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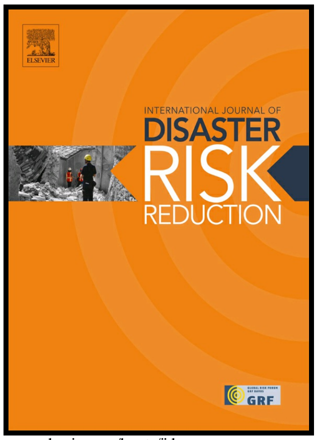

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Disasters as Opportunity for Change: Tsunami Recovery and Energy Transition in Japan

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Abstract

Disasters may offer a window of opportunity, in which extraordinary circumstances create momentum for positive social change. While this potential is popularized through the concept of "building back better," few studies have examined quantitatively the processes and drivers of broader social change in a post-disaster context. Using renewable energy transition (specifically, solar photovoltaic diffusion) as one measure of building back better, this study explores how pre-and post- disaster contexts, capacities, and policies affected recovery outcomes of 30 coastal communities nearly 5 years following the Great East Japan earthquake, tsunami, and nuclear disaster (Tohoku disaster). Our study shows that the disaster-affected communities adopted significantly more solar power than the rest of Japan following the introduction of the country's Feed-in-Tariff (FIT) system in 2012. The communities examined are highly diverse in their solar energy adoption as of 2015, and regression analysis was conducted to explain differences in overall solar energy diffusion as well as in adoption of very large scale mega-solar projects. The dynamic relationship between physical damage and subsequent solar adoption was found to be nonlinear, as was the relationship between degree of household relocation and solar energy adoption. Differences in communities' mega-solar adoption were also explained by the variability in hazard zone designation and extent of physical damage. These findings suggest that a disaster may serve as an opportunity for positive community change when immediate impact (or the level of change involved in a reconstruction process) is high enough but not overwhelming. Overall, this study finds potentially complex relationships.

Keywords

Disaster Recovery, Building Back Better, Change, Energy Transition, Tsunami, Japan

1. Introduction

Disasters have long been posited as "windows of opportunity" for change and societal improvement, particularly to reduce risk. "Building back better," a term popularized after the catastrophic 2004 Indian Ocean tsunami, emphasizes the importance of capitalizing on opportunities for building resilience in disaster reconstruction. A number of frameworks and practical guidelines for "building back better" have since been developed [1]. The Sendai Framework for Disaster Risk Reduction [2], among others, emphasizes the importance of preparing before a disaster to integrate risk reduction into reconstruction, recovery and the broader sustainability agenda.

Disasters enable change for many reasons. For a short period of time, a disaster event will bring natural hazard risks to the fore of media, popular, and policy attention. Governments are pressured to take action to ensure future safety. Damaged buildings and physical infrastructure must be restored, and can be repaired or replaced in ways that reduce vulnerability to future hazard events. More generally, disasters upset the *status quo* and create opportunities for new ideas and change. Yet forces for change will also compete against pressures to restore disrupted systems as quickly as possible to familiar, pre-disaster conditions. Furthermore, pressures to rapidly rebuild communities can lead to hastily designed policies for risk reduction that inadvertently serve to aggravate vulnerability. An example is the case of Sri Lanka's short-lived coastal buffer zone policy following the 2004 Indian Ocean tsunami [3].

Research is needed to develop a theoretically informed, empirically sound, and contextualized understanding of societal change in disaster recovery. Knowledge is as yet sparse regarding the frequency and extent to which change actually occurs following disasters, the factors that facilitate or impede change, the processes by which change occurs, and the benefits and unintended consequences of deliberate change.

This paper investigates change during recovery from the 2011 Great East Japan earthquake, tsunami, and nuclear disaster (Tohoku disaster). Recent studies indicate that this catastrophe, while not altering governance systems [4, 5], has triggered substantial change in areas such as coastal land-use and the energy sector. Focusing on the latter, this paper inquires into the growth in renewable energy sources, particularly solar photovoltaic (PV) technology, as a measure of "building back better" in the disaster region. In this disaster, the Fukushima nuclear power plant accident greatly accelerated Japan's energy transition toward renewable energy sources. Renewable energy was promoted in recovery strategies by all levels of government (e.g., [6]). Through a cross-sectional, quantitative analysis of 30 tsunami-affected towns and cities, this study examines the degree to which localities were able to capitalize on the opportunity for energy transition, as well as factors influencing this change.

As a case study, renewable energy is particularly interesting because it represents an example of how communities can pursue other societal objectives (e.g., increasing energy security, reducing energy costs, reducing greenhouse gas emissions) synergistically with disaster recovery and risk reduction. For example, the tsunami-impacted town of Higashimatsushima (pop. 40,000), incorporated bold energy changes into its reconstruction plan, including turning a flooded park into a 2MW solar PV project and building smaller PV projects for emergency power at designated evacuation areas. The town's longer-term plans, pending feasibility studies, envision building Japan's first microgrid community, in which a city-owned electricity system could autonomously provide power if disconnected from the grid in a future disaster [7].

This paper is organized as follows. Following a review of the literature on change in disaster recovery (Section 2), background for the case study is provided in terms of the disaster event itself and the context of energy transition at the national and prefectural levels (Section 3). Data for the community-level analysis are described in Section 4 and results presented in Section 5. Conclusions (Section 6) summarize findings, implications, limitations, and further research needs.

2. Change in disaster recovery

Recovery is a rapidly emergingarea of disaster research. Early theories of recovery – particularly the influential work of Haas et al. [8] – focused on physical reconstruction and conceptualized recovery as a linear, phased sequence of post-disaster activities and outcomes. Subsequent critiques have emphasized social recovery and the differentiated, iterative, and nonlinear processes and experiences involved, as well as the influence of the broader societal context (see [9]). While progress has been made, because recovery research is dominated by individual case studies, a unifying theory of recovery remains elusive.

Comparative analysis using multiple cases is needed to test causal relationships and develop generalized insights to support recovery theory [9~11]. In one recent example, Aldrich [12] utilized data on over 30 tsunami-affected cities in Japan to conduct a quantitative analysis to explain variations in an index of functional recovery. In this index, developed by the National Institute for Research Advancement (NIRA), full recovery is indicated by all convenience stores reopening, no persons remaining in evacuation shelters, full utility restoration, complete debris clearance, etc. The cross-sectional analysis in [12] found that recovery was faster in communities with stronger political ties to the central government – an important factor in facilitating flows of disaster aid.

