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Adaptation to Climate Change: Revisiting Infrastructure Norms

James Neumann[1]

As defined by the Intergovernmental Panel on Climate Change, adaptation includes a set of actions to moderate harm or exploit beneficial opportunities in response to climate change. To date, little research has addressed public policy options to frame the nation's approach to adapt to a changing climate. In light of scientific evidence of extreme and unpredictable climate change, prudent policy requires consideration of what to do if markets and people fail to anticipate these changes, or are constrained in their ability to react. This issue brief is one in a series that results from the second phase of a domestic adaptation research project conducted by Resources for the Future. The briefs are primarily intended for use by decisionmakers in confronting the complex and difficult task of effectively adapting the United States to climate change impacts, but may also offer insight and value to scholars and the general public. This research was supported by a grant from the Smith-Richardson Foundation.

Policy Recommendations

The main threats presented by climate change to infrastructure assets include damage or destruction from extreme events, which climate change may exacerbate; coastal flooding and inundation from sea level rise; changes in patterns of water availability; and effects of higher temperature on operating costs, including effects in temperate areas and areas currently characterized by permafrost conditions.

Almost half of the more than $60 billion annual federal infrastructure investment is for highways (in excess of $30 billion annually), with smaller but significant capital expenditures in dams and flood control (about 12 percent of the total), mass transit (about 11 percent), and aviation (about 9 percent). The federal role relative to state, local, and private roles is also highest in the

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transportation subsector. The best opportunity for the federal government to influence and enhance infrastructure's adaptive capacity is thus in the transportation sector.

In almost all cases, some adaptive capacity exists to respond to these threats through both public and private sector actions, but adaptive capacity can be significantly enhanced in the public sector by adopting three key policy reforms.

- First, although most public infrastructure is maintained as a capital asset, with annual operating, maintenance, and repair functions and a periodic replacement schedule, adopting a formal asset management approach could yield immediate benefits and provide a framework for incorporating climate forecasts to enhance adaptive capacity.
- Second, the location of major capital infrastructure should be mapped against those areas of the country considered most vulnerable to climate stress, and that information should be used to guide current and future investment in public infrastructure. These results should be actively publicized to most effectively signal the private sector about the expectations and limits of federal infrastructure provision.
- Third, efforts must begin to update infrastructure design standards to ensure that future infrastructure capital is more resilient to anticipated climate change and extreme events.

Introduction

U.S. infrastructure has enormous value, both directly as a capital asset and indirectly as an essential element contributing to a productive economy. Recognition of the value of infrastructure is evident, for example, in the central role of infrastructure investment in the American Recovery and Reinvestment Act of 2009, which particularly focuses on investment in the nation's transportation, water-related, and energy infrastructure.

Our understanding of the vulnerability of U.S. infrastructure to climate stress has seen several recent advances. Research studies have begun to clarify the level of assets at risk from climate change stressors and the value of effective and efficient adaptation measures at all spatial scales: local (Kirshen et al. 2006), regional (Larsen et al. 2008), national (TRB 2008) and international (World Bank 2009). These studies identify the main threats that climate change presents to infrastructure assets: possibly exacerbated damage or destruction from extreme events; coastal flooding and inundation from sea level rise; changes in patterns of water availability; and increased maintenance costs associated with higher temperatures in both temperate and permafrost regions (Neumann and Price 2009).

In almost all infrastructure sectors and locations, some adaptive capacity exists to respond to these threats through both the public and the private sector. Private sector activities are mainly motivated by market incentives to protect, maintain, or replace valuable assets. For example, privately owned electric generating capacity is often sited near a source of water for cooling. Climate change could reduce water supply in some of these areas, and proximity to natural bodies of water could exacerbate existing flood risks from coastal storms or, in the case of riverside facilities, extreme precipitation events.

In the private sector, there are clear incentives to understand these risks, adjust operations and capital planning to respond to them, and effectively invest in resiliency. In some cases, maintaining insurance coverage for these assets will mandate risk analyses and protective investments.

For publicly owned infrastructure, however, the same incentives are not always present. Infrastructure assets generally, and public infrastructure in particular, tend to yield value as an input to the production of something else, rather than having a distinct asset value, and governments tend to self-insure against environmental risks. As a result, from time to time, basic maintenance and repair of public infrastructure has received low public priority. Infrastructure in poor repair may be even more vulnerable to climate-induced damage.

