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ORIGINAL ARTICLE

Japan's mega solar boom: quantifying social equity expectations and realities at the local scale

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Abstract

This research aims to quantitatively identify the variation in equity and burden distribution associated with mega-solar siting at the local level in Japan, and to identify mega-solar siting outcomes in each region and prefecture, in terms of social equity and burden distribution outcomes relative to stated preferences. Methodologies employed include survey and interviews to identify critical energy policy factors associated with mega-solar siting, and their perceived importance according to local officials associated with deployment. Building on the critical factor and important findings from 29 of Japan's largest 200 mega-solar sites, a quantitative analysis of social equity outcomes in terms of health, environmental improvement, electricity prices, employment and community development is undertaken. Additionally, an analysis of the burden distribution resultant from mega-solar deployment in each region is undertaken. In all cases explored, mega-solar deployment leads to an improvement in social equity levels, with desirable burden distribution which closes the gap between rich and poor. Regional and local factors impact upon the comparative equity and burden distribution outcomes between sites, notably pre-existing particulate matter concentrations and employment changes between fossil fuel and renewable industries, and the reduction of electricity tariffs. These findings identify challenges and opportunities for policy makers and the proactive, equitable deployment of mega solar based on national, regional and local attributes.

Keywords Mega solar · Japan · Siting · Equity · Burden · Local preference

Introduction

The development of over 2800 mega-solar power plants in Japanese communities since 2012 necessitates a rigorous analysis of the impacts of mega-solar development locally and at large, to determine to what degree these impacts are meeting expectations of stakeholders, specifically, municipal governments. Mega-solar plants consist of 1 MW or more in installed capacity and can consume 0.5–1.0 hectares per MW, making their economic, environmental, and social impacts potentially significant. Following up on a formative study investigating the social equity impacts recognized by stakeholders in mega-solar siting (Fraser and Chapman 2018), this paper seeks to quantitatively evaluate these impacts across a number of sites. Social equity refers to a 'fair' distribution of social costs and benefits to resident consumers, which we measure by assessing health impacts, electricity prices, employment, community development, and offset greenhouse gas emissions. We measure social equity in terms of mega-solar siting and its ability to improve the identified, important factors in general (i.e., at the site and regional level), and also how the benefits and costs are shared depending on household socio-economic status. Research underpinning this study suggests that solar power affects the distribution of costs and benefits of energy policy in terms of tax revenue and land use, among other aspects. However, the pilot study did not examine net changes in equity due to new renewable power capacity supplanting demand for fossil fuel-based generation, nor did it discuss the distribution or geographic influence of these changes (Fraser and Chapman 2018).

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Important questions remain about variation in equity outcomes based on geography (host municipality conditions) and scale (size of plant). Specifically, how equitably does the current policy regime distribute the impacts of mega solar among host communities at the local level?

This paper quantitatively measures social equity impacts for mega solar at the local level, through an agreed importance-based weighting regime, incorporating local government preferences on social equity impacts informed by surveys and interviews in towns hosting 29 of Japan's 200 largest mega-solar power plants.

The key aim of this paper is to quantitatively identify the variation in equity (the overall improvement of individual energy policy factors identified by stakeholders, i.e., the net social benefit) and burden distribution (i.e., how fairly the burden of mega-solar siting is shared across income quintiles) associated with mega-solar siting at the local level, and to identify within regions the prefectures where mega-solar siting generates the best (and worst) equity and burden distribution impacts relative to stated preferences. Below, we review the literature on social equity and mega solar, outline our research design and methodology, review our survey results, quantify equity impacts, and compare and discuss case results and implications.

Background

We ground our analysis of Japanese mega solar in a recent swell of research on social equity outcomes of renewable energy (Hori and Shibata 2017; Tanaka et al. 2017; Ohira 2017; Chino 2015, 2016; Raupach-Sumiya et al. 2015). Below, we review advances in evaluating sustainability incorporating the concept of social equity, our past research on the social equity impacts of Japan's boom in mega-solar power plant siting and means by which new renewable projects are meeting local preferences for equitable development.

