framework presented shows the need for an integrated and planned approach towards the problem. Although both adaptation and mitigation are needed for managing risks, lack of information about the costs and benefits of adaptation hinders the decision-making process[42]. Therefore, the framework also highlights the need for assessment of risks through damage functions, which will help in understanding the level of adaptation. Many financial risk management processes are a way to ensure monetary compensation in the case of an adverse event, but risk reduction must ideally be achieved by giving cues to the state and market to incorporate risk management in policy making. Experience of developed nations also shows that ultimately risk reduction activities should be embedded into the activities of all countries. Improved research is needed in understanding the inter-linkages between various components of a system, and projecting key climate change parameters affecting them and mainstreaming risk management with national policies. It also presents research gaps in terms of practically implementing appropriate adaptation strategies based on these damage assessments for specific infrastructure assets in developing countries.

1. Garg, A., Shukla, P. R. and Kapshe, M., From climate change impacts to adaptation: a development perspective for India. *Nat. Resour. Forum*, 2007, **31**, 132–141.
2. NATCOM, Climate change and India: a 4 × 4 assessment – a sectoral and regional analysis for 2030s. Ministry of Environment and Forests. Government of India, 2010.
3. Sathaye, J., Shukla, P. R. and Ravindranath, N. H., Climate change, sustainable development and India: Global and national concerns. *Curr. Sci.*, 2006, **91**(3), 314–325.
4. Burton, I., Diringer, E. and Smith, J., *Adaptation to climate change: International policy options*. Pew Center on Global Climate Change, Arlington, USA, 2006.
5. O'Brien, G., O'Keefe, P., Rose, J. and Wisner, B., Climate change and disaster management. *Disasters*, 2006, **30**(1), 64–80.
6. Planning Commission, Eleventh Five Year Plan (2007–2012), Planning Commission, Government of India, 2008.
7. Kapshe, M., Shukla, P. R. and Garg, A., Climate change impacts on infrastructure and energy systems. In *Climate Change and India: Vulnerability Assessment and Adaptation* (eds Shukla, P. R. *et al.*), Universities Press, Hyderabad, 2003, pp. 291–325.
8. Ministry of Power, Report of the Working Group on Power for Eleventh Plan, Government of India, 2007.
9. Ministry of Housing and Urban Poverty Alleviation, Report of the 11th Five Year Plan, Working Group on Urban Housing with focus on slums, Government of India, 2007.
10. Ministry of Rural Development, Final Report of the Working Group on Rural Roads in the 11th Five Year Plan, Government of India, 2006.
11. Ministry of Shipping, Road Transport and Highways, The Report of the Working Group on Roads for the 11th Five Year Plan, Government of India, 2007.
12. Ministry of Shipping, Road Transport and Highways, Report of Working Group for Port Sector for the 11th Five Year Plan, Government of India, 2007.
13. Chen, A. and Kubik, J. W., Sustainable development for India: solving the infrastructure puzzle. *J. Struct. Finance*, 2007, **13**(2), 29–39.
14. Schenker-Wicki, A., Inauen, M. and Olivares, M., Unmastered risks: from crisis to catastrophe. An economic and management insight. *J. Bus. Res.*, 2010, **63**, 337–346.
15. Shukla, P. R., Kapshe, M. M. and Garg, A., Development and climate: impacts and adaptation for infrastructure assets in India. OECD Global Forum on Sustainable Development: Development and Climate Change, Conference Proceedings. ENV/EPOC/GF/SD/RD(2004)5/FINAL, OECD, Paris, 2004.
16. Botzen, W. J., Bouwer, L. M. and van den Bergh, J. C., Climate change and hailstorm damage: Empirical evidence and implications for agriculture and insurance. *Resour. Energy Econ.*, 2009, 1–22.
17. Linnerooth-Bayer, J., Bals, C. and Mechler, R., *Climate Insurance as a Part of a Post – Kyoto Adaptation Strategy*, Germanwatch, Bonn, 2008.
18. Kumar, R. K. *et al.*, High-resolution climate change scenarios for India for 21st century. *Curr. Sci.*, 2006, **90**(3), 334–345.
19. Unnikrishnan, A. S., Kumar, R. K., Fernandes, S. E., Michael, G. S. and Patwardhan, S. K., Sea level changes along the Indian coast: observations and projections. *Curr. Sci.*, 2006, **90**(3), 362–368.
