QUANTIFYING THE SOCIAL, ECONOMIC, AND ENVIRONMENTAL SUSTAINABILITY OF DISASTER POLICIES

Elaina J. Sutley¹ and Wil V. Srubar III²

ABSTRACT

There are three pillars of sustainability: environmental, economic, and social. Many researchers have advanced our ability to quantify various economic and environmental impacts through life cycle cost analysis and life cycle assessment. A very limited amount of work has been performed on quantifying and evaluating social impacts, which are critical in a hazard and disaster context where social inequality is consistently manifested through the disparities in disruption and destruction experienced by the most vulnerable populations. The past century of disasters have resulted in numerous important and significant public policies that attempt to preemptively improve disaster resilience of buildings and communities. Sometimes, however, the policies that are adopted overlook the resulting negative consequences on the most vulnerable populations. The present work presents a probabilistic framework for evaluating the social, economic, and environmental sustainability of hazard mitigation policies. The framework is exemplified in a case study of San Francisco in its evaluation of the soft-story wood-frame building seismic retrofit mandate passed in 2013 and in its comparison to those outcomes to projections of a scenario if the mandate had not been passed.

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Quantifying the Social, Economic, and Environmental Sustainability of Disaster Policies

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Introduction
Natural hazard-induced disasters are occurring at an increasing rate [1] due to sea level rise, rising temperatures, population growth, and urbanization, among other factors. Increasingly, cities, building owners, and homeowners are faced with major decisions on whether or not to invest in hazard mitigation and better performing structural designs. Rebuilding is a major post-disaster responsibility, but rebuilding in a way that safeguards against the next inevitable disaster is imperative. This paper offers a framework for sustainable hazard-mitigation decision-making that can be used during the rebuilding after a disaster, or in preparation before a future disaster.

Many researchers have advanced our ability to quantify various economic and environmental impacts through LCCA and LCA across a building’s life cycle with hazard considerations, including those caused by retrofit, enhanced structural design, repair, and reconstruction [2-3]. Only one study has quantified environmental, economic, and social impacts in a life cycle assessment which considered natural hazards [4]. This study estimated casualties from disaster-damaged buildings. Social impacts are critical in a hazard and disaster context where social

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inequality is consistently manifested through the disparities in disruption and destruction experienced by the most vulnerable populations. The past century of disasters have resulted in numerous important and significant public policies that attempt to preemptively improve disaster resilience of buildings and communities. Sometimes, however, the policies that are adopted overlook the resulting negative consequences on the most vulnerable populations. A few studies have investigated hazard mitigation grants or policy decisions considered one social impact – casualties. There are, however, many additional measures of social impacts that need to be quantified for inclusion in engineering analyses and related policy decisions and evaluations to reach a level more representative to actuality than only a casualty estimate.

**Social, Economic, and Environmental Sustainability Framework**

A proposed framework for measuring social, economic, and environmental sustainability (SEES) of hazard mitigation policies is shown in Figure 1. The first step is to identify the assessment target, which might include the physical or social infrastructure, hazard risks, and the policy being considered. The second step is to identify and evaluate the social, economic, and environmental costs and benefits for the assessment target(s). The third step is to make comparisons across the costs and benefits to formulate recommendations for policy action.

The framework extends current social impact estimates by including (1) forced household dislocations, (2) social equity, and (3) social capital. Victims and social capital can be measured at the individual building-level, or at the policy level (see forthcoming article by Sutley and Fedders). For example, household dislocations can be estimated using the number of buildings experiencing structural damage in a hazard scenario. Social capital can be measured through the
protection of buildings that promote social capital, such as residential buildings, libraries, museums, coffee shops, and houses of worship, either through their physical building attributes or their organization. Social equity generally must be measured at the policy level by assessing whether the policy promotes or hinders the resilience of those most socially and physically vulnerable or whether the policy provides access to gain from it from all types of people.

**Case Study: Soft-Story Retrofit Mandate**

Implementation of the framework shown in Figure 1 is illustrated using the 2013 soft-story retrofit mandate of San Francisco, California. The target infrastructure includes soft-story wood-frame buildings. Two retrofit design levels are considered (collapse prevention and immediate occupancy) for a scenario of a magnitude 7.2 earthquake occurring at the San Andreas Fault [5]. A comparison is made between a no-policy scenario versus a scenario in which all soft-story buildings are retrofitted to immediate occupancy for the hazard level under consideration. The hazard scenario and building damage data are adopted from [5]; environmental impacts are adopted from [6]; social impact data are adopted from [7]; and policy equity is discussed herein. There are 2,800 soft-story buildings in total; Table 1 provides the estimated upper and lower bounds of green-, yellow-, and red-tagged buildings with and without the retrofit [5]. For simplification, green-tagged buildings are assumed to have no damage; yellow-tagged buildings are assumed to experience moderate to severe damage; and red-tagged buildings are assumed to experience severe to complete damage. Using initial, repair, and replacement costs for a single building from [7], the total cost for all 2,800 buildings can be estimated and assumed as the economic sustainability of the mandate in terms of U.S. dollars (USD). Similarly, [6] provides an estimate of global warming potential (kg CO₂ eq.), given moderate, severe, and complete damage for an individual soft-story building retrofitted to immediate occupancy and not retrofitted. Multiplying this value by the 2,800 soft-story buildings distributed across the damage states, the total global warming potential can be estimated as the environmental sustainability for the policy in kg CO₂ eq. Lastly, using the social impacts and social vulnerability measures from [7], which are articulated for all three damage levels and both the retrofit and non-retrofitted case, the total number of physical and mental injuries, fatalities, and number of dislocated households can be estimated as the social sustainability for the policy in terms of persons impacts, considering the social vulnerability level of the population. For comparison, these measures are normalized with respect to the lower bound of the no retrofit scenario to overcome the vastly different units and orders of magnitude. Figure 2 plots a comparison of these impacts with uncertainty captured by the width of the triangular curves, and provides a summary table of the measures prior to normalization. As shown in Figure 2, the upper bound of the retrofitted case reduces the social, economic, and environmental impacts below the lower bound of the unretrofitted case.

<table>
<thead>
<tr>
<th>Retrofit</th>
<th>Green-Tagged Buildings</th>
<th>Yellow-Tagged Buildings</th>
<th>Red-Tagged Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LB</td>
<td>UB</td>
<td>LB</td>
</tr>
<tr>
<td>Without Policy</td>
<td>168</td>
<td>980</td>
<td>252</td>
</tr>
<tr>
<td>With Policy</td>
<td>1876</td>
<td>1988</td>
<td>588</td>
</tr>
</tbody>
</table>

Table 1. Estimated lower bounds (LB) and upper bounds (UB) of green-, yellow-, and red-tagged buildings for each policy scenario [5].
Social sustainability is an important, but difficult, measurement that is critical for informing and comparing new hazard mitigation policies. The case study presented here quantified all three pillars of sustainability allowing for the potential benefits of the retrofit policy to be quantitatively evaluated and compared to the no-retrofit scenario. The potential benefits are exacerbated when social equity of the policy is considered. Soft-story buildings typically house low-income residents, as is the case in San Francisco. A city-wide mandate that requires building owners to improve the seismic safety of their at-risk buildings preserves affordable housing and decreases the physical vulnerability of thousands of socially vulnerable households. Due to page limitations, the formulation of the social, economic, and environmental measures were not provided nor were the detailed results from the individual analyses. Details can be found in the referenced literature and will be compiled and expanded in a forthcoming publication by the authors.

**References**