Build Back Better? Effects of Crisis on Climate Change Adaptation Through Solar Power in Japan and the United States

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Abstract

Do communities struck by disaster build back better, or not? Recent small- and medium-*N* studies have shown mixed effects. This mixed-methods study tests the effect of disasters on the adoption of solar power as a key form of building back better and adapting to climate change. To test this effect, we applied a large-*N* longitudinal matching experiment on cities affected and unaffected by disaster paired with qualitative case studies, focusing on the 2011 triple disaster in Japan and Hurricane Sandy in 2012 in the United States. We find that disaster-hit cities adopt more solar farms and rooftop solar than cities unaffected by crisis and that the social capital of these disaster-hit communities shapes their adoption patterns. By clarifying the effects of disasters on the build-back-better phenomenon in comparative cases, this article aims to guide recovery priorities after large-scale shocks.

Cities are increasingly at the forefront of efforts to adapt to climate change and climatic hazards. At the subnational level, in many developed democracies, cities are the actual crafters and implementers of climate change adaptations. Recent scholarship on disaster resilience highlights reconstruction after crisis as an opportunity to "build back better," building new infrastructure with sustainable technologies, using urban planning to reduce inequality, and integrating neighborhoods to increase community resilience to shocks. Now, as the world grapples with catastrophic floods, fires, storms, a global pandemic, and economic fallout from the loss of human life and change in business patterns, policy makers, scholars, and environmental activists are considering investing in green technologies and policy programs like the United States' Green New Deal as a way to "build back better" after megadisasters (Barrett 2020; Meyerson 2019). The choice to adopt solar power plants in a community is a micro-level policy decision and a key form of building back better after crisis. Communities with greater access to solar power tend to have greater energy system resilience; because solar is made up of many panels, disaster affects them less severely than it does single, centralized power

Global Environmental Politics 21:1, February 2021, https://doi.org/10.1162/glep_a_00588
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plants like coal, hydropower, and nuclear power (Estevan and Portugal-Pereira 2014; Roege et al. 2014). We urgently need empirical evidence of how many efforts to build back better with renewable energy have succeeded following disasters.

Our mixed-methods study tested whether communities struck by disaster build back better, using a large-*N* longitudinal matching experiment on cities affected and unaffected by Japan's 2011 triple disaster and Hurricane Sandy in the US Northeast in 2012. We used statistical models, visualization, and case studies to investigate why some communities adopted more rooftop solar and solar farms after crisis. By clarifying the effects of disasters on the build-back-better phenomenon in comparative cases, our article aims to guide recovery priorities after large-scale shocks.

We find that disaster-hit communities overwhelmingly adopt more solar, adding support for the idea that efforts to rebuild from crisis with renewables can and do succeed. However, social capital—the social ties that enable trust, reciprocity, and collective action in a community—plays an intervening role in disaster adaptation as well. We find that disaster-hit communities with stronger bridging social capital tend to support other forms of recovery rather than solar; only those towns with strong bridging *and* linking social ties tended to adopt more solar farms (For a more expansive discussion of the role of social capital in disaster recovery, see the Literature Review).

This article makes four contributions to the literature. First, it builds on recent explanations for why some governments are more prolific than others in their embrace of solar power (Jenner et al. 2012; Lyon and Yin 2010; Matisoff 2008; Yi and Feiock 2014). While past scholars focused more on international (Fischhendler et al. 2015; Skjærseth et al. 2013) and state-level explanations (Hochstetler and Kostka 2015; Tobin 2017) for solar policy, we build on recent literature that takes seriously the role of local communities in solar policy adoption (Feldhoff 2016; Fraser 2021; Mochizuki and Chang 2017; Ohira 2017; Walker et al. 2007).

Second, we build on literature of single-country studies of disaster reconstruction (Francis et al. 2018; Kage 2011; Mannakkara and Wilkinson 2014; Twigg 2009) by comparing reconstruction across the United States and Japan.

Third, we use matched samples in two countries to clarify two conflicting findings in past literature. Past scholars found that disaster damage was linked to *increased* adoption of solar farms in Japanese communities (Mochizuki and Chang 2017), but later studies found the opposite (Fraser 2019). We find that among similar communities, differing only in their exposure to disaster, they *do* tend to adopt more solar after crisis, consistent with Mochizuki and Chang's findings. These two states are comparable to advanced industrialized democracies, hit around the same time by major disasters, shortly before or after new renewable energy promotion programs. These cases are useful comparisons for scholars and decision makers evaluating how to recover after the onslaught of disasters in 2020.

Fourth, this article integrates the literature on social capital and recovery with literature on solar power. While past literature suggests that crises can actually

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increase communities' capacity for civic engagement (Kage 2011; Lee and Fraser 2019), our findings suggest that communities' capacity for civic engagement does not necessarily lead them to invest in renewable energy technologies. Past scholarship found that communities with stronger social capital, especially bridging and linking social ties, tend to recover stronger and faster from disaster (Aldrich 2019; Aldrich and Meyer 2015). Our research finds that, primarily in Japan, the presence of bridging and linking ties together boost solar adoption. However, we also find that disaster-hit towns with bridging social capital alone do *not necessarily* adopt more solar; towns with strong bonding social capital adopt more solar in both countries, while bridging social capital is frequently associated with less solar in comparison. This may be because communities with stronger bridging social capital may be focusing on other local needs, such as housing and employment after crisis. These interactions match past literature, which argued that communities with stronger civic engagement might resist the siting of controversial facilities after crisis (Aldrich and Crook 2008) or, in this case, solar. Therefore, to help communities rebuild with renewable energy and promote the combined bridging and linking effect shown in Japan, scholars and policy makers should increase opportunities for solar adoption after disaster to yield economic benefits to all community members.

Literature Review

Why do some communities adopt more solar than others? Past studies have coalesced around five major explanations for cities adopting new policies like rooftop solar and solar farms. These include technical resources, socioeconomic motivations, state governance capacity, social capital, and *disasters*, the last of which this article focuses on. We review recent scholarship on these explanations for solar adoption below.

Solar Adoption

Many studies have examined why some states and countries adopt more solar than others, but few have tackled this at the city level, the primary level at which communities recover from crisis. These studies largely explained solar policy as the result of national and state-level factors; some attributed governments' decisions to adopt renewable energy to the quality of regulatory institutions, party affiliations of decision makers, and choice of policy toolkits (Yi and Feiock 2014), while others highlighted political ideology and private interests (Jenner et al. 2012; Lyon and Yin 2010). While policies of other types may diffuse from state to state, Matisoff (2008) found that the internal traits of governments mattered more to solar policy than diffusion, through motivations, resources, and obstacles specific to those governments. While national-level dynamics do not explain variation from city to city, recent studies have reapplied Matisoff's perspective

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to the city level, finding that governments' motivations, resources, and obstacles still matter to solar adoption (Fraser 2019).

Rooftop solar adoption also depends on household factors, including the age and expense of installation and individuals' wealth, education, and environmentalism (Briguglio and Formosa 2017) and the willingness to pay for renewable energy (Sundt and Rehdanz 2015). However, household-level data are rare, especially for cross-country analysis. Furthermore, these individual traits largely correlate with community-level wealth and social capital; for example, affluent communities have more time and money to spend on rooftop solar, encourage environmentalism, and invest in housing quality. As a result, this article examines solar adoption at the municipal level.

At the city level, local bureaucrats, mayors, and city council members all serve as decision makers in solar policy, advancing or stymieing renewable energy development through zoning, property taxes, programs to match open land to companies, and citywide rooftop solar subsidies (Feldhoff 2016; Fraser and Chapman 2018). However, this article does not investigate the policy tools used so much as the internal traits that make some cities more motivated, face more obstacles, or able to draw on more resources to employ such tools than others.

Below, we review the effects of technical resources, socioeconomic motivations, governmental resources, and social resources on solar adoption and adds a new perspective: disasters' intervening role in solar adoption.

Technical Resources

Some communities might host more solar due to sheer technical resources, such as access to renewable resources like sunlight; cheap, available land; and high demand for electricity from a large population (Vajjhala 2006). Decision makers who focus on these technocratic criteria tend to envision policy implementation as a top-down process, where governments can achieve policy goals only if they avoid key obstacles to obtaining those technical resources (Bardach 1977; Pressman and Wildavsky 1973). At the local level, too, street-level bureaucrats might resist or reshape the effects of policy (Lipsky 1980). However, these implementation perspectives do not explain why communities with ample renewable resources, land, or demand still experience varying levels of solar adoption after crisis. Access to technical resources does not ensure renewable energy transition after disaster.

Socioeconomic Motivations

Some cities might adopt more solar because economic crises like high unemployment motivate them to invite new businesses (Fraser 2020). This trend occurs when cities adopt other energy technologies, such as nuclear power plants (Aldrich 2008; Lesbirel 1998). Communities with greater socioeconomic inequality and residents from racial or ethnic minorities tend to focus more on pressing social issues, such as unemployment and housing, and arguably less so on energy and

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environmental issues, making it easier for companies to site polluting facilities nearby without backlash (Kasuga and Takaya 2017; Taylor 2014). However, wealthier neighborhoods with greater education *also* tend to be more interested in climate change issues like renewable energy and have greater funds to afford rooftop solar or a community solar farm (Burke and Stephens 2017; Hess and Winner 2007). These groups might be more likely to adopt specialized smart city policies and ecodistricts to deploy renewables and other climate change adaptations (Affolderbach et al. 2019; Fitzgerald and Lenhart 2016).

State Governance Capacity

Alternatively, communities might adopt more solar due to the financial and institutional capacity of states and city governments. Renewable energy initiatives benefit when governments' policy architecture commits to climate action across economic sectors, including electricity, transportation, air pollution, and natural resources (Rabe 2004). In the United States, state governments have proved more ambitious in implementing climate policies than federal governments, linking greenhouse gas reduction initiatives with economic development opportunities, such as emissions trading or energy efficiency profitability (Rabe 2004). New Jersey, for example, embraced the Kyoto Protocol, despite the United States never ratifying the treaty (Rabe 2004).

State governments' structure can even determine their potential in climate legislation. For example, the protected budget, staffing structure, and past successes of California's Air and Resources Board (CARB) helped California design and implement comprehensive climate policy to meet legislative emissions goals (Carlson 2014). This was possible because California delegated policy design to an autonomous bureaucratic agency, CARB, rather than one controlled by political motives (Meckling and Nahm 2018). Communities with stronger governance capacity are better able to produce these institutional innovations, increasing solar adoptions.

Social Capital

On the other hand, separate from socioeconomic motivations or governance capacity, communities with strong social networks might mobilize to encourage or oppose solar adoption. Social capital refers to social ties that enable reciprocity and collective action (Putnam 1993) and comes in three forms: bonding, bridging, and linking social capital. *Bonding* connects members of the same social and ethnic groups and might lead to not-in-my-backyard movements against unpopular industrial installations (Hager and Haddad 2015; McPherson et al. 2001). In contrast, *bridging social ties* connect residents across social and ethnic groups, fostering civic engagement, volunteerism, and good governance (Haddad 2012; Putnam 1993); bridging social capital helps neighborhoods start local solar cooperatives and public solar initiatives (Fraser 2019). Finally, *linking social ties* connect

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residents to local officials, helping them access public goods, funding, and subsidies for initiatives they care about (Aldrich 2019; Szreter and Woolcock 2004; Tsai 2007). We might expect that communities with strong linking ties will adopt more solar because residents push their elected officials to initiate new programs and collaborations with solar power companies.

Past research on the United States and Japan highlighted that social capital can have divergent effects on environmental policy outcomes. Cities with strong bonding social capital tend to host more wind farms, because these social ties help communities mobilize, share local preferences, and jump-start environmental activism (Fraser 2020; Motosu and Maruyama 2016). Recent research also suggests that strong bonding, but especially bridging, social ties have helped Japanese municipalities tackle other environmental issues, including greenhouse gas emissions (Fraser et al. 2020). On the other hand, Aldrich and Crook's (2008) study of siting controversial Federal Emergency Management Agency trailers after Hurricane Katrina highlighted that neighborhoods with strong bonding social capital tend to oppose hosting controversial facilities, such as renewable power plants, after disaster. These contrasting results exemplify attention to how domestic institutions and communities influence countries' environmental policy approaches (Schreurs 2002), but further research is required to disentangle whether social capital solidly boosts the recovery of communities through renewables or whether social capital has more nuanced effects.

Disasters

Additionally, others argue that disasters can boost or block adoption of solar power and other efforts to build back better. Some studies highlight that any community can build back better to reduce future risks (Mannakkara and Wilkinson 2014), while others highlight that communities' poorest and most vulnerable members tend to fall through the cracks; agency-driven reconstruction projects are less effective at building back better than community-driven projects (Kitzbichler 2011). Several studies specifically analyzed Japanese recovery, which aids our comparison of the United States and Japan (Aldrich 2019; Ohira 2017). A study of 1,741 Japanese municipalities nationwide showed that disaster-struck towns struggled to adopt more solar farms after Japan's 2011 tsunami and earthquake, due to challenges with acquiring insurance and getting permission from landowners to develop the land (Fraser 2019). However, Mochizuki and Chang's (2017) analysis of thirty communities in Japan's Tohoku region showed a different trend: that disasters actually had an exponentially positive effect on the adoption of solar farms. These mixed results raise questions. The nationwide approach may have included outlier communities, while Mochizuki and Chang's medium-*N* analysis may not have included enough cases to control for other intervening factors. Furthermore, it remains unclear how generalizable these results are to other countries and different disasters.

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Disasters and Social Capital

Finally, disaster-struck communities might adopt more solar depending on the strength and type of social ties those communities can mobilize for recovery efforts. In other words, strong social ties and trust among residents may assist them in overcoming disasters and other collective action problems, as seen in New Orleans in 2005 and Tokyo in 1923 (Aldrich 2012a, 2012b).

Conversely, traumatic events also encourage communities to unite and address collective needs; During the Brisbane floods, flooded suburbs saw greater community mobilization than suburbs left untouched (Wickes et al. 2015). However, lacking this community approach, the psychological urgency to address disaster damage and provide immediate shelter and safety often takes precedence over long-term concerns like recovery planning and community resilience (Cox and Perry 2011). Additionally, bridging and bonding social capital have diverging effects on recovery rates. Bridging organizations, such as advocacy groups, help reduce poverty rates postdisaster, while bonding organizations frequently allocate resources to select individuals and render marginalized subgroups worse off (Smiley et al. 2018).

We hypothesize that the Janus-faced nature of social capital (Aldrich et al. 2018), where bridging and linking social capital aid recovery more than bonding social capital, shapes not just general recovery (Aldrich 2012a) but specific efforts to build back better. The alternative to this hypothesis is that social capital uniformly benefits or restricts disaster-struck communities' efforts to build back better. Alternatively, it might convey no effect, and communities instead adopt renewable energy due to the availability of technical resources, socioeconomic motivations, governance capacity, or sheer disaster damage alone.

Methods

We test why some communities in the United States and Japan adopt more solar power plants after disaster than others. To inform future disaster policy, we selected two disasters that affected a wide geographic scale, namely, the 2011 tsunami, earthquake, and nuclear disaster in Japan's Tohoku region and Hurricane Sandy in 2012 in the northeastern United States. These are good cases to compare because each occurred just before or after the introduction of renewable energy subsidies in each country. We use coarsened exact matching to identify a matched sample of comparable towns, statistical modeling to identify the effect of disasters on solar, and case studies of towns demonstrating and diverging from the trends we present.

Outcomes

For the United States, we draw from the National Renewable Energy Labs' Open PV database, which reports the number of solar installations that utilities and contributors voluntarily reported in their jurisdictions per *zip code*. It is the largest publicly

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available data set of solar installations in the United States. These data range from November 2012 to June 2018 and were downloaded in September 2019, shortly before the Trump administration discontinued the program. We focus on New York, New Jersey, Connecticut, and Rhode Island, the four states containing counties where presidential disaster declarations were made for Hurricane Sandy. For Japan, we draw from Japan's Agency of Natural Resources and Energy data set of Feed-in Tariff–certified solar installations per *municipality*. This sample ranges from April 2014 to June 2019.

While ordinarily, comparing the amount of solar before and after the disaster would be ideal, these data are not available, because there was very little solar in any of these communities before the introduction of Japan's Feed-in Tariff or the Renewable Portfolio Standards for towns in the United States. Instead, we examine change over time in solar adoption after disaster to test its effect.

To represent solar adoption, we use the number of solar farms adopted in a municipality, in three categories. First, we examine adoption of small, rooftop solar systems under 10 kilowatts in installed capacity. Next, we examined adoption of large, ground-mounted, utility-scale solar farms for systems 10 kilowatts or greater in installed capacity. We use the *number* of solar farms rather than *kilowatts* of solar because each farm requires effort and compliance with government protocols, meaning that projects could hypothetically be supported or opposed by communities. In Appendix A, we present proxies used in the subsequent matching and modeling parts of this analysis, including units and justifications. In Appendix B, we describe social capital indices used in this study (Kyne and Aldrich 2019; Fraser 2021). [See https://www.mitpressjournals.org/doi/suppl/10.1162/glep_a_00588 for all Appendices.]

Matched Samples

Next, this analysis zooms into communities as similar as possible, except that some were hit by the disaster, while others were not. To do so, we applied coarsened exact matching, using whether a community experienced *any* dollars' worth of property damage per 1,000 residents in the United States or *any* buildings destroyed or damaged per 1,000 residents in Japan as a cutoff for experiencing each disaster. Coarsened exact matching (CEM) is a widely used method for causal inference (Iacus et al. 2011) and has been applied to economics research (Azoulay et al. 2011) and health care studies (Sidney et al. 2015), among others. Compared to propensity score matching (Brandt et al. 2010), CEM estimates causal effects with the least bias among sample sizes (King et al. 2011).

We identified towns that at the starting period had similar levels of population, available land, average land prices, shares of municipal government employees, college-educated residents, unemployment rates, and, in the United States, shares of Black and Hispanic or Latino residents. We could not control for photovoltaic output or average income through design by CEM without reducing the number of matched cases considerably; as a result, we control for these alongside

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all other variables directly in our models. Finally, we allowed the bonding, bridging, and linking social capital of communities in our matched sample to vary, to observe how different levels of social capital shaped the solar adoption patterns of disaster-struck communities. Having identified communities as similar as possible during the starting period, we then gathered all subsequent time steps of data on outcomes to examine how solar adoption changed over time in these socioeconomically and physically similar cities.

This produced 68 monthly time steps of data for 702 matched US zip codes out of all 2,744 zip codes in the four-state study region, where 270 reported disaster damage and 432 reported none, and 43 monthly time steps of data for 147 matched Japanese municipalities out of all 226 municipalities in the Tohoku region, where 68 reported disaster damage and 79 reported none. Each monthly observation estimates the number of solar installations adopted in that jurisdiction.

Modeling

Next, we modeled whether disaster-hit communities adopted more solar than others over time in the United States and Japan, using negative binomial and Poisson models. Using this approach, we modeled the adoption of rooftop solar installations under 10 kilowatts and solar farms over 10 kilowatts of installed capacity, controlling for all variables described in Appendices A and B. Our modeling strategy and goodness of fit tests are described further in Appendix C. We analyzed these outcomes from three temporal perspectives: total solar adopted during the study period, new solar installations annually, and new solar installations monthly. Using this three-pronged temporal approach helped us triangulate the effects of disaster damage and social capital on solar adoption.

First, we tested the effect of disaster damage and overall social capital. Second, we tested the effect of disaster damage and bonding, bridging, and linking social capital. Third, we applied interaction effects to distinguish solar adoption by disaster-hit communities and solar adoption by disaster-hit communities with strong bonding, bridging, or linking social capital. Fourth, because bridging and linking social capital are known to enable better recovery, we tested an added three-way interaction between disaster damage, bridging, and linking social capital. These results for rooftop solar units and solar farms are displayed in Appendix D.

Case Studies

Finally, we triangulate the intervening effects of disasters and social capital on solar adoption using two qualitative case studies, to demonstrate and investigate two different trends found. First, we selected Toms River, a rural community in New Jersey that built back better after Hurricane Sandy using vast quantities of rooftop solar and utility-scale solar farms. Second, we selected Ofunato City in Iwate prefecture, which was heavily damaged by Japan's 2011 tsunami but rebuilt with large amounts of rooftop solar in community-engaged projects. This emblematic

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case of the intervening effect of disasters and solar highlights a second, potentially more productive path to developing renewables after disaster trauma.

Results

Model tables for our total, annual, and monthly analyses (Appendix D) report the marginal effects of each predictor on solar adoption, showing the expected increase in solar installations given a one standard deviation increase in the predictor, holding all other predictors at their means. Since all continuous predictors were rescaled, the size of marginal effects can be compared among all variables (except state effects).

First, in each analysis, we found that communities damaged more by disasters tended to adopt more rooftop solar and more solar farms over time ($p < 0.001$). This effect was especially strong in Japan because Japanese municipalities have more aggressively deployed renewables since 2012 to deal with energy shortages since suspending nuclear. Japanese models saw strong, statistically significant effects throughout, while models for the United States saw somewhat statistically significant effects, due to the smaller number of solar farms in the states. After accounting for the interaction between disaster damage and social capital, the strong, positive effect of disasters on solar adoption increased. We confirmed these results in total, annual, and monthly models of solar adoption. This shows that communities with at least one solar installation *do* tend to build back better with more solar after crisis. Using bivariate difference of means tests, we confirm in Figure 1 that towns suffering any disaster damage adopted many more installations over time than towns that reported no disaster damage.

Second, to further explore *how* disasters shape solar adoption, we broke social capital into three subtypes—bonding, bridging, and linking ties—and then applied interaction effects. Our models in Appendix D revealed that disaster-hit towns with strong social capital see varying patterns in solar adoption depending on geography. In Japan, disaster-hit towns with strong linking social ties see more new solar farms and rooftop solar units annually and monthly; the same effect was observed for bonding social ties. On the other hand, bridging social capital was associated with a decrease in rooftop and solar farm adoption in Japanese disaster-hit towns. However, towns with strong bridging *and* linking social ties see even more new rooftop solar installations. These effects are portrayed in Figure 2, which shows that Japanese disaster-hit towns with greater amounts of each kind of social capital generally adopted more rooftop solar units each month.[1]

Curiously, however, disaster-hit towns in the United States with strong social capital see mixed results. Our monthly analysis showed that disaster-hit towns with strong linking ties tended to see fewer rooftop solar installations ($p < 0.05$) but more solar farms ($p < 0.10$). In contrast, our monthly and annual analyses showed that towns with strong bonding social capital saw greater adoption of

1. Points were jittered by 0.25 units of solar to clarify visualization.

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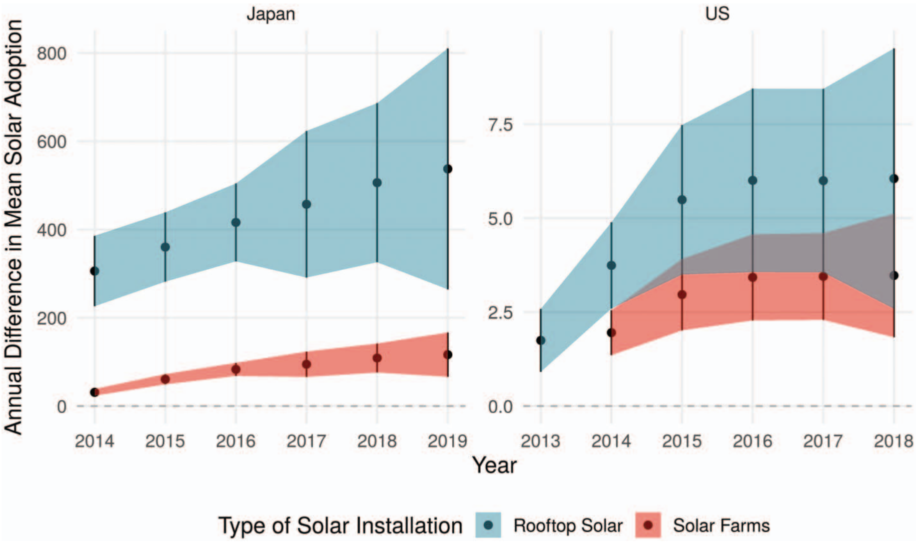

Figure 1
Annual Difference in Mean Solar Adoption

Bands depict the 95% confidence interval for each annual *t*-test. East test assesses the difference between communities with any disaster damage and those with no reported damage. All statistics shown are significant at the $p < 0.05$ level.

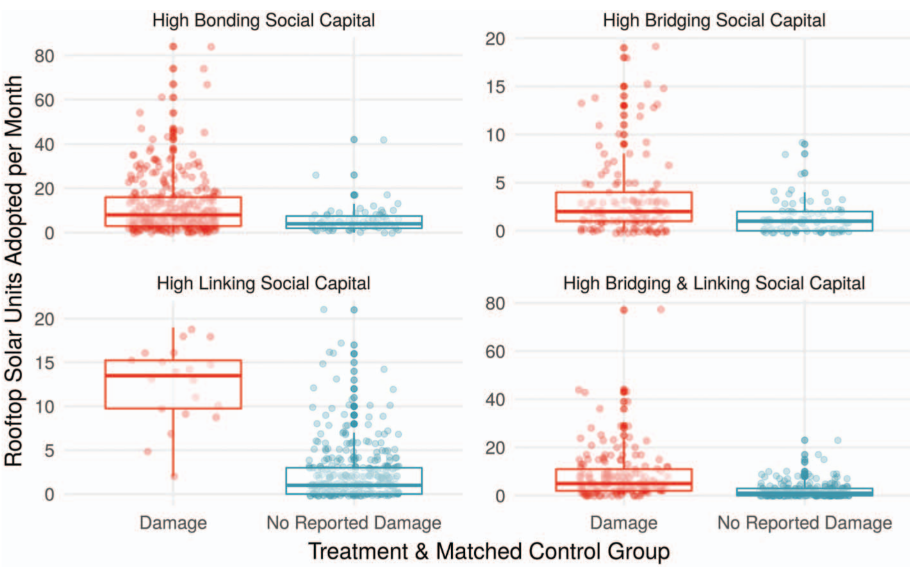

Figure 2
Japanese Disaster-Hit Towns with Strong Social Capital Adopt More Solar

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rooftop solar but fewer new solar farms. The divergent interaction effect of linking capital raises questions as to whether Japan's centralized state channels linking social capital more than the subnational, state-centric system of renewable energy policy in the United States. On the other hand, disaster-hit towns with stronger bonding social capital consistently tend to adopt more rooftop solar; these grassroots ties may help members of neighborhoods or other close-knit community groups start community solar or household solar initiatives.

Qualitative Case Studies

Below we turn to qualitative case studies to investigate the two trends found. First, using the emblematic case of Toms River in New Jersey, we examine how increased disaster damage can lead a community to adopt more renewable energy installations over time. Second, using the outlier case of Ofunato City in Iwate, Japan, we examine how strong social networks can help communities adopt more renewable energy but also emphasize why such outcomes are currently rare.

Figure 3 highlights the cumulative adoption of solar installations for Toms River and Ofunato City, compared with the average solar adoption by disaster-hit communities and communities not hit by disaster. Both cases match the upward trend of solar adoption by disaster-hit communities.

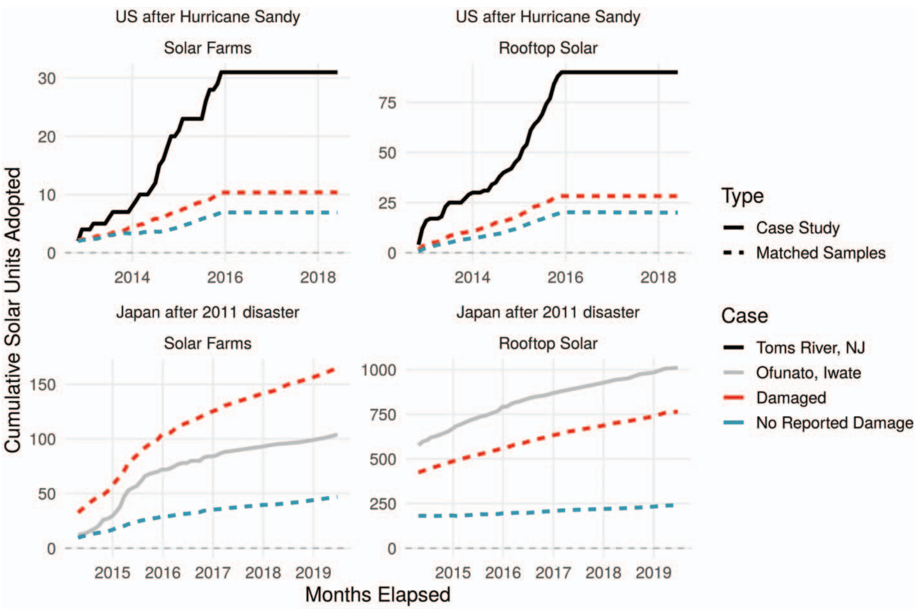

Figure 3
Solar Adoption from Case Studies Compared with Overall Matched Samples

Solid lines depict solar adoption for case studies. Dashed lines for matched samples depict the mean number of solar units adopted for communities damaged and not damaged by disaster.

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Case Study of Toms River, New Jersey (Zip Code 08755)

The case of Toms River, a rural coastal community in Ocean County, New Jersey, highlights how disasters jump-start interest in energy resilience and adoption of renewable energy. Postdisaster assessments ranked Ocean County second in New Jersey in terms of overall hardship from disaster damages (Halpin 2013). Furthermore, Hurricane Sandy was not the county's first disaster. Twenty years earlier, the local Ciba-Geigy plant's industrial dye-making operations were linked to many years of groundwater pollution and childhood cancer cases. After Sandy, 44 percent of residents had no homeowners insurance, residents suffered $12,570,470 in lost wages, and Toms River required $16,880,000 in grant aid from FEMA for recovery operations. Finally, municipalities statewide incurred sizable costs dealing with power outages (Halpin 2013). Though flood damage remains a persistent threat, residents did not relocate inland, and the moral hazard of relocation remains a problem for decision makers (Kaufman 2016).

However, Toms River made significant strides in adaptation to climate change through renewable energy. The 4.5 megawatt solar installations on Toms River School District facilities largely survived Hurricane Sandy undamaged, increasing interest in solar as a resilient energy source. After the state's renewable energy promotion efforts post Sandy, Toms River and similar communities have since become hosts for dozens of solar installations. By 2018, the city became host to thirty-one solar farms and ninety rooftop solar units, including a 35 megawatt farm to be built over top of the Ciba-Geigy plant (Mikle 2019).

In our matched sample of 480 US zip codes, twenty-one communities struck by Hurricane Sandy built at least ten solar farms afterward, and thirty-eight communities adopted at least five solar farms; thirteen communities adopted fifty or more rooftop solar installations. One of the best-known examples of adaptation after Hurricane Sandy occurred in the Rockaways, New York, embankment just south of JFK International Airport outside of New York City. The coastal community suffered significant damage to its electrical system during Hurricane Sandy, but days after Sandy, volunteers from New York City helped residents initiate the Power Rockaways Resilience campaign to install rooftop and large-scale solar in flooded neighborhoods, eventually earning the group recognition from the White House (Emergency Management 2013). The case of Toms River and our statistical analysis show that efforts to adopt solar after crisis were not limited to Power Rockaways Resilience but that communities across New Jersey, Connecticut, and New York adopted similar strategies to build back better.

Case Study of Ofunato City, Iwate Prefecture

The case of Ofunato City in Iwate prefecture demonstrates how bridging and linking social networks help disaster-struck communities rebuild with more solar installations than their peers. The 2011 tsunami and earthquake ravaged the coastal city with a strong fishing industry, destroying nearly 4,000 of its 15,000

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homes and forcing 8,000 residents into temporary housing (Chang 2013). However, our data, starting two years afterward in 2014, reveal that Ofunato had built 576 rooftop solar installations and 12 solar farms by April 2014, and by June 2019, the city had adopted 1,011 rooftop units and 104 solar farms.

In contrast, the city of Ninohe in northern Iwate started out with fourteen solar farms and built sixty-two by 2019, an increase just half that compared to Ofunato, despite similar levels of population (27,600 people to Ofunato's 38,058), income (936,000 vs. 983,000 yen per capita), and overall social capital (0.446 vs. 0.46). Two key differences explain why Ofunato adopted more solar than Ninohe. First, the disaster damaged 95 buildings per 1,000 residents in Ofunato, compared to just 0.40 buildings per capita in Ninohe. Second, though both shared similarly high overall social capital and linking social capital, Ofunato's bonding and bridging social capital scores ranked above the median in our sample, while Ninohe ranked below the median. In our models, communities with more disaster damage, bridging social capital, *and* linking social capital tended to adopt more solar farms and especially more rooftop solar. These horizontal community resources helped Ofunato residents create successful community partnerships with citizen participation. In contrast, Ninohe's weak bridging social capital limited opportunities for civil society participation in energy policy.

How, then, did Ofunato mobilize its social capital to adopt more solar than similar communities? First, Ofunato received disaster aid from numerous sources, and thanks to collaboration between city government, local companies, and resident associations, the city channeled these resources into community projects. In particular, Habitat for Humanity collaborated with resident volunteers to introduce new rooftop solar installations to community centers and to local households with persons with disabilities. The installations save each household up to US$ 600–1,000 annually, because excess electricity produced by these panels is sold to the grid, generating income for centers to allocate toward revitalization efforts (Chang 2013).

However, this collaboration did not appear spontaneously. Ofunato mayor Kimiake Toda's strong linking ties to the Morioka Chamber of Commerce in the prefectural capital and in Tokyo helped introduce the city to All Hands, Habitat for Humanity's disaster support partnership (Littler 2011). Furthermore, city officials, developers, businesses, and residents channeled their bridging social capital and collaborated to build a new public market, dubbed Kyassen Ofatuno, which launched environmentally friendly businesses in the city (Daiwa House Group 2020; Kyassen Ofunato 2020). Ofunato's recovery relied on local participation, intentional design, and contacts, all demonstrating bridging and linking social capital.

However, richly networked communities like Ofunato are hard to find. Towns with strong bonding and bridging social capital might instead invest in new urban planning, housing, and local businesses, like when Onagawa Town chose to redesign the town center rather than invest heavily in renewables (Fraser 2019). While bridging and linking ties boost solar adoption efforts, other combinations of social ties lead communities to concentrate their efforts in other forms of recovery.

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Discussion

We tested how disasters affect the adoption of rooftop and utility-scale solar installations in communities in the United States and Japan. Using CEM, we identified samples of communities as similar as possible, except that the treatment group received damage from a major disaster while the matched control group did not. Then, we used models of total, annual, and monthly solar adoption and diagnostic case studies to test the effect of disasters on solar adoption and examine the intervening effect of social capital on community adoption of solar energy systems.

We found that disasters are related to an increase in cities' adoption of solar energy installations. However, disaster-hit communities with strong social capital see different adoption patterns depending on the type of social capital they access. Communities with strong bridging *and* linking social capital are likely to host more renewable energy installations after disaster in Japan, but in the United States, linking ties are associated with a decrease in solar adoption. The main transferable finding across geographies was that disaster-hit communities with strong bonding social capital tended to adopt more rooftop solar.

These results have major implications for countries recovering from recent climate change–induced disasters. Our research naturally has several key scope conditions. First, we examined major liberal democracies with highly successful postindustrialized economies. Second, we examined variation across two similarly large-scale disasters (Japan's 2011 earthquake and tsunami and the United States' Hurricane Sandy). The consistency of recovery patterns across national contexts and different disasters supports a relationship between disasters and adaptation to climate change through solar power.

Third, our findings are most applicable to disasters that cause major physical *and* economic devastation. This is because, like in Rockaways, New York, loss of electricity catalyzed resident interest in renewable energy, and physical devastation was key to *that* process. Physical devastation, however, might not be necessary; solar adoption was a long-term economic recovery strategy, not an immediate fix for damage to power plants and transmission lines. And while floods did create open land available to host solar, they also created obstacles for Japanese solar developers, since it became difficult to identify landowners or obtain insurance for these properties. A pandemic like COVID-19 would not likely motivate the same level of interest in resilient electricity that these disasters did. Readers should take caution comparing findings from these past disasters with COVID-19. However, we do show that after suffering major disasters, communities have made meaningful strides toward renewable energy transitions, suggesting that investing in solar is a realistic economic recovery target for contemporary disasters.

Finally, our research comes with several limitations. First, we examined aggregate, city-level factors; future studies should investigate household- and individual-level drivers of renewable energy adoption, such as individuals with strong social networks in communities with weak social capital, as data become available. Second, we focused on the internal determinants of solar adoption, but

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future studies should investigate at more granular levels the process by which mayors, bureaucrats, and company representatives decide to site solar installations in disaster-struck communities. Third, we examined towns with complete census data available. Since we generated a matched sample, these towns were largely comparable, but cases with large amounts of missing data, such as Onagawa, Japan, were unavailable for study. Third, the analysis of the United States relied on county-level disaster damage data from the Spatial Hazards Events and Losses Database for the United States (SHELDUS), which was then averaged across zip codes. This is because zip code–level disaster damage data were unavailable across New York, New Jersey, Connecticut, and Rhode Island. Fourth, we relied on data starting in 2014 for Japan, which was necessary because reports on solar adoption prior to 2014 were inundated with poorly designed projects and projects that were never built. To estimate solar adoption, we used Feed-in Tariff–certified project tallies starting in 2014, which included the number of solar farms *successfully* completed. These limitations notwithstanding, our comparative, mixed-methods approach allowed us to find a generalizable booster effect of disasters on solar across the United States and Japan.

Conclusions

We find that communities suffering greater property damage overwhelmingly adopted more solar installations of both types in both countries, resolving a long-standing question of how *feasible* building back better with renewables is after disaster.

Furthermore, we verified how the survival of solar installations in Toms River, New Jersey, and surrounding communities after Hurricane Sandy encouraged the town to adopt more than thirty-one solar farms and nearly a hundred rooftop solar installations over six years. Finally, the case of Ofunato City, Japan, showed us that disaster-hit towns that leverage robust bridging and linking social networks can adopt new, community-engaged renewable energy projects, but communities with stronger social networks in just one or two areas tend to adopt fewer solar installations.

Future research should compare these findings with additional large-scale disasters and with additional developed countries. In particular, research is urgently needed to investigate how the onset of 2020 megadisasters like Hurricane Laura, the California wildfires, and COVID-19 has affected the solar market in the United States. To leverage social capital going forward, scholars and policy makers involved in renewable energy policy after disasters should increase opportunities for more bottom-up participation in solar power initiatives and closer ties between community members and decision makers, rather than solely corporate-led projects. By encouraging the design and implementation of community-engaged solar initiatives like in Ofunato, Japan, disaster-hit communities can rebuild their energy systems and energize local economies simultaneously.

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