This issue brief therefore focuses on mechanisms and processes to better prepare public infrastructure for the stresses of climate change.[2] The focus is on three recommended changes to current federal infrastructure policies:

- incorporating climate forecasts more effectively in infrastructure capital and maintenance decisions,
- reconsidering the location of new and updated infrastructure investments, and
- updating infrastructure design standards.

Current State of Policy

The federal government is most heavily involved in funding new and improved infrastructure in the transport, water, and sewer sectors, presenting an opportunity for adaptation through federal policy. Federal roles vary by infrastructure subsector and location, however. Almost all major U.S. road transportation and public transit infrastructure is publicly owned, and much is built with a large share of federal funding and then maintained with state and local resources. The same is true of airports, but freight rail networks and port facilities are more commonly privately owned and operated. Energy infrastructure, both generation and transmission, tends to be privately owned but highly regulated by the public sector. Large-scale flood defense infrastructure is most

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[2] A series of issues in infrastructure planning related to greenhouse gas emissions reductions (e.g., transport efficiency, smart energy and transport infrastructure, encouraging innovation in low-carbon technologies, water use efficiency), though not the main focus of this brief, are nonetheless important issues and strategies for climate change mitigation policy. Choices to reduce greenhouse gas emissions in an attempt to mitigate climate effects will also intersect with adaptation-focused policies; as a result, the effect of adaptation and mitigation policies will need to be considered jointly as part of the nation’s portfolio of responses to climate change.

often financed and maintained in the public sector, though often with cost-sharing from multiple layers of government.

Total public spending on infrastructure exceeds $300 billion annually, with roughly 25 percent of that total spent at the federal level, accounting for about 3 percent of total federal spending (CBO 2007; see also Table 1). In many cases, however, infrastructure budgets are under strain to keep up with necessary repairs and replacement. Ideally, public infrastructure would be maintained as a capital asset, with annual operating, maintenance, and repair functions occurring on a regular basis and with a clear periodic replacement schedule, but too often infrastructure budgeting is not optimized to maintain a consistent level of performance. Recent analyses suggest large gaps between existing capital and maintenance spending and the level of expenditure necessary to maintain current levels of service, and that these gaps would be larger if the country were to pursue all economically justifiable investment, though determining what is economically justified is difficult and methods are argued among economists (CBO 2008). These analyses suggest that highways and aviation spending would need to increase about 20 percent from current levels, or about $15 billion, to maintain current levels of service. Investments in freight railroad infrastructure would need to increase by much more, by almost 65 percent of current levels, or more than $4 billion, to maintain current service.[3]

The American Recovery and Reinvestment Act (ARRA) attempts to address some of these shortfalls in infrastructure provision; the act authorizes up to $150 billion in infrastructure funding over three years.[4] Most of this funding is focused on the transportation and energy sectors, with smaller amounts focused on wastewater, drinking water, and flood protection. Some does consider the impact of climate change on infrastructure operation and demand. For example, much of the energy infrastructure investments are focused on renewable technologies and development of a smart grid to accommodate greater reliance on renewables; there is a $1 billion allocation to the Bureau of Reclamation for water resource development in drought-likely areas; and the roughly $4.5 billion allocation to the U.S. Army Corps of Engineers includes upgrades to flood protection infrastructure, which is perhaps a nod to the likelihood of climate change increasing flood risks. Nonetheless, virtually no provisions in the transportation funding take account of the risks of climate change to these resources. The priority instead is on quickly moving money to maximize the short-term economic stimulus effect of the spending. As discussed in the

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[3] Some analysts argue that the level of sustainable infrastructure spending should be assessed relative to levels of GDP. In the United States, public infrastructure spending has sometimes exceeded 3 percent of GDP; this occurred most recently almost 50 years ago, during the initial construction of the interstate highway system. Since 2000, total public infrastructure spending has hovered around 2.5 percent of GDP. These crude evaluation measures, however, ignore a host of factors that ought to affect choices for infrastructure spending—whether inadequate infrastructure provision slows economic growth, differences among regions in economic growth and infrastructure requirements, lags between infrastructure provision and economic benefits, and the overall infrastructure intensity of the economy in a given location (infrastructure intensity being an estimate of development intensity as a function of transportation and industrial infrastructure). They are thus less useful in assessing whether current infrastructure funding is sustainable.

[4] See http://www.recovery.gov/?q=content/act (accessed September 8, 2009).

next section, this shortcoming in efficiently adapting to climate change is potentially serious, because shovel-ready is almost certainly not climate-ready.