20. Patnaik, U. and Narayanan, K., Vulnerability and climate change: an analysis of the eastern coastal districts of India. Munich Personal RePEc Archive – MPRA Paper No. 22062, 2010, pp. 1–19.
21. IPCC, Historical overview of climate change science. Working Group I Contribution to the IPCC Fourth Assessment Report. IPCC, Brussels, 2007.
22. Oliveira, A. D., Political economy of the Brazilian power industry reform. In *The Political Economy of Power Sector Reform: The Experience of Five Major Developing Countries* (eds Victor, D. G. and Heller, T. C.), Cambridge University Press, New York, 2007, pp. 31–75.
23. Rai, V. and Victor, D. G., Climate change and the energy challenge: a pragmatic approach for India. *Econ. Polit. Wkly*, 2009, **44**(31), 78–85.
24. Kousky, C. and Cooke, R. M., Climate change and risk management: challenges for insurance, adaptation, and loss estimation. In *Resources for the Future*, 2009, pp. 1–29.
25. Carminati, M. V., Clean air and stormy skies: The EU-ETS imposing carbon credit purchases on United States Airlines. *Syracuse J. Int. Law Commerce*, 2010, **37**(2), 127–144.
26. Vespermann, J. and Wittmer, A., Financial, ecological and managerial impacts of emission trading schemes: the case of Lufthansa. *Bus. Strat. Environ.*, 2010.

27. IPCC, *Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, III to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (eds Watson, R. T. and the Core Team), Cambridge University Press, Cambridge, 2001.
28. Sharma, D. and Tomar, S., Mainstreaming climate change adaptation in Indian cities. *Environ. Urban.*, 2010, **22**(2), 451–465.
29. Revi, A., Climate change risk: an adaptation and mitigation agenda for Indian cities. *Environ. Urban.*, 2008, **20**(1), 207–229.
30. Anderson, T. J., Managing economic exposures of natural disasters: exploring alternative financial risk management opportunities and instruments. IDB, Washington DC, 2001.
31. Auffret, P., Catastrophe insurance market in the Caribbean region: Market failures and recommendation for public sector interventions. World Bank Policy Research Working Paper No. 2963, 2003.
32. Bayer, J. L. and Verheyen, R., Insurance-related actions and risk assessment in the context of the UNFCCC. Background paper for UNFCCC workshops – commissioned by the UNFCCC Secretariat, 2003.
33. Pollner, J., Managing catastrophic risks using alternative risk financing and insurance pooling mechanisms. World Bank, Washington DC, 2000.
34. Clean energy and development: Towards an investment framework. World Bank, Washington DC, 2006.
35. Kirshen, P., Ruth, M. and Anderson, W., Interdependencies of urban climate change impacts and adaptation strategies: a case study of metropolitan Boston USA. *Climatic Change*, 2008, **86**, 105–122.
36. Klein, R. J. and Persson, A., Financing adaptation to climate change: Issues and priorities. Climate Policy Research Programme and the Centre for European Policy Studies, Svartsjö, Sweden, European Climate Platform (ECP), 2008.
37. Ross, R., An analysis of the New Orleans housing market before and after hurricane Katrina. Robert Schalkenbach Foundation, New York, 2008.
38. Warner, K. *et al.*, Adaptation to climate change: Linking disaster risk reduction and insurance. Geneva: United Nations International Strategy for Disaster Reduction Secretariat, 2009.
39. Botzen, W. J. and van den Bergh, J. C., Insurance against climate change and flooding in The Netherlands: present, future and comparison with other countries. *Risk Anal.*, 2008, **28**(2), 413–426.
40. King, R. O., Hurricane Katrina: insurance losses and national capacities for financing disaster risk. Congressional Research Service – Report for Congress. Congressional Research Service, Washington DC, 2005.
41. Kates, R. W., Colten, C. E., Laska, S. and Leatherman, S. P., Reconstruction of New Orleans after hurricane Katrina: A research perspective. *Proc. Natl. Acad. Sci. USA*, 2006, **103**(40), 14653–14660.
42. IPCC, Climate Change 2007: Impacts, Adaptation and Vulnerability – Summary for Policymakers. Working Group II Contribution to the IPCC Fourth Assessment Report. IPCC, Brussels, 2007.