The issue of change during recovery remains an important gap in the literature. Research has increasingly recognized that while recovery may in some cases entail a return to pre-disaster conditions, in other cases, systems stabilize at a different, new equilibrium: "Recovery may thus be viewed as an adaptive process that negotiates the tensions between re-establishment of pre-disaster systems and significant alteration of those systems." [9: 127]. Change following disturbances is an integral part of resilience theory in the context of social-ecological systems, yet very few studies have examined change in disaster recovery, and methods for investigating change remain poorly developed [13]. Research is needed on what kinds of interventions are more effective under various circumstances to enable disaster-affected communities to achieve positive recovery trajectories [14].

In broad terms, three types of factors have been identified in the literature as influencing change during recovery: factors related respectively to actions, capacity, and context. Actions at the community scale include pre-disaster planning, which is especially important since speed and quality of decision-making are often in conflict during reconstruction and recovery [11, 15]. Recovery processes that favor speed over deliberation can be expected to facilitate restoration of pre-disaster systems rather than change. Communities that establish recovery committees and other participatory, information-sharing forums have a greater tendency to try to change negative pre-disaster conditions [16].

Local capacity is also critical for implementing change during recovery. Local government capacity, local leadership, and the availability of recovery funding are all important [17, 18]. Public participation in post-disaster decision-making processes has also been found to promote change during recovery [17~19]. Strong advocacy coalitions can be influential in effecting policy change [20].

The scale of the disaster itself may be one of the most important factors influencing change. Catastrophic events have been clearly linked to changes in risk-related policies [20, 21] and in urban economic and spatial structures [18, 22, 23]. Small shocks that can be managed by existing structures and systems may not provide sufficient impetus for change. On the other hand, it can be argued that conditions in catastrophic events may overwhelm local capacity to such a degree as to impede deliberate efforts for improvement.

Finally, studies have shown the importance of the broader societal context for post-disaster recovery outcomes. Disasters have been found to accelerate prior trends, for example of growth or decline, because the underlying system dynamics (e.g., economic competition) remain in force after the disaster [8, 10, 14]. It can thus be hypothesized that communities with growing populations, younger demographics, and more innovative economic, social, and political environments may be more likely to implement post-disaster improvements. Entrenched interest groups can impede change (see [11]). The structure of nationally defined disaster assistance policies is also important; flexible policies that support local decision-making can facilitate change, while top-down, prescriptive policies reinforce the *status quo ante* [18].

The literature thus suggests through qualitative and case study analysis some of the factors that may be important in understanding changes during recovery. This paper quantitatively tests the influence of these factors through an analysis of local-level change in renewable energy uptake following the Tohoku disaster in Japan. Before doing so, however, it is important to set out the context in which these changes have occurred.

3. Context

3.1 The Tohoku disaster and national energy policy

The 2011 Great East Japan earthquake, tsunami, and nuclear disaster was a catastrophe with long-term local as well as national impacts. According to the National Reconstruction Agency (www.reconstruction.go.jp), the disaster led to over 15,000 deaths (with another 2,500 missing) and caused 470,000 people to evacuate from their homes. Over 1.1 million buildings were damaged. Direct economic losses have been estimated at 16.9 trillion yen (US$ 199 billion), making it the world's costliest natural disaster on record. Five years after the disaster, 174,000 persons remain displaced. Housing reconstruction continues, including relocation of residents to upland areas. The reconstruction budget over a 9-year reconstruction period is estimated at 32 trillion yen (US$263 billion).

The Fukushima nuclear power plant disaster instigated a dramatic transformation in Japan's energy sector. On the demand side, conservation measures by both industry and households achieved substantial energy savings and averted short-term crises; moreover, some of these behavioral changes have persisted for years, well beyond the immediate crisis [24~26].

On the supply side, under substantial public pressure, all of the nation's 54 nuclear power plants were shut down, with only 2 restarted as of 5 years after the disaster. Prior to the disaster, Japan's energy policy had been heavily based in nuclear power, a direction driven by energy security concerns from the oil shocks of the 1970s. Indeed, prior to the Fukushima nuclear disaster, the national energy strategy had been targeting an increase in the share of nuclear power from 30 to 50% by 2030, and there was no effective regulatory framework for investment in renewable energy sources [27]. With the shutdown of nuclear capacity, Japan became even more dependent on importing fuel (oil, liquefied natural gas (LNG), and coal), which had negative consequences for both the economy [28] and carbon emissions [29]. In contrast to the pre-disaster energy policy that strongly emphasized nuclear power and energy efficiency [30], the government's post-Fukushima policy incorporated a rapid growth in renewable energy sources, with a target of 20% renewables share by the 2020s [28].

The primary policy instrument used was a feed-in-tariff (FIT) that, under discussion prior to the disaster, was launched in July 2012. FITs, the most commonly used renewable energy policy tool worldwide, provide a guaranteed (usually premium) price and grid access over a long-term period for electricity that is generated from renewable sources. Japan's energy policy continued to change in the years after the disaster, with FIT rates for solar power being lowered and some nuclear capacity being reintroduced into national energy plans [28].

Renewable energy capacity has expanded rapidly as a result of the policy change. Since the introduction of the FIT in 2012, installed PV capacity has been growing at over 40% per year [28, 31]. The vast majority of the renewable energy capacity in Japan is solar photovoltaic (PV), comprising distributed PV systems that are connected to the grid. Wind energy lags considerably, due to land constraints and grid investment requirements [28] as well as resistance from vested interests in the energy sector [27, 30]. As a share of electricity production in Japan, renewables grew from 3.0% in 2010 to 5.6% in 2013 [28].

Key challenges to the growth of renewable energy in Japan include transmission and grid limitations, cost, land constraints, permitting requirements, and heightened uncertainty due to restructuring in the energy sector [28]. The latter is unique to Japan, where the Fukushima disaster revealed weaknesses in the system (e.g., the technical inability of major utilities to share electricity between regions) and prompted an acceleration of structural reforms. Thus, the large-scale introduction of renewables is happening concurrently with deregulation of the energy market and dismantling of the vertically integrated, regional utilities that had largely monopolized power supply prior to the disaster.

Furthermore, the pace of change itself posed challenges, as the capacity of approved PV projects soon exceeded the hosting capacity of some electric power utilities. In late 2014, several electric utilities suspended accepting further grid connection applications. In the case of Tohoku Electric Power Company, approved capacity of the FIT program at the end of 2014 (10.76 GW) was nearly twice its hosting capacity (5.52 GW) and approached peak summer demand (13.6 GW) [31]. Thus, there is currently a lag between approved projects and installed capacity for renewables (70.1GW and 15.4GW, nationally), and not all approved projects may eventually be installed [31].

3.2 Energy transition at the prefectural level

While published policy analyses of the Japanese energy transition have focused on the national level, insights regarding the transition process are also critical at the regional and local levels. Energy transition is fundamentally a geographical process in many ways, involving not only issues of location and landscape but also territoriality, spatial differentiation, scalability, and historic path dependency [32]. The three prefectures most heavily affected by the tsunami (Iwate, Miyagi, and Fukushima prefectures) have shown contrasting views towards renewable energy transition in their reconstruction plans: while Miyagi emphasized the need for “radical reconstruction” and “innovative community development” through deregulation and private sector involvement in areas such as eco-town demonstration [1:33], energy independence from nuclear power was heralded as one of the primary goals of Fukushima’s reconstruction [34]. Iwate’s renewables emphasis was perhaps the least visible, with residents’ safety, rebuilding of livelihoods, and local industry promotion being seen as the primary foci of disaster reconstruction [35]. At the regional level, differences can be seen between the three prefectures and the rest of the country.

The tsunami affected regions experienced unprecedented growth in renewable energy penetration in the post-disaster years, particularly for solar photovoltaic technology. Growth rates matched and in some categories greatly exceeded the national pace of change. Figure 1 shows the growth in renewable energy approvals on a per capita basis since the introduction of the national FIT system in July 2012, by prefecture and energy type. For small-scale solar projects (below 10kW), these figures represent a 30-fold (i.e., roughly 3000%) increase in Iwate, Miyagi, and the rest of Japan over 3.5 years, and a 25-fold in Fukushima. Approvals for medium-sized solar projects (between 10kW and 1,000kW capacity) have increased even more dramatically, by more than 330-fold in Iwate, 760-fold in Miyagi, and 5300-fold in Fukushima.

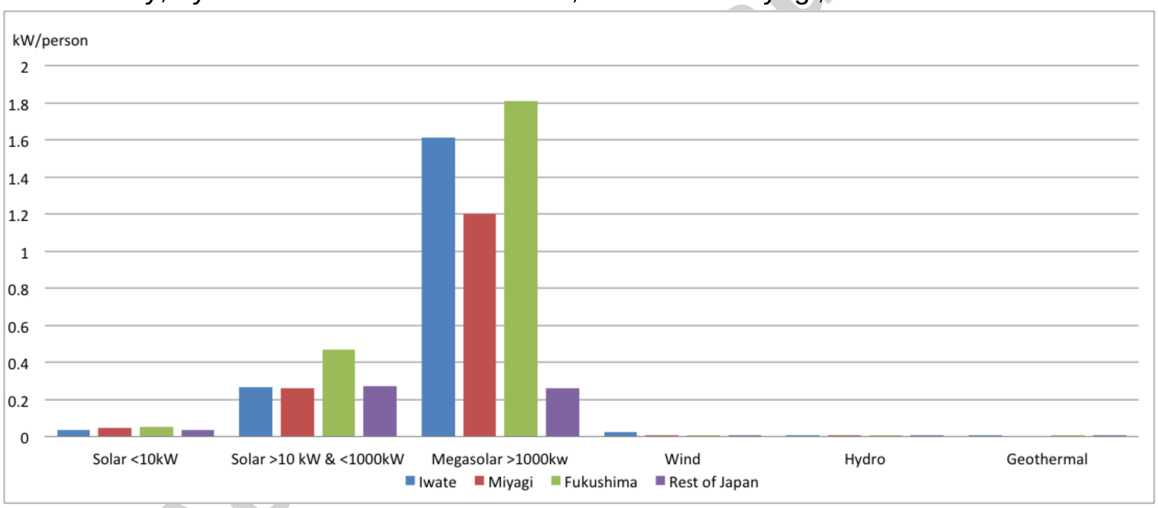

Figure 1. Increases in per capita renewable energy approvals, July 2012 to December 2015 (source: author calculations based on FIT website and Statistics Bureau, various years).

The contrast between the disaster region and the rest of the country is especially striking for mega-solar systems (>1000kW). While 0.26 kW of mega-solar capacity per person had been approved in the rest of Japan from the beginning of the FIT program through December 2015, approximately 1.5 kW per capita has been approved in the tsunami-affected prefectures (Figure 1). By way of comparison, 4.5 kW per household of solar installation would be nearly sufficient to meet the average annual household electricity consumption of approximately 5,200 kWh in Japan [1]. The figures thus indicate an unprecedented rate of solar PV diffusion in the disaster-affected region. Furthermore, the average scale of approved mega-solar facilities was significantly larger in the tsunami-affected areas than in the rest of Japan (Appendix Table A1).

Actual installation of renewable energy capacity – particularly mega-solar projects – has lagged behind approval capacity. As noted previously, factors include difficulties in securing grid connections, along with a wait-and-see attitude on the part of investors. For mega-solar projects, actual installation has stalled at approximately 7% and 22% of approved capacity in the tsunami affected areas and the rest of Japan, respectively. This contrast sharply with the installation rate of above 80% achieved for small-scale solar (below 10kW capacity) throughout Japan. Furthermore, the uptake of other renewable energy sources including wind, hydro and geothermal remains minimal in both areas. Per capita approval of wind power was on average a mere 0.01 kW and 0.009 kW in the tsunami affected prefectures and rest of Japan, respectively. For hydro power, the figures are 0.01kW and 0.002kW, and for geothermal, 0.001kW and 0.0003 kW (see Appendix Table A1).

Energy transition occurring at the regional level, therefore, is yet to achieve the scale of all-embracing renewable energy transformation. Unlike solar power, which enjoyed decades of government largesse prior to the disaster, opposition to wind power continues among Japan's electric power utilities. Geothermal resources, despite their abundance, also remain under-utilized due to the environmental sensitivity of surrounding areas (the majority of which are in national parks). In general, longer and more complex permitting processes along with perceived risk of hitherto unused technologies discourage non-solar renewable uptake throughout Japan [37]. As a window of opportunity gradually closes, supporting infrastructure and regulatory reforms have not kept pace with the post-disaster rhetoric of a renewable energy big bang. Responding to these challenges, the Japanese cabinet has recently approved several revisions of its FIT policy including more stringent approval processes based on detailed project feasibility and auctioning of solar power to encourage the diffusion of non-solar renewable technologies [38].