Table 1. Capital Spending on Infrastructure in 2004 (Billions of 2004$)

	Public		Total		
	Federal	State–Local	Public	Private	Total
Transportation infrastructure					
Highways	30.2	36.5	66.7	n/a	66.7
Mass transit	7.6	8.0	15.5	0	15.5
Freight railroads	0	0	0	6.4	6.4
Passenger railroads	0.7	0	0.7	0	0.7
Aviation	5.6	6.8	12.4	2.0	14.4
Water transportation	0.7	1.7	2.4	0.1	2.5
Total transportation	44.7	53.0	97.7	8.5	106.2
Other infrastructure					
Drinking water and wastewater	2.6	25.4	28.0	n/a	28.0
Energy	1.7	7.7	9.4	69.0	78.4
Telecommunications	3.9	n/a	3.9	68.6	72.5
Pollution control and waste disposal	0.8	1.8	2.6	3.6	6.2
Postal facilities	0.9	0	0.9	0	0.9
Prisons	0.3	2.6	2.9	n/a	2.9
Schools	0.4	75.5	75.9	23.8	99.7
Water and other natural resources	7.1	4.3	11.3	n/a	11.3
Total utilities and other	17.6	117.2	134.9	165.0	299.9
Total	62.4	170.2	232.6	173.5	406.1

Source: CBO 2008.

Solutions

The federal government has already begun to see the need to improve climate forecast information and dissemination. Following closely on the recommendations of a recent National Academy of Sciences panel (NAS 2009), the draft version of the American Clean Energy And Security Act (also known as the Waxman-Markey bill, passed in the House and currently awaiting action in the Senate) includes provisions for NOAA to establish a National Climate Service, and for agencies to develop adaptation plans to be integrated across the federal government.

If Congress moves forward with climate legislation of this type, three actions are needed for adaptation efforts to be effective in enhancing the resiliency and climate readiness of U.S. infrastructure resources. First, forecasts of future climate, particularly those aspects of climate that have the greatest impact on infrastructure, must be meaningfully incorporated in infrastructure capital and maintenance decisions. Second, the location of major capital infrastructure should be mapped to identify those areas of the countries considered most vulnerable to climate stress, and that information should be used to guide future investment. Third, efforts must begin to update infrastructure design standards to ensure that future infrastructure capital is more resilient to anticipated climate change and extreme events.

IMPROVE DECISIONMAKING AND INCORPORATE FORECASTS

Providing information on climate forecasts to infrastructure engineers and planners will not be sufficient to achieve adaptation goals, for two reasons. First, most agencies have not adopted an asset management framework that can effectively consider climate inputs. Second, climate forecasts are inherently uncertain, and uncertainty as well as changes in trends need to be a part of infrastructure design and planning. Resolving these two obstacles to more effective use of climate information is feasible, but will require significant effort.

Adopting an asset management framework would have efficiency benefits now but would also provide a framework for considering the effects of future climate. In general, what is needed in infrastructure management is more rigorous thinking about how climate changes ought to affect the capital investment and maintenance cycle. This is described in the CBO publication *Issues and Options in Infrastructure Investment* (2008, 23):

> Asset management relies on monitoring the condition of equipment and the performance of systems and analyzing the discounted costs of different investment and maintenance strategies. For existing infrastructure, the key issue is making efficient choices about maintenance and replacement. In constructing new infrastructure, asset management involves evaluating total life-cycle costs—both the initial capital costs and the subsequent costs for operation, maintenance, and disposal— to ensure not only that projects are prioritized appropriately, but also that they are built cost-effectively.

Examples from the highway transportation arena could include making a larger initial investment in thicker pavement to provide a more-than-proportional increase in pavement life, or shortening the period between pavement overlays, which could reduce the fuel and maintenance costs of highway users. It is interesting that some of the actions identified as optimal through an asset management approach could also be responses to climate change, because shortening replacement cycles has been suggested as a measure to address threats to infrastructure from more frequent and intense coastal storms (Neumann and Price 2009; Hallegatte 2008).

A study of the optimal response to climate change for Alaska's infrastructure adopts a similar framework of analysis, seeking least-cost adaptation strategies for roads, airports, water systems, public buildings, and telecommunications networks (Larsen et al. 2008). That study sought to estimate the total present value of maintenance and replacement cost of infrastructure under three assumptions: no climate change (i.e., historical climate), climate change with no adaptation, and climate change with adaptation.[5] The net present value of maintenance and replacement costs for transportation infrastructure in their inventory through 2030 is approximately $24.5 billion (2006$). The authors estimate that, under climate change with no adaptation, transportation systems could incur increased maintenance and replacement costs of $2.3 to $4.3 billion, or about 9.3 to 17.7 percent of the base case expenditures, depending on the climate scenario.

The Larsen and colleagues adaptation case, however, assumes that agencies responsible for managing infrastructure will act strategically to design replacement infrastructure in a way better tuned to changed climate conditions. Deploying this type of adaptive capacity reduces the cost of infrastructure provision from climate change by up to 13 percent by 2030 compared to the no adaptation case; the maximum effect is seen when the model is applied for the most extreme, warmest, climate model inputs. The effect of adaptation in reducing costs of providing infrastructure services is much more pronounced in the long term—by 2080, adaptation reduces costs by an estimated 10 to 45 percent overall. The reason for an increasing long-term effect is that, as the useful life of existing infrastructure is exhausted, opportunities to replace that infrastructure with strategically designed capital more resilient to the changed climate increase. Clearly, this approach has great potential for improving adaptive capacity.

The most robust attempts to isolate the marginal effects of climate model infrastructure as long-lived assets that will, in a stable climate, require annual or periodic maintenance, repair, and eventual replacement. The marginal impact of a stressor such as climate change could involve a revised maintenance period, adjusted maintenance costs, or both; a change in the need for repair, perhaps because of a change in the frequency of damaging events (such as storms); or a change in the replacement cycle (Neumann and Price 2009). It is reasonable to conclude that the engineering process for much long-lived infrastructure capital considered historical climate conditions when built, and that design was optimal for those historical conditions. As climate changes, however, the design becomes no longer optimal, and damages are therefore incurred.

One of the key adjustments needed to respond effectively to climate change is that infrastructure planners will need to expect a changing rather than a stable climate. As noted in a special

[5] The authors use three global circulation model (GCM) temperature and precipitation scenarios, which they characterize as *warm*, *warmer*, and *warmest*, for two target years, 2030 and 2080. All are based on IPCC A1B emissions scenarios, characterized by IPCC as a medium emissions scenario. The warm scenario is derived from the CSIRO Atmospheric Research, Australia, warmer from NOAA's Geophysical Fluid Dynamics Laboratory, and warmest from the Center for Climate System Research from the University of Tokyo.

National Academy of Sciences report (TRB 2008), climate scientists often describe the future in probabilistic terms, whereas transportation and other infrastructure management professionals typically focus on knowns. This narrow focus is an obstacle to developing dynamic decisionmaking processes that can adapt to new information and accommodate feedback as knowledge about climate change changes over time.

In some cases, the sign as well as the magnitude of climate change will be unpredictable, and the temporal profile for such factors as precipitation and floods will also be more uncertain. As Hallegatte (2008) has noted, adapting the planning process for long-lived assets is not as simple as reoptimizing infrastructure and capital planning for a new climate. Reoptimizing planning can yield great gains, but effectively dealing with an uncertain climate also requires a new way of thinking. Infrastructure engineers accustomed to designing infrastructure using historical climate data will need to assess a much broader range of future outcomes, and look for robust adaptive measures, which might include such counterintuitive adjustments as designing these assets with shorter lives.

RECONSIDER LOCATION OF INVESTMENTS

Several studies have noted that climate change puts a wide range of critical infrastructure at new risk, particularly infrastructure in coastal zones subject to sea level rise and heightened storm surges (CCSP 2007, 2008a, 2008b; Kirshen et al. 2006; Titus and Richman 2001). Investing in infrastructure in these areas needs to be carefully planned with full consideration of what we know about future risks, as well as acknowledgement that providing public infrastructure signals the private sector about the viability of an area for economic activity and habitation. For example, as Nicholls et al. note (2008), one reason for concern about coastal losses is the trend of increasing development and property value in coastal areas, both because of the amenity value and that U.S. urbanization remains strong in most coastal cities.

The public sector could take a proactive stance in integrating land-use and infrastructure planning and thereby limit the growth of coastal resources at risk, either through regulation or by developing new and more compelling information on the increasing risks of climate change to coastal development. Policy approaches that clarify the limits of public sector willingness to protect coastal properties “in harm’s way” might reinforce the private incentive to internalize coastal and other climate change risks, which could reduce the expected value of damages from climate change over time.

Examples of such integrated planning are rare, but at least one state has developed a process. New Jersey’s state budgeting office allocates infrastructure funds using an aggregate land-use plan built up from local plans. The resulting clarity on infrastructure development (and replacement) can leverage private investment by sending signals about geographic areas where development is supported. Ideally, signals from the state government about where infrastructure investment will be supported should also influence local-level zoning decisions, which in turn signal private sector landowners and developers. Integrated planning may also help facilitate financial sector adaptation (such as insurance schemes), which some have argued is much easier and more flexible and robust than its technical counterpart (Hallegatte 2008).

This type of strategy is responsive to another reality of long-lived infrastructure provision—that adapting to climate stresses (or just about any risk that evolves over time) is more cost-effective during the design phase of projects, rather than as a retrofit. Clarifying the limits and expectations of providing and replacing public sector infrastructure could allow the federal government to be better prepared to respond to extreme events associated with climate change. More frequent and destructive extreme events, such as recent hurricanes and riparian floods, have already proved a huge challenge to maintaining public infrastructure. At the same time, many studies note that although extreme events are devastating to affected regions, the rebuilding process is an opportunity to replace damaged infrastructure with more resilient capital. Targeting the provision of infrastructure, however, may require large doses of political courage—in post-Katrina New Orleans, for example, a preliminary finding by the "Bring New Orleans Back" panel to prioritize rebuilding housing stock based on flood damage, to consolidate neighborhoods with minimal populations, and to conduct neighborhood planning to determine the future of heavily damaged areas was swiftly rejected by local groups, prompting the mayor to withdraw from those findings.[6]

UPDATE DESIGN STANDARDS

A longer-term policy goal is investment in updating design standards. Some of this work is already happening in Canada (Canadian Standards Association 2005, 2006). The asset management framework described might be usefully deployed, for example, to develop new climate-ready standards and specifications. In the United States, it is acknowledged that updating standards is a long process, involving many government, commercial, and nongovernmental standard-setting organizations (Meyer 2008; TRB 2008).

The potential in using standard-setting approaches to enhance adaptive capacity is significant, however. Updating flood-proofing measures in coastal zones, for example, has encouraged innovation in architectural and building practices to improve the resiliency of structures built or rebuilt in high-risk areas. Similar innovation can be spurred in such areas as materials science,

[6] See "Action Plan for New Orleans: The New American City," a presentation by the Bring New Orleans Back Commission, Urban Planning Committee on January 11, 2006. For a summary of local reaction and a link to the report, see http://www.npr.org/templates/story/story.php?storyId=5151102 (accessed September 27, 2009).

engineering, and construction trades through a continuously updated standard-setting process that considers forecasts of climate change and variability.

Conclusions

Public infrastructure is a major current and future investment at the federal level, and many of these resources face a new risk in sea-level rise, temperature and precipitation changes, and extreme events associated with climate change. The infrastructure investments currently being made for economic stimulus purposes under ARRA have not required that risks to infrastructure presented by climate change be considered, but adopting the adjustments to infrastructure planning and design suggested in this paper can significantly enhance adaptive capacity.

The most urgent short-term goal is to establish a framework for infrastructure planning that optimizes service provision while recognizing that climate change, and policy responses to mitigate greenhouse gases, will alter both the need for and the performance of public infrastructure. A decision-support framework in which to interpret climate change forecasts is critically needed in the near term.

Consistent with our broad recommendations, the following initial priority list for new public policy action on key infrastructure resources at risk identifies important steps for enhancing adaptive capacity.

- Develop a system for sharing and communicating projections of downscaled climate data—for both sudden and gradual climate change—to support better federal and local planning.
- Initiate capacity-building demonstration projects showing the proper use of probabilistic modeling concepts to identify cost-effective adaptation projects that are robust in the face of climate uncertainty.
- Foster interregional technology transfer among areas that might provide a current spatial analog, where possible. Infrastructure planners in the mid-Atlantic may have insights for those in the Northeast, for example.
- Adopt a risk-based approach to infrastructure planning that involves a conversation between planners and climate scientists. The role of infrastructure planners would be to define the information they need to do their job well, such as thresholds of temperature, precipitation, and the likelihood of extreme events. Climate scientists and other analysts could use this information to provide assessments of the current and projected future risk of crossing those thresholds under various future climate scenarios.

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