Social equity and sustainability evaluation

There is broad agreement among scholars that sustainability is made up of interdependent economic, environmental and social factors (Wheeler 2002; IAEA 2005). However, within sustainability evaluations, the evaluation of social equity is not a simple task, as the study of social factors, and their quantification have been given a lower level of attention by scholars when compared to the more prominent factors of economy and the environment (Tol 2001; Chapman et al. 2016). Further, terms associated with equity are often vague, leading to a lack of consensus between stakeholders (Been 1993). To overcome these issues, this research uses a social equity quantification methodology, the Energy Policy Sustainability Evaluation Framework (EPSEF; Chapman et al. 2016), previously used for local and national renewable energy policy evaluation in Australia and Japan (Chapman and Pambudi 2018). Further, the critical factors which underpin social equity are derived in an inclusive manner, from jurisdictions impacted by mega-solar siting through surveys and interviews, to clarify the social factors which need to be considered and quantified to effectively and holistically evaluate mega-solar projects in Japan.

Social equity impacts of mega-solar siting

Japan's Feed-in Tariff (FiT) resulted in the construction of 2800 mega-solar power plants since 2012 (Kitamoto 2017), many in rural areas, raising questions about their impact on host communities. The FiT raises consumer electric bills to guarantee that utilities will purchase a fixed minimum rate of renewable energy; high rates have made mega-solar a lucrative investment opportunity at consumers' expense (Tanaka et al. 2017). Previous research identified social equity impacts of siting mega-solar power plants reported by local government officials in host municipalities, focusing on the siting process, the point in time that joins together operators, host communities, economic pressures, and national policy. Officials documented minimal, non-existent, or unclear social equity impacts in 66% of cases, with the main benefit documented being marginal increases in fixed asset tax revenue for municipalities in at least 38% of cases (Fraser and Chapman 2018). Meanwhile, other recent studies suggest that landscape degradation, sediment discharge, and flood vulnerability caused by mega-solar development have triggered negative public reactions particularly in communities where plants are proximate to national parks, tourism sites, residential areas, or schools (Hori and Shibata 2017). These qualitative studies suggest a need for more quantitative tools in weighing the costs and benefits of mega-solar development.

Analysis identified that (1) an abundance of cheap land and (2) lack of municipal government involvement in siting significantly impact the siting process and equity outcomes, the FiT's guarantee of profit from generation incentivizes companies to build on cheap land to increase their guaranteed profit margin. Many host municipalities had numerous cheap public and private land plots that they struggled to sell. This surplus was largely due to globalization and Japan's lost decades of economic stagnation, which led local industries to cut costs by relocating production to overseas or to Japan's urban industrial corridor. As a result, companies, rather than local governments, take the most initiative in the siting process. Companies often build mega-solar plants on golf courses, polluted industrial sites, landscapes harvested for natural resources, or unused reclaimed land made inexpensive due to a lack of interest in development. Abundance of these kinds of sites throughout rural Japan limits the bargaining power of potential host communities, lest interested companies facing demands from one town choose a different town in which to invest.

Prefectural or local government ownership appears comparatively rare among the country's largest utility-scale projects. These require significant investment capital, which rural governments can rarely spare from already tight budgets. Instead, investment often comes from major industrial or electronic corporations (e.g., Softbank or Sharp), city or regional banks. Typically, companies only need mayoral approval if renting land owned by local governments. Lacking government ownership, companies need only the approval of landowners and basic consultation with local government before deployment. This leaves no formal requirements for community buy-in. In worst cases, host communities could bear social or environmental consequences of facilities they did not consent to hosting in the first place. Consequently, the most communities can bargain for are temporary jobs for local workers during the construction phase and the use of underutilized land, either selected by the company or offered by the municipality (Fraser and Chapman 2018).

It is noteworthy that solar siting policy is defined by abundance rather than scarcity of available land. In contrast, past Japanese siting policy for centralized (and sometimes controversial) power generation sources, e.g., nuclear, hydropower, and coal power plants, regularly provided government subsidies to compensate communities so that they would permit hosting such plants (Aldrich 2008). Instead, the mega-solar boom has put underutilized land to use, yet often fails to meaningfully improve the social equity of host communities. While some impacts of a given technology are fixed (e.g., solar does not require significant maintenance and thereby employment), others can vary based on a variety of local and political factors (e.g., degree of privatization, community participation, or local government involvement in the given project; Fraser and Chapman 2018). Depending on the operating company's ownership model, profits from the power plant are sometimes taxed in urban jurisdictions hosting the company rather than the rural municipalities that host the point of production, leading to uneven flows in social equity between rural and urban sites (Ohira 2017; Chino 2015, 2016; Raupach-Sumiya et al. 2015).

Previous research by the authors identifies that social equity impacts of mega-solar and their causes are small, not well recognized, and perhaps not always deeply considered when projects begin. However, this research did not quantify impacts, or compare them between sites (Fraser and Chapman 2018). Finally, questions also remain about local government officials' preferences toward social equity. Furthermore, this comparison begs several larger questions about the impact of mega-solar as the largest form of non-hydro-based renewable power in Japan currently. How equitably does Japan's mega-solar boom distribute its social costs and benefits among host communities? How well do social costs and benefits meet the expectations of local officials, and how do these social equity impacts vary between locales?

Methodology

The methodology for this study consists of two parts, beginning with an outline of surveys and fieldwork, which are then used to inform an evaluation of energy policy impacts from a social equity point of view.

Survey to identify important energy policy issues associated with mega-solar siting

Quantifying the social equity impacts of mega-solar power deployment requires the identification of an importance-based weighting regime for relevant factors. To identify the most important factors regarding energy policy for local governments, we utilize survey and in-person interview response data collected between May and June 2017 from 29 local government offices across Japan (summarized in Table 5 in "Appendix"; municipal population characteristics detailed in Table 6 in "Appendix"). These data were not analyzed in our previous paper and adds to our understanding of local government priorities.

Municipalities were selected from Japan's 200 biggest solar power plants in megawatts (MW) of installed capacity to capture the dynamics most relevant to large-scale solar development (10 MW → 100 MW), rather than 1–10 MW facilities. Our selection method prioritized the 100 biggest plants, and then included others within the top 200 range located within the same municipality to maximize responses from cooperative municipalities.

We designated our target population as local government officials, rather than local residents, landowners renting property for solar, or power plant operators, as the most able to speak to the priorities and expectations of local government. Where available, we surveyed officials responsible for energy affairs. However, many rural communities lack specific energy officials. In these cases, we surveyed urban planning, local industry promotion, or general affairs departments as available, in that order. For their protection, the identities and positions of these respondents remain confidential. While such municipalities tend to lack RE experts, these officials are the most likely persons to receive the concerns and complaints of all local parties involved or interested in renewable power development, making them the best suited population for a survey of 100 cases throughout Japan.

Local government officials from municipalities throughout seven of Japan's eight major regions detailed their priorities in local energy policy through interview and survey responses (Fig. 1). Out of 100 plants corresponding to the municipal offices solicited, 37% of recipients responded to requests for survey or interviewing, and 29% completed the survey questions referenced in this paper. Officials from 25 municipalities in 17 prefectures provided responses about factors corresponding to the 29 individual mega-solar sites located in these municipalities, generating unique responses for each of the 29 plants. In addition, the authors interviewed 18 representatives from operators, municipal government, and prefectural government in six cities on the solar siting process and relevant social impacts (see Table 7 in "Appendix", results detailed in Fraser and Chapman 2018). Our analysis includes interview responses from the same structured survey in Hamamatsu, Shizuoka Prefecture and Tahara, Aichi Prefecture, while fieldwork informs interpretation of our findings in the discussion. Regions investigated include Kyushu, Chugoku, Kansai, Chubu, Kanto, Tohoku, and Hokkaido; no responses were received from municipalities in Shikoku or Hokuriku.

Local government officials ranked issues on an adapted Likert scale to demonstrate the degree of importance of each issue to local energy policymaking. Ten issues were ranked on a scale from "extremely important (5)", "very important (4)", "important (3)", "somewhat important (2)", "a little important (1)", to "not important at all (0)". Issues measured included environmental conservation, climate change countermeasures, pollution countermeasures, electricity prices, community tax base, employment, fair labor conditions, community development, disaster resilience, and social equity. The survey presented issues without prefacing to avoid biasing one issue over another. Additionally, officials ranked issues individually, such that an official could rank any or all issues 'extremely important' without affecting the score of another issue. Our interview cases showed that officials interpreted environmental conservation as landscape degradation, while climate change countermeasures were understood to mