# 9 Technical Presentation 5: An Economic Framework for Evaluating Climate Proofing Investments on Infrastructure

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## Key Messages

- El Salvador suffers significant risk of damages due to climate change impacts, but contributes little to the cause of climate change (i.e. greenhouse gas emissions). It is appropriate for El Salvador to focus on climate change adaptation over mitigation.
- An economic approach to setting climate-proofing priorities implies a focus on efficiency, whereby the goal is to choose projects that have the greatest net social benefits.
- Determining the net social benefits of infrastructure projects, and the climate proofing of them, requires consideration of both costs and benefits.
- Estimating costs and benefits often requires the use of both market and nonmarket valuation techniques.
- The framework developed here is useful for setting priorities for the climate proofing of infrastructure investments and determining how much to invest in each.
- The framework can also be modified to incorporate climate-proofing externalities, such as co-benefits of projects and regional network effects.
- Other important considerations include changes in infrastructure priorities more generally due to climate change impacts and the importance of discounting.
- Building capacity for efficient climate change adaptation requires identifying the set of potential infrastructural adaptations, expanding knowledge of nonmarket values, and strengthening institutions for greater international and regional coordination of efforts.
- Building human capital for institutional support is also important and could include the use of geographic information systems to identify vulnerability, census and economic data, storm impact and response data, training in microeconomic theory and statistical methods, and ongoing program evaluation.

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# Full Presentation

This technical presentation offers an economic framework for evaluating the climate proofing of investments on infrastructure. Emphasis on economic valuation focuses on consideration of costs and benefits, evaluated through market valuation (impacts measureable through prices) and nonmarket valuation (impacts not easily monetized, such as risks to human health). The framework proposed here for setting priorities given finite resources complements frameworks previously discussed during the conference. Further considerations include co-benefits, geographic scope, proofing vs. prioritizing infrastructure projects, and discounting. Recommendations for building capacity to implement the framework for efficient climate-change adaptation precede final thoughts.

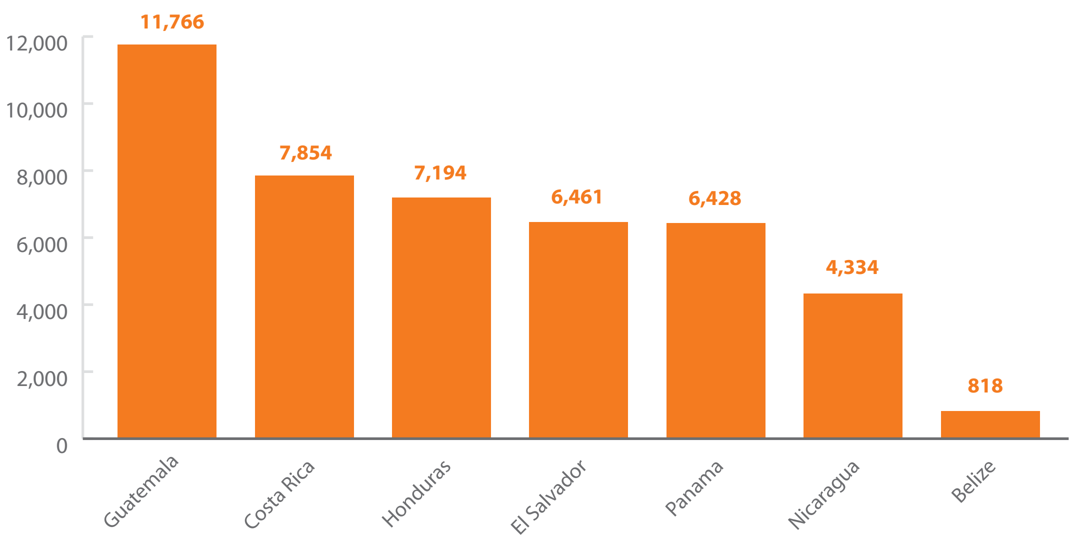
## Rationale

### Focus on adaptation over mitigation

Where climate change discussions and policy tend to focus on mitigation (i.e. the reduction of greenhouse gas emissions), dialogue is often embedded in scepticism and debate about whether or not climate change is a problem. Where climate change effects are already being seen and thought to be getting worse, dialogue tends to focus on adaptation, that is, not on whether climate change is a problem, but rather on what needs to be done about it.