Nonetheless, since large-scale renewable energy investment projects require significant mobilization of capital, land, and other resources, it is striking that the disaster-affected regions chose to initiate these changes and were able to do so amid complex reconstruction processes. This uptake was likely facilitated by numerous national and regional policies, including direct subsidy, land use deregulation, and expedited permitting processes that were allowed under targeted schemes such as special zones for reconstruction. At the same time, local communities' willingness to embrace change must have played an important role in such processes. The local dynamics will be explored further in this paper through quantitative analysis.

4. Methodological Approach

Energy transition is experienced and enabled locally in different ways. The analysis presented below investigates why some communities achieved greater renewable energy adoption than others. In the case of Tohoku recovery, because the local communities all faced a disaster-driven opportunity for change and were all operating in the context of Japan's national energy transition, differences between various localities' experiences are of particular interest for clarifying the processes and challenges of "building back better."

Local-level analysis in this study focused on 30 coastal municipalities in Iwate, Miyagi, and Fukushima prefectures that were affected by the 2011 tsunami (Figure 2). Municipalities located in the nuclear evacuation zone in Fukushima were excluded due to the special circumstances affecting their recovery. Thus, the dataset includes only three coastal communities in Fukushima prefecture: Shinchi, Soma, and Iwaki. Statistical data were gathered from government sources and published research papers for the 30 municipalities for various periods between 2005 and 2015 (Appendix Table A2). Descriptive statistics for variables in the dataset are shown in Table 2.

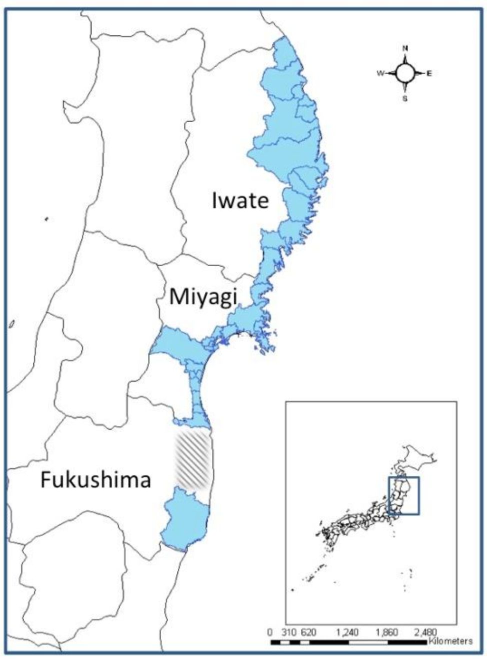

Figure 2. Study region. (Blue = localities included in analysis; hash pattern = Fukushima nuclear evacuation area)

Statistical modeling was conducted to explain variation across the municipalities in renewable energy uptake following the disaster. The study focused on solar photovoltaic systems since this has been the predominant source of renewable energy adopted in this region. As noted previously, solar energy projects are very diverse: while some 99% consist of small-scale (<10kW) units, there has also been rapid growth in mega-solar projects in the disaster region. Separate analyses were therefore conducted to explore these phenomenon.

First, diffusion of solar energy was modeled using ordinary least squares (OLS) regression, with the dependent variable being the number of approved solar energy projects per capita in each municipality. Municipal-level data were only available for the post-disaster period, so it was assumed that the localities had no PV installation prior to 2011; while not entirely accurate, this is unlikely to affect the results of the analysis since data available at the prefectural level indicate that pre-disaster PV installation was minimal. As noted previously, there is a considerable lag between solar energy approvals and installations. The analysis therefore focuses on the number of approved projects as a more meaningful indicator of intention to engage in post-disaster change.

Second, mega-solar investment strategy was modeled using binary logistic regression, with the dependent variable being whether or not each municipality had approved very large-scale mega-solar project(s). Although an official definition of mega-solar installation refers to projects with a capacity of above 1,000 kW, this study uses 2,000 kW as the cutoff since all but three municipalities have adopted some form of mega-solar systems above 1,000 kW. Note that the two dependent variables are not statistically correlated, that is, in terms of broad-based solar diffusion, communities with mega-solar projects were not notably different from those without them. Diffusion and intensive investment thus appear to be distinct processes of change.

Table 2. Descriptive Statistics of Municipal-Level Data

	Mean	SD	Min	Max
Dependent Variables				
Number of approved solar projects per capita	.020	.0096	.0072	.047
Mega-solar above 2,000kW (0 or 1)	.53	n.a.	0	1
Independent Variables				
Context				
Population change between 2005-2010 (%)	-4.30	4.10	-9.38	6.51
Nuclear subsidy (0 or 1)	.1	n.a.	0	1
Change in fiscal capacity* between 2008-2010 (%)	-4.21	4.88	-18.0	6.90
Capacity				
Fiscal capacity*	.493	.265	.13	1.28
Adaptive capacity (waste recycling rate as a proxy)	17.8	6.02	9.60	36.5
Social capital (suicide rate per 100,000 residents as a proxy)	28.8	23.7	0	126
Physical damage (% of houses destroyed])	37.3	38.2	.037	120**
Action				
Relocation (% of households)	4.22	4.63	0	13.9
Recovery period (years)	8.03	2.09	5	10

Prior renewable energy plan (0 or 1)	.467	n.a.	0	1
Designated tsunami risk area (sq km)	4.38	5.67	0	19.5

Note: * Fiscal capacity index takes a value of 0-100, calculated as a 3-year average ratio of reference fiscal revenue over demand; ** calculated as the total number of houses destroyed divided by the pre-disaster number of households reported. Due to different data sources used for these quantities, some communities have calculated physical damage of above 100%.

In both sets of analyses, a similar set of explanatory variables was utilized. The severity of the disaster as experienced locally is perhaps the factor of greatest interest. All else equal, a more severe shock (as measured by physical damage) is expected to create a greater impetus and opportunity for change in recovery. The percentage of population being relocated to higher ground similarly indicates the severity of the disaster and extent of post-disaster change, but more directly reflects the reconstruction burden on local governments. In order to capture expected nonlinear effects of these factors, the squared terms are also included in the regression models.

As suggested by the literature reviewed in Section 2 above, other independent variables are also included that capture pre- and post-disaster actions, capacities, and context. The existence of a pre-disaster plan, in this case for renewable energy, is also expected to have a positive influence on post-disaster change. The recovery period indicated in municipalities' reconstruction and recovery plans provides a measure of orientation toward speed versus deliberation in recovery. Greater local capacity is expected to enhance post-disaster renewable energy adoption; capacity variables include the local government's pre-disaster fiscal capacity, community adaptive capacity (measured using rate of waste recycling as a proxy), and community social capital (measured negatively, using rate of suicidal deaths as a proxy). Contextual variables include the pre-disaster rates of change for population and for fiscal capacity; both are expected to have a positive influence on the dependent variables. Prior to the disaster, some localities had accepted subsidies as compensation for nuclear power plant locations and can be expected to have less interest in (i.e., a negative influence on) shifting toward renewable energy sources. In addition to variables shown in Table 2, two prefectural dummy variables are included to capture other policy and contextual variables operating at that scale. Finally, one variable was included only in the logistic regression: designated tsunami risk area was used as a measure of land availability, which was hypothesized to affect the uptake of mega solar projects (which require large tracts of vacant land), but not the overall diffusion of solar PV (which consists overwhelmingly of small-scale projects).

As shown in Table 2, the 30 municipalities are remarkably diverse. Many communities have shared common challenges of aging population, declining economy and fiscal positions prior to the 2011 disaster, but have suffered different extent of physical damage. Communities have also shown divergent views over speed versus deliberation of their reconstruction processes and over the extent to which they perceived the promotion of renewable energy to be an integral part of 'building back better.' Of 30 communities examined in our study, 16 have adopted mega-solar above 2,000kW. The number of solar projects approved per capita ranges from 0.0072 to 0.047 with the mean of 0.02. In general, the functional recovery of community infrastructure proceeded in parallel with the progress of energy transition. These two processes are not entirely identical, however: the degree of change measured in terms of per capita approval of solar units shows low correlation (*r*=0.41) with basic infrastructure and functional recovery as measured with the NIRA Index (using the latest compiled data as of December 2012) [39].

5. Results

Table 3 shows the estimated coefficients for OLS regression models explaining the broad-based diffusion of solar PV technology, measured in terms of the per capita number of approved units. Models I and II represent the full models and differ only in the variable used to measure scale of disaster (in Model I, population relocating to higher ground; in Model II, physical damage). As expected, higher physical damage and more households relocating were positively related to greater solar adoption; however, the effect was offset at extreme levels of damage, when communities faced competing resource demands for larger and more complex relocation projects. These findings combined speak to the potential for the disasters – up to a point – to break communities' 'business-as-usual' modes of operation, providing an impetus for positive social change.

Results in Table 3 also indicate that other factors in the communities' contexts, capacities, and actions also seem to matter. Communities with higher population growth prior to the disaster were better able to facilitate greater energy transition. The two prefectural dummy variables were statistically significant, indicating that prefectural-level policy and environment also seem to play a role. Counter-intuitively, communities with less fiscal capacity and with no prior renewable energy plans actually experienced wider adoption of solar technology. Negative and statistically significant relationships found regarding fiscal capacity and prior renewable energy plan may indicate that the broad-scale diffusion of solar power experienced thus far is not a top-down and planning-oriented diffusion, but is instead a self-organized or market-oriented diffusion triggered by the national policy change of FIT introduction.

Other variables were not statistically significant in the models. Policy variables such as prior existence of nuclear power plants (i.e., acceptance of nuclear subsidies) and community capacity variables such as prevalent adaptive capacity, measured in terms of waste recycling rate as a proxy, and (the lack of) social capital, measured in terms of the rate of suicidal deaths, were also insignificant. Broad-based solar diffusion took place regardless of whether communities chose faster versus slower reconstruction processes. Re-estimating the models without these insignificant variables (reported as reduced models in Table 3) does not change the major findings, and improves the models slightly.

Overall, the models have very high explanatory power, explaining more than 80% of the variation in per capita solar approvals. Regression diagnostics indicate the models do not suffer from significant multicollinearity, heteroskedasticity, or spatial autocorrelation.

Table 3 Estimated OLS regression coefficients (unstandardized)

	Model I	Model II	Model I-Reduced	Model II-Reduced
	DV: # of approved unit	DV: # of approved unit	DV: # of approved unit	DV: # of approved unit

Context				
Population change	.00069 **	.00086 **	.00044	.00072**
Nuclear subsidy	.00027	.00061		
Change in fiscal capacity	-.00034	-.00015		
Capacity				
Fiscal capacity	-.0206***	-.023**	-.018***	-.019 ***
Adaptive capacity	.00015	.000078		
Social Capital	-.000026	-.000059		
Physical Damage		.00025**		.00021***
Physical Damage^2		-0.00000014*		-0.00000011***
Action				
Relocation	.0020**		.0018 **	
Relocation ^2	-.00012*		-.000092	
Recovery period	-.00046	-.00084		
Prior renewable energy plan	-.0058***	-.0058***	-.0068 ***	-.0061***
Prefecture dummy (Miyagi)	.0057 **	.0058 **	.0057**	.0061**
Prefecture dummy (Fukushima)	.025***	.027***	.025***	.028***
constant	.027 ***	.033***	.025***	.025***
Adjusted R^2	0.80	0.809	0.809	0.82
F	10.9***	11.2***	18.5***	20.3***
Mean VIF	5.17	5.23	6.12	5.16
White's test statistic	30	30	26.5	27.0
Moran's I	-0.00013	0.0157	0.1087	0.0679

Sample size	30	30	30	30

Note: Significance levels: *10%, **5%, and ***1%.

Table 4 summarizes results from the logistic regressions, which model the likelihood of communities engaging in very large mega-solar projects. As before, Models III and IV represent the full models and differ only in the variable used to measure scale of disaster. In contrast to diffusion of small-scale solar projects, adoption of these large-scale, complex investments may require mobilizing substantially more human and financial resources and addressing issues of public acceptance. They may thus create competing demand for resources and time in already capacity-constrained reconstruction processes. This expectation is corroborated by results in Table 4, which indicate that while a wider designation of disaster risk areas opened up further opportunities (i.e., land) for mega-solar systems, communities undergoing larger household relocation projects (or experiencing greater damage) were nevertheless unlikely to opt for such options. In contrast to the OLS regressions, the scale of the disaster has a negative influence on change, and no other variables are statistically significant. The models overall are statistically significant at the 5% level or better, and re-estimating the logistic models without the insignificant variables does not materially change the findings.

Table 4. Estimated logistic regression coefficients (log-odds ratios)

	Model III	Model IV	Model III-reduced	Model IV-reduced
	DV: 1= mega solar, 0=no mega solar	DV: 1= mega solar, 0=no mega solar	DV: 1= mega solar, 0=no mega solar	DV: 1= mega solar, 0=no mega solar
Context				
Population change	.203	.015		
Nuclear subsidy	3.33	7.03		
Change in fiscal capacity	.026	.030		
Capacity				
Fiscal capacity	-3.81	-5.80		
Adaptive capacity	-.044	.052		
Social Capital	-.113	-.286		
Physical		-.162*		-.0757 **

Damage				
Action				
Relocation	-.479**		-.314**	
Recovery period	-.567	-.830		
Prior renewable energy plan	1.26	1.56		
Designated tsunami risk area	.236 *	.715*	.158*	.313 **
constant	11.6 *	17.8	.660	1.25*
Pseudo R^2	0.46	0.58	0.22	0.37
LR chi2	19.2**	24.1***	9.09**	15.5***
Moran's I	-0.0492	-0.0292	-0.0182	-0.0758
Sample size	30	30	30	30

Note: Significance levels: *10%, **5%, and ***1%.

6. Conclusions

While the notion of “building back better” has become commonplace in the lexicon of reconstruction efforts globally, disaster recovery is still rarely measured beyond the speed and extent of return to pre-disaster conditions, and few studies have quantitatively examined the processes and drivers of broader social change in the context of post-disaster recovery. To shed light on this topic, this study used the status of energy transition as one example of such social change and examined its primary drivers in cross-sectional analysis of 30 communities recovering from tsunami in the Tohoku region of Japan. The study contributes both methodological and empirical insights on the “window of opportunity” for community betterment during disaster recovery. Several observations can be made.

First, measuring change in terms of “building back better” is complex. Traditional measures of recovery, including efforts to monitor recovery progress over time [39,40], typically consider statistical indicators that refer to pre-disaster levels. Examples include percent of utility service restored, population as a percent of pre-disaster levels, and percent of damaged housing that is rebuilt. Measuring change is more complex, as it requires differentiation between types of change for which appropriate measures may differ. In this study, broad-based diffusion of small-scale solar PV was better captured by per capita counts of solar projects, while more intensive, singular mega-solar projects were more appropriately considered with a binary measure.

Second, results from this study provide evidence that while disasters do create opportunities for change, the degree to which communities capitalize on the opportunity depends on many factors. The scale of the disaster is important, exerting a nonlinear influence on solar energy diffusion (i.e., facilitating change, but only up to a point) but a negative influence on (i.e., impeding) intensive mega-solar investments. Aside from scale of disaster, factors explaining diffused change differed from those explaining intensive investment. One possible explanation may be that the processes are very different, with diffusion drawing on the decentralized initiative of many actors and intensive change particularly requiring the attention and resources of local government. In general, community preferences toward mega-solar projects are harder to identify with the variables explored in this study, and factors such as external influence may play a larger role.

A particularly interesting issue is the degree to which efforts towards risk reduction in recovery may constrain improvements towards other societal objectives, in this case, transition towards more renewable energy. Given that the designation of disaster risk areas is closely linked to nationally determined tsunami safety guidelines (which also served as a prerequisite for publically supported relocation projects), the potentially competing and cross-scale nature of safety versus wider community betterment found in our analysis deserves further reflection.

Third, findings from this study point to the importance of cross-scale interactions in bringing about change. The Fukushima nuclear accident instigated sweeping change in Japan’s national energy sector, including introducing the FIT mechanism for promoting investment in renewable energy, deregulating markets, and dismantling vertically integrated utilities. These national changes in energy policy created an environment that encouraged change at the local level. At the same time, local efforts also encountered barriers to renewable energy adoption from higher levels, such as constraints in the national grid infrastructure and ambiguity regarding the country’s energy future. Unless these are resolved, wider and more tangible uptake of renewable energy is unlikely to occur, and there is little that communities can do to address these issues.

The lessons drawn from our study are highly relevant for designing effective disaster reconstruction policy: when communities and nations seek to “build back better,” it is important to think beyond return to the pre-disaster normal, identifying potential cross-scale barriers and enablers for positive changes and developing workable strategies accordingly. Such processes should ideally take place before the next major disaster. As indicated in this study, disaster reconstruction processes are complex, and the pursuit of one objective may come at the cost of another.

Further study is needed to clarify these complexities and to test the wider applicability of the findings in this study. The cross-sectional, quantitative analysis indicated that prefectural differences were influential, and that characteristics of local planning processes were not (or may even have impeded change). Furthermore, both physical damage and relocation had a non-linear relationship with solar diffusion, which remains open to alternative interpretations. These puzzles should be further explored through in-depth, qualitative case study. Such investigation may clarify such important aspects as the role of funding sources for the renewable energy investments (e.g., local vs. external capital), the role of national, prefectural and local policies, winners and losers, and the qualitative or hidden factors influencing the processes of change.

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References

[1] Mannakkara, S., S. Wilkinson, and R. Potangaroa. (2014) "Build back better: implementation in Victorian bushfire reconstruction" *Disasters* 38(2): 267-290.

[2] United Nations (2015). *Sendai Framework for Disaster Risk Reduction 2015-2030*. Geneva, Switzerland: UNISDR United Nations Office for Disaster Risk Reduction.

[3] Ingram, J.C., G. Franco, C. Rumbairis-del Rio, B. Khazai. (2006) "Post-disaster recovery dilemmas: challenges in balancing short-term and long-term needs for vulnerability reduction," *Environmental Science & Policy* 9: 607-613.

[4] Cho, A. (2014). "Post-tsunami recovery and reconstruction: governance issues and implications of the Great East Japan earthquake," *Disasters* 38(S2): S157-S178.

[5] Aldrich, D.P. (2015) "It's who you know: Factors driving recovery from Japan's 11 March 2011 disaster," *Public Administration*, doi: 10.1111/padm.12191

[6] Iwate Prefecture (2014). Iwate Moving Toward Reconstruction. Morioka, Iwate. Available from: http://www.pref.iwate.jp/fukkounougoki/joukyou/index.html. Last accessed June 1, 2016.

[7] Movellan, J. (2015) "Born from disaster: Japan establishes first microgrid community," renewableenergyworld.com, available at: http://www. renewableenergyworld.com/articles/2015/05/born-from-disaster-japans-first-microgrid-community-represents-future-of-energy.html. Last accessed June 1, 2016.

[8] Haas, J. E., R. Kates, and M. Bowden. 1977. *Reconstruction Following Disaster*. Cambridge: MIT Press.

[9] Tierney, K. and A. Oliver-Smith (2012). "Social Dimensions of Disaster Recovery," *International Journal of Mass Emergencies and Disasters* 30(2): 123-146.

[10] Chang, S.E. and A.Z. Rose (2012). "Towards a Theory of Economic Recovery from Disasters," *International Journal of Mass Emergencies and Disasters* 30(2): 171-181.

[11] Smith, G. and T. Birkland (2012). "Building a Theory of Recovery: Institutional Dimensions," *International Journal of Mass Emergencies and Disasters* 30(2): 147-170.

[12] Aldrich, D.P. (2015) "It's who you know: Factors driving recovery from Japan's 11 March 2011 disaster," *Public Administration*, doi: 10.1111/padm.12191

[13] Birkmann, J., P. Buckle, J. Jaeger, M. Pelling, N. Setiadi, M. Garschagen, N. Fernando, and J. Kropp (2010). "Extreme events and disasters: a window of opportunity for change? Analysis of organizational, institutional and political changes, formal and informal responses after mega-disasters," *Natural Hazards* 55: 637-655.

[14] Alesch, D.J. and W. Siembieda (2012). "The Role of the Built Environment in the Recovery of Cities and Communities from Extreme Events," *International Journal of Mass Emergencies and Disasters* 30(2): 171-181.

[15] Olshansky, R. and S. Chang (2009). "Planning for Disaster Recovery: Emerging Research Needs and Challenges," *Journal of Progress in Planning* 72: 200-209.

[16] Geipel, R. (1991). *Long-term Consequences of Disasters: The Reconstruction of Friuli, Italy, in Its International Context, 1976-1988*. New York: Springer-Verlag.

[17] Reddy, S.D. (2000) "Factors influencing the incorporation of hazard mitigation during recovery from disasters," *Natural Hazards* 22: 185-201.

[18] Olshansky, R.B., L.A. Johnson, and K.C. Topping (2006). "Rebuilding communities following disaster: Lessons from Kobe and Los Angeles," Built Environment 32(4): 354-374.

[19] Fois, F. and G. Forino (2014) "The self-build ecovillage in L'Aquila, Italy: community resilience as a grassroots response to environmental shock," *Disasters* 38(4): 719-739.

[20] Scolobig, A., J. Linnerooth-Bayer, and M. Pelling (2014) "Drivers of transformative change in the Italian landslide risk policy," *International Journal of Disaster Risk Reduction* 9: 124-136.

[21] Birkland, T. (2006) *Lessons of Disaster*. Washington, DC: Georgetown University Press.

[22] Chang, S.E. (2010) "Urban disaster recovery: a measurement framework with application to the 1995 Kobe earthquake," *Disasters* 34(2): 303-327.

[23] Okuyama, Y. (2014) "Disaster and economic structural change: case study on the 1995 Kobe earthquake," *Economic Systems Research* 26(1): 98-117.

[24] Wakiyama, T., E. Zusman, and J.E. Monogan III. (2014) "Can a low-carbon-energy transition be sustained in post-Fukushima Japan? Assessing the varying impacts of exogenous shocks," *Energy Policy* 73: 654-666.

[25] Fujimi, T. and S. E. Chang. (2014). "Adaptation to Electricity Crisis: Businesses in the 2011 Great East Japan Triple Disaster," *Energy Policy* 68: 447-457.

[26] Fujimi, T., Y. Kajitani, and S.E. Chang. (2016). "Effective and persistent changes in household energy-saving behaviors: Evidence from post-tsunami Japan," *Applied Energy* 167: 93-106.

[27] Huenteler, J., T.S. Schmidt, and N. Kanie. (2012). "Japan's post-Fukushima challenge – implications from the German experience on renewable energy policy," *Energy Policy* 45: 6-11.

[28] Ebinger, C., J.P. Banks, and A. Schackmann. (2014) "Transforming the electricity portfolio: Lessons from Germany and Japan in deploying renewable energy," Policy brief 14-03, Washington, DC: The Brookings Institution.

[29] Agency for Natural Resources and Energy (ANRE) (2014). FY2013 Annual Report on Energy (Energy White Paper 2014) Outline, June. Available from: http://www.enecho.meti.go.jp/en/. Last accessed June 2, 2016.

[30] Moe, E. (2012) "Vested interests, energy efficiency and renewables in Japan," *Energy Policy* 40: 260-273.

[31] Yamaya, H., T. Ohigashi, H. Matsukawa, I. Kaizuka, and O. Ikki. (2015) "PV market in Japan and impacts of grid constriction," *Proc. IEEE 42nd Photovoltaic Specialist Conference (PVSC)*, June 14-19, New Orleans, LA. DOI: 10.1109/PVSC.2015.7356204

[32] Bridge, G., S. Bouzarovski, M. Bradshaw, and N. Eyre. (2013) "Geographies of energy transition: Space, place and the low-carbon economy," *Energy Policy* 53: 331-340.

[33] Miyagi Prefecture (2011) *Miyagi prefecture earthquake disaster recovery plan: the bond between Miyagi, Tohoku and Japan--from recovery to prosperity.* available at: http://www.pref.miyagi.jp/uploaded/attachment/36634.pdf Last accessed June 8, 2016.

[34] Fukushima Prefecture (2012) Plan for revitalization of Fukushima prefecture (second version): forming a link to the future, beautiful Fukushima. available at https://www.pref.fukushima.lg.jp/download/1/plan_for_revitalization2_outline.pdf Last accessed June 8, 2016.

[35] Iwate Prefecture (2011) *Iwate prefecture Great East Japan Earthquake and Tsunami reconstruction plan (basic reconstruction plan):to protect life, to live together with the sea and land, and to create a homeland Iwate and Sanriku.* available at: http://www2.pref.iwate.jp/~hp0212/fukkou_net/pdf_doc/kihonkeikaku_english.pdf Last accessed June 8, 2016.

[36] Japan Photovoltaic Energy Association (2015) Can residential PV supply sufficient power for typical household consumption? Available at: http://www.jpea.gr.jp/inquiry/q_a/index.html (in Japanese).

[37] Vlado, V. (2014) *Energy Security in Japan: Challenges After Fukushima.* Routledge

[38] Japan Times (2016) Cabinet approves solar-power auctioning in shake-up of sector. available at: http://www.japantimes.co.jp/news/2016/02/09/business/cabinet-approves-solar-power-auctioning-shake-sector/#.V0Wxv_l97RZ Last accessed June 1, 2016.

[39] National Institute for Research Advancement (NIRA) (2013) *Status of recovery and current problems in three disaster-hit prefectures.* Tokyo: NIRA. Full report in Japanese available from http://www.nira.or.jp/pdf/1301report.pdf Last accessed June 1, 2016.

[40] Brookings Institution, Metropolitan Policy Program (2008). *The New Orleans Index: Tracking the Recovery of New Orleans & The Metro Area*, anniversary edition three years after Katrina. Washington, DC: Brookings Institution.

[41] Murao, O., and Hoshi,T. (2014) Comparative study of the post-tsunami recovery plans after the 2011 Great East Japan Earthquake *Journal of Disaster Research* 9: 743-751.

[42] Fukuda, K. (2014) Current state and issues regarding collective relocation projects. Reference 12:131-150. Available: http://dl.ndl.go.jp/view/download/digidepo_8841940_po_076709.pdf?contentNo=1(in Japanese).

[43] Uragami, K. (2013) The Actual Situation and Problems of Renewable Energy Policy in Reconstruction Plan of the Great East Japan Earthquake: The subject of municipalities in the tsunami disaster area and the evacuation area of TEPCO Fukushima Daiichi nuclear power plant accident. *Journal of Rural Planning Association* 31(4): 581-588 (in Japanese).

[44] Center for Development of Power Supply Regions (2010) List of municipalites receiving nuclear siting subsidies. available at: http://www2.dengen.or.jp/html/works/kyufu/files/H22.pdf. Last accessed June 8, 2016 (in Japanese).

[45] Araki, Y. and Hokugo, A. (2014) Analysis of relationship among the designation of disaster risk areas and the loss rate of lives, houses and the rate of inhabitable land in areas devastated by the Great East Japan Earthquake Tsunami. *Koube daigaku daigakuinkougakukenkyuka shisustemu jyohoukagakukakiyou* 6: 24-31 (in Japanese).

Appendix 1. Prefectural Statistics

Appendix Table A1. Number of approved projects and average capacity of renewables, July 2012 to December 2015 (source: author calculations based on FIT website)

Type of Renewables		**Iwate**	**Miyagi**	**Fukushima**	**Rest of Japan**
Solar <10kW	# approved (per 1,000 persons)	8.3	10.8	11.8	7.3

	Average capacity (kW/unit)	4.6	4.4	4.6	4.5
Solar >10 kW & <1000kW	# approved (per 1,000 persons)	5.8	5.8	11.3	6.6
	Average capacity (kW/unit)	46.9	45.8	41.5	41.2
Megasolar >1000kw	# approved (per 1,000 persons)	0.2	0.2	0.2	0.1
	Average capacity (kW/unit)	9,562.1	7,105.9	7,556.8	3,685.3
Wind	# approved (per 1,000 persons)	0.0	0.0	0.0	0.0
	Average capacity (kW/unit)	5992.1	372.8	2924.7	5305.6
Hydro	# approved (per 1,000 persons)	0.0	0.0	0.0	0.0
	Average capacity (kW/unit)	2,035.9	32.5	2,578.6	1,650.5
Geothermal	# approved (per 1,000 persons)	0.0	0	0.0	0.0
	Average capacity (kW/unit)	7,499.0	n.a.	400.0	1,224.4

Appendix 2. Data Sources

Variables	Years (and months where applicable)	Sources
Prefectural-Level		
Renewable energy approval	July 2012-December 2015	FIT website http://www.fit.go.jp/statistics/public_sp.html

Population	2012-2014*	Statistical Bureau of Japan STATISTICAL OBSERVATIONS OF PREFECTURES http://www.stat.go.jp/data/k-sugata/gaiyou.htm
Municipal-Level		
Renewable energy approval	2015	Statistical Bureau of Japan STATISTICAL OBSERVATIONS OF SHI, KU, MACHI, MURA http://www.stat.go.jp/data/s-sugata/index.htm
Population	2005, 2010	Statistical Bureau of Japan STATISTICAL OBSERVATIONS OF SHI, KU, MACHI, MURA http://www.stat.go.jp/data/s-sugata/index.htm
Land areas	2013	Statistical Bureau of Japan STATISTICAL OBSERVATIONS OF SHI, KU, MACHI, MURA http://www.stat.go.jp/data/s-sugata/index.htm
Fiscal capacity	2008-2010	Statistical Bureau of Japan STATISTICAL OBSERVATIONS OF SHI, KU, MACHI, MURA http://www.stat.go.jp/data/s-sugata/index.htm
Adaptive capacity (rate of waste recycle as proxy)	2010	Statistical Bureau of Japan STATISTICAL OBSERVATIONS OF SHI, KU, MACHI, MURA http://www.stat.go.jp/data/s-sugata/index.htm
Social capital (rate of suicidal death as proxy)	2009-2010	Cabinet office database on suicidal deaths in Japan http://www8.cao.go.jp/jisatsutaisaku/toukei/index.html
Physical Damage	2011	Cabinet office database on Great East Japan Earthquake and Tsunami http://www.stat.go.jp/info/shinsai/
Recovery planning	2011	[41]
Relocation	Various years	[42]
Prior energy plan	Various years	[43]
Nuclear siting subsidy	2010	[44]
Tsunami risk areas	2014	[45]

Note: *latest available year was used instead of 2015.

[1] Assumes an average household size of 3 persons. Annual system production capacity is estimated as approximately 1,000 kWh/kW assuming a panel angle of 30 degrees facing south [36].