El Salvador's focus on adaptation, rather than mitigation, is appropriate given that the country accounts for less than 0.1 percent of worldwide $CO_2$ emissions (the primary greenhouse gas) and ranks 107th among nations for emissions (based on 2006 data). All of Central America emits only 1.6 percent of global emissions, of which El Salvador contributes the median amount (see Figure 9.1).

**Figure 9.1: Carbon dioxide emissions (in 1000s metric tons) from fossil fuels by country in Central America (2006)**



## Forecasts of climate change impacts in El Salvador

In El Salvador, according to predictions reported by the Central American Integration System (SICA), the average temperature will increase between 0.8°C and 1.1°C by 2020, and between 2.5°C and 3.7°C by 2100. It is likely that in the next 10 years annual precipitation will change, with estimates showing a high degree of variability, from a decrease of 11.3 percent to an increase of 3.5 percent. By 2100 these changes are predicted to range from a decrease in precipitation of 36.6 percent to an increase of 11.1 percent. These forecasts also include significant seasonal differences. There are also predictions that sea level will increase by 20 cm by 2030, 40 cm by 2040 and by 70 cm by 2100. While there is much variability in these numbers, the probabilities are alarming enough to necessitate serious consideration about how best to adapt to a changing climate.

## Costs and benefits

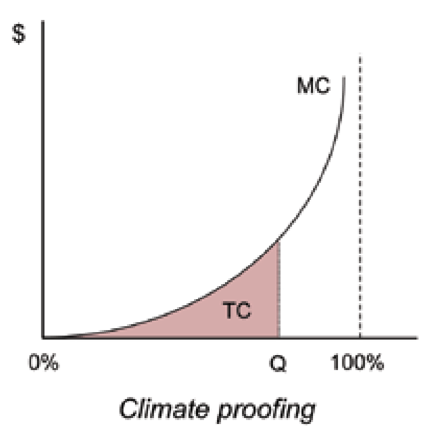
The climate proofing of infrastructure can be conceptualized from an economics standpoint as insurance against the adverse impacts of climate change. Determining the right amount of climate proofing requires consideration of both the costs and benefits.

## The costs of climate proofing infrastructure

The climate proofing of infrastructure projects (e.g. roads, bridges, etc.) seeks to reduce vulnerability of the investments to increased variability in climatic conditions (e.g. increased rainfall, high-speed winds, flooding, etc.). In principle, we can measure the effectiveness of an infrastructure project as ranging between 0 and 100 percent, where 100 percent means that with certainty floods or winds will not damage or destroy the infrastructure. Climate forecasts, as well as input from engineers, can be used to determine such effectiveness and the specifications need.

With this information, market valuation can be used to evaluate the direct costs of climate proofing based on the additional costs necessary to increase effectiveness. Figure 9.2 is useful to illustrate the basic relationship.

**Figure 9.2: The costs of climate proofing effectiveness**



The horizontal (x) axis represents effectiveness of climate proofing, ranging from 0 to 100 percent; zero percent effectiveness indicates immediate destruction of a project (e.g. a bridge) due to high vulnerability, while 100 percent effectiveness indicates that construction of the bridge will withstand climate-change impacts.

The curve represents the marginal cost (MC), that is, the additional cost of constructing the bridge to increase effectiveness. The increasing curve shows how improving the strength of the bridge becomes increasingly more costly. Also, because some uncertainty always exists, it becomes increasingly more costly to increase effectiveness, until it may be infinitely expensive to approach 100 percent effectiveness.

The total cost (TC), represented by the shaded area under the curve, is the total cost of constructing the bridge at Q value of climate proofing (i.e. the sum of marginal costs for each unit of climate proofing up to Q). Communicating with engineers to determine the costs of climate proofing for any level of Q is relatively straightforward compared to estimating the benefits, but information on both costs and benefits is necessary to determine the economically efficient level of Q.

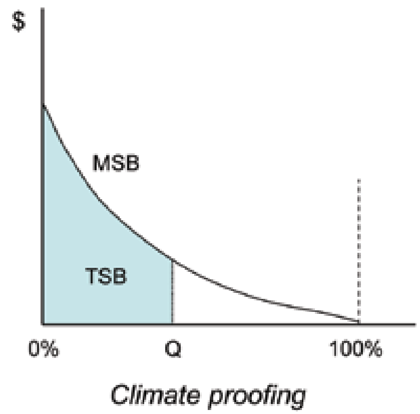
## The benefits of climate proofing infrastructure

The benefits of climate proofing are avoided damages to property (e.g. destruction of buildings), forgone economic activity as a result of damages (e.g. electrical outages, failed bridges), effects on health and human life, and impacts on environmental services (e.g. erosion, loss of natural capacity to protect from future climate change). Typically, these benefits are not straightforward to monetize because they are not observable through market transactions and do not have prices. Quantification of them, therefore, usually requires some form of nonmarket valuation.

Recognizing the difference between the private perspective and the social perspective is important when it comes to thinking about the right benefits to include. From the private investment perspective, the benefits of climate proofing are financial returns. From the social perspective, the benefits often include the non-market values associated with things like avoiding loss of life, health benefits, diffuse economic activity, and environmental services. Here we consider the social perspective for purposes of public sector investments and policy.

In parallel to the cost curve above, modeling the benefits (see Figure 9.3) uses the same metric on the x-axis, 0 to 100 percent climate-proofing effectiveness. In Figure 9.3, the curve represents the marginal social benefits (MSB), that is, the additional benefit to society of having one more unit of climate proofing effectiveness. These benefits are positive but decreasing with increased fortification of infrastructure against climate risks.

**Figure 9.3: The benefits of climate proofing effectiveness**



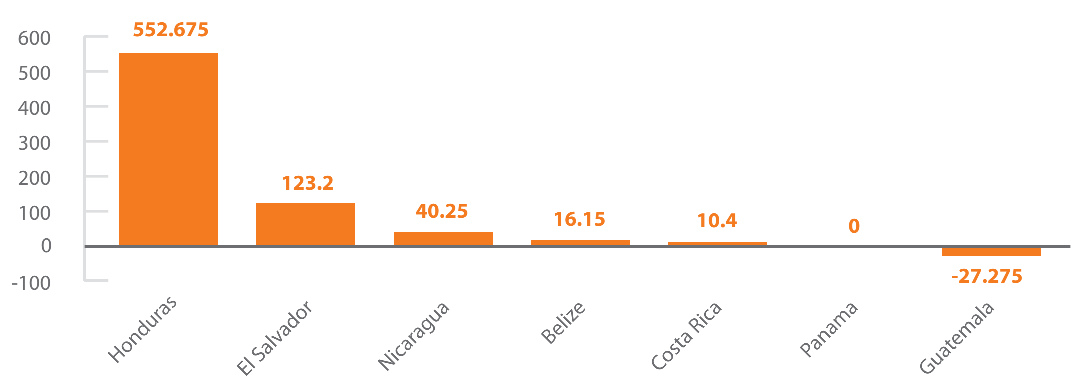

The total social benefit (TSB) of climate proofing to level Q, represented as the shaded region in Figure 9.3, is the sum of all marginal benefits to society for each unit of effectiveness up to Q.

## The example of tropical storms

Statistics for Hurricane Mitch and Hurricane Stan provide examples of how storm impacts can be translated into estimated costs and benefits. Hurricane Mitch (1998) destroyed 49 percent of the agricultural and livestock sectors in El Salvador, and resulted in 240 direct fatalities and $400 million in estimated damages. Hurricane Stan (2005) destroyed 70 percent of basic crops and resulted in 69 direct fatalities and $355 million in estimated damages. These statistics represent the damages that could have been reduced or avoided with climate-proofing policies.

Climate models predict an increase in the frequency and intensity of these types of storms. Using four different models to predict storms, a recent study by a Yale colleague simulates data on damages that storms are likely to cause over the next 90 years as a result of climate change (see Figure 9.4). The study uses past damages and predications about how climate change will increase storm intensity to derive the estimates.

**Figure 9.4: Damages relative to no climate change baseline 2100 (million $/year)**




Source: Forecasted impacts in Central America (Mendelsohn et al. 2010).

PART II

TECHNICAL PRESENTATION 1
WHAT A COUNTRY SHOULD THINK ABOUT AND THEN DO TO ADDRESS CLIMATE CHANGE AND INFRASTRUCTURE RISKS

TECHNICAL PRESENTATION 2
INTERNALIZATION OF CLIMATE RISKS IN THE CONTEXT OF PLANNING AND URBAN DEVELOPMENT

TECHNICAL PRESENTATION 3
A FRAMEWORK FOR RISK ASSESSMENT AND RISK-INFORMED DECISION-MAKING FOR INFRASTRUCTURE DEVELOPMENT

TECHNICAL PRESENTATION 4
PROBABILISTIC RISK MODELING: BASIC PRINCIPLES AND APPLICATIONS

TECHNICAL PRESENTATION 5
AN ECONOMIC FRAMEWORK FOR EVALUATING CLIMATE PROOFING INVESTMENTS ON INFRASTRUCTURE

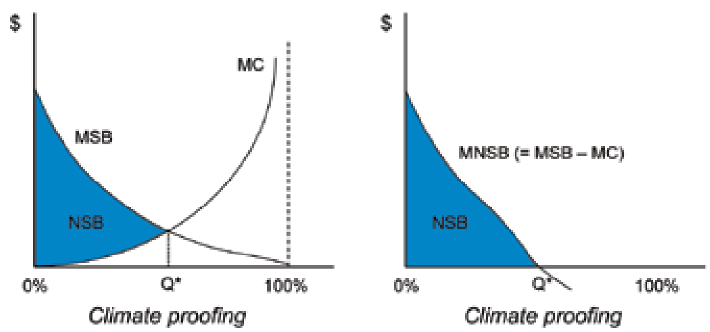
TECHNICAL PRESENTATION 6
SUPPORTING EL SALVADOR TO REDUCE INFRASTRUCTURE RISKS WITHIN A GREEN, LOW-EMISSION AND CLIMATE-RESILIENT FRAMEWORK FOR DEVELOPMENT

Figure 9.4 shows economic damages (in millions of dollars per year) from storm impacts predicted to be significantly greater than the expected baseline of what damages would be in the absence of climate change (Honduras is an outlier with especially high damages). In El Salvador, estimation of the annual average cost of climate change from storm damage (without adaptation measures) is over $100 million. Total economic damages for El Salvador would be equal to this value plus damages predicted in the absence of climate change. This is an example of how nonmarket valuation can be used to estimate the benefits of what can be gained by pursuing adaptation strategies.

## Economically efficient climate proofing

Cost-benefit analysis for economically efficient climate proofing can help to determine the efficient amount of climate proofing for a nation such as El Salvador. Considering the cost and benefit curves (Figures 9.2 and 9.3) simultaneously is the way to determine the optimal, or economically efficient, level of climate proofing. The graph on the left-hand-side of Figure 9.5 defines Q* as the optimal level of climate proofing. This is where the MC and MSB curves intersect. The graph also indicates the net social benefit (NSB) as the area representing the difference between TC and TSB. Note that Q* is the level of climate proofing that maximizes this area.

**Figure 9.5: Efficient level of climate proofing**



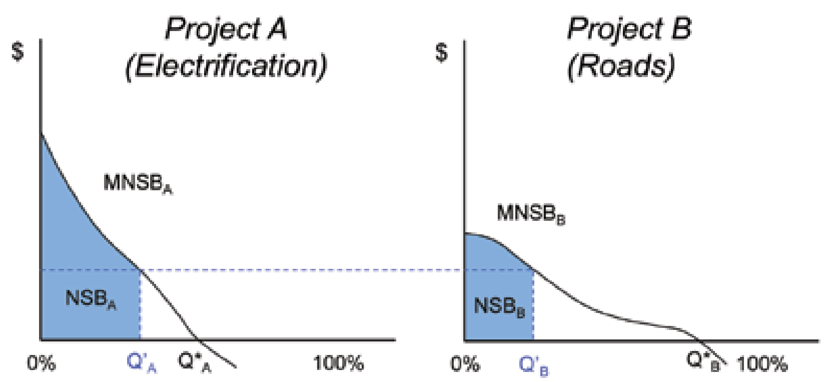

Note: Net social benefit (NSB); marginal net social benefit (MNSB) = MSB - MC.

Another way to see this is with the right-hand-side graph in Figure 9.5. This shows the marginal net social benefit (MNSB) curve, which traces out the area beneath it representing the NSB (the same area on both graphs in Figure 9.5). From this graph, it is clear that efficient climate proofing occurs up to the point where the MNSB curve remains positive, for beyond that point the additional marginal social benefits would not exceed the additional marginal costs.

## Prioritizing among projects with a fixed budget

When prioritizing climate-proofing actions among projects given a budget that prohibits doing them all at the economically efficient level, the objective is to optimally allocate investments by maximizing total net social benefits subject to the budget constraint. For example, when comparing Project A for electrification (e.g. bolstering the strength of power lines while expanding the distribution of electrical services) with Project B for roads (e.g. constructing and fortifying bridges and roads for flood-resistance), the net social benefit for a given budget can be identified for each project (see NSBA and NSBB in Figure 9.6).

**Figure 9.6:** **Prioritizing among projects with a fixed budget**




Note: Objective is to maximize total net social benefits subject to a budget constraint; solution is MNSBA = MNSBB while also exhausting the budget.

Figure 9.6 illustrates the nature of an efficient solution. The efficient amount of climate proofing for each project occurs at the levels of QA and QB where the marginal net social benefits are equated between them both, and simultaneously achieving the values of QA and QB that exhaust the budget. If both of these conditions are met, then total net social benefits (=NSBA + NSBB) are maximized.

## Implications of the framework

In general, the framework described here requires information about marginal social net benefits of projects, which are based on estimates of the marginal costs and marginal social benefits. At the crudest level, when information is incomplete, the objective can be understood to imply that priority should be given to projects expected to yield relatively large social net benefits, which requires consideration of both costs and benefits. The framework also provides a mechanism for choosing which projects to undertake (the extensive margin) and how extensively to pursue them (the intensive margin).

## Importance of climate proofing externalities

The framework can be modified to incorporate climate-proofing externalities, such as valuable co-benefits of projects. For example, infrastructure for flood control might also provide water storage. Vegetation planted along coastlines to prevent landslides might also promote biodiversity and provide opportunities for carbon-offset payments.

In addition, infrastructure is often closely tied with networks, which can contribute to the spread of benefits. Infrastructure projects for climate proofing a country's transportation system, for example, can benefit international trade, but only to the extent that transportation across national boundaries is also less vulnerable to climate change impacts. This requires multinational coordination. Likewise, infrastructure projects can result in positive and even negative externalities across regions (e.g. department borders within El Salvador) and ministries (e.g. transportation, communication, and electricity distribution). Hence maximizing all positive benefits may entail spillovers across jurisdictional boundaries.

**Figure 9.7: Map of Central America (left) and departments of El Salvador (right)**


Note: Potential for infrastructure (e.g. transportation) to lead to positive externalities across borders.

## Prioritizing among projects accounting for externalities

Positive externalities can be mapped into the framework if included in the graphs for prioritizing investment projects. For example, considering the transportation benefits of roads (Project B) to either neighbouring departments or countries, the social benefits for Project B become the benefits (indicated in Figure 9.6) plus the positive externality, as shown on the right-hand-side graph of Figure 9.8. Then equating the adjusted marginal net social benefits between projects, we see that pursuing less electrification (Project A) and more of road network (Project B) optimizes total benefits given the same budget constraint. This results in greater overall social net benefits, as illustrated with the graphs in Figure 9.9. There is less benefit associated with electrification but more benefit associated with roads, and the latter effect is larger than the former.

**Figure 9.8: Prioritization among projects accounting for externality**

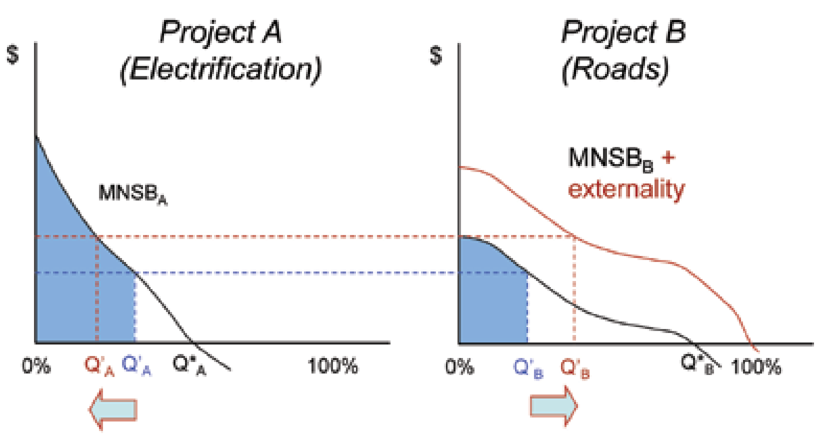
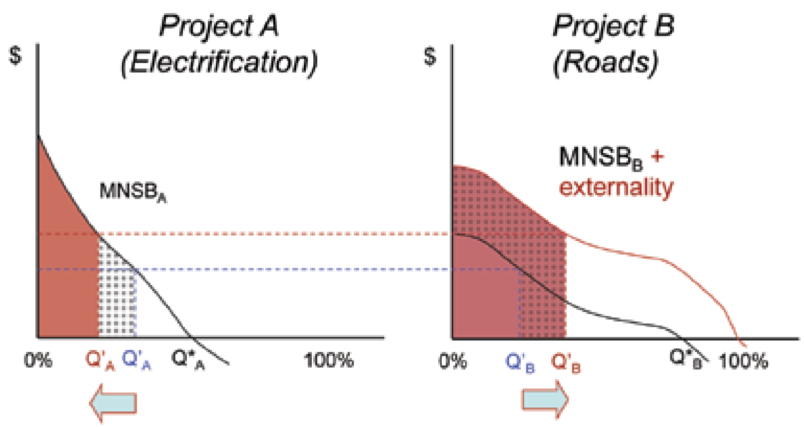


**Figure 9.9: Prioritizing among projects accounting for externality**




Note: Additional net social benefit represented by difference between pink dotted area and white dotted area.

Accounting for these external effects is crucial, as it not only can change climate-proofing strategies across different investment projects, but it also can affect decisions about when to optimally invest and at what levels.

## Further considerations

### Proofing vs. prioritizing infrastructure projects

The framework presented here has been discussed in terms of climate proofing infrastructure projects. However, it is worth emphasizing that when the impacts of climate change are considered, the priorities for which infrastructure projects to undertake at all (regardless of whether they are climate proofed or not) could very well change. In El Salvador, for example, the Intergovernmental Panel on Climate Change (2007) predicts a 10 to 27.6 percent decrease in land area by 2100 due to sea-level rise. Such information might not only change which infrastructure projects would be efficient to climate proof; it is likely to change which infrastructure projects to undertake at all.

### Discounting

Though controversial in the field of economics and policy analysis, discounting is the standard way to account for differences in the timing of costs and benefits. Discounting takes into consideration that a dollar today is worth more than a dollar in the future because (1) that dollar can be invested for future returns and (2) there is an inherent impatience for the present over the future. Higher discount rates imply less value placed on the future.

Discounting is an important consideration for infrastructure investments that deal with future risks of climate change. In general, the costs occur now, or relatively soon, while the benefits of potential avoided damages happen far into the future and are often quite uncertain. It is often argued that considering climate change for the welfare of future generations thus calls for a lower discount rate.

## Building capacity for efficient climate change adaptation

Three recommendations can be made about how to develop concrete strategies for adaptation:

1. **Identify the set of all potential infrastructural adaptations:** Initially, this list should be complied without regard to costs and benefits, considering both nationwide and region-specific impacts, as well as historical successes and failures. Then based on this list, economic analysis of the type outlined here should be applied to those of greatest interest, after eliminating those that seem infeasible or not likely to be efficient candidates.
2. **Expand knowledge of nonmarket valuation:** This may include conducting additional studies on nonmarket valuation in developing nations, as well as improving availability of existing data through 'benefits transfer' (i.e. the transfer of benefit estimates from one study area to another). Canada's Environmental Valuation Reference Inventory (EVRI) — which lists nonmarket valuation studies for North America (1,178 studies), Asia (229 studies) and Latin America (38 studies) — may be a useful resource for benefits transfer information. In the long-term, Central America and El Salvador, specifically, might benefit from efforts to bolster the capacity for conducting nonmarket valuation studies throughout the region.
3. **Strengthen institutions for greater international and regional coordination of efforts:** Nations can share information and experience about the climate proofing of infrastructure: what works, what doesn't, and what are the most cost-effective ways of getting it done. And when it comes to regional coordination, this meeting has been great example of what needs to be done.

### Human capital for institutional support

Recommended capacity building includes the development of human capital for institutional support. For example, the value of geographic information systems with mapping software is key for identifying vulnerabilities. El Salvador can benefit from capacity building for developing methods to synthesize such geophysical and socioeconomic information. Consideration of the interconnectedness of different regional economies can also influence how best to build infrastructure and take advantage of positive externalities. In addition, census and economic data are important for developing tangible recommendations. By collecting data during storm events, capacity can be built for evaluating damages, impacts and responses; past records of disaster responses can help to improve future responses to similar events. Finally, training in microeconomic theory (particularly in the fields of welfare economics and nonmarket valuation) and quantitative statistical methods, as well as ongoing program evaluation, can build the human capital necessary to improve decision-making about infrastructure investments and climate-proofing priorities.

## Concluding thoughts

From an economic perspective, the role of public policy is to intervene in markets to promote efficiency. This often means taking account of public goods and externalities. There are real opportunities in this regard for the management of the climate proofing of infrastructure. Because infrastructure is effectively a permanent or irreversible investment, careful analysis and assessment is crucial for reducing 'regrettable' public policy decisions. These policies can include direct regulation or the setting of price signals to get incentives right.

Finally, it is important to keep in mind that economic development is among the most important adaptation strategies. Nevertheless, it is important not to focus exclusively on the most vulnerable (poorest) populations. While they often need the most immediate help, sometimes the best way to promote further development is to increase efficiency were development is already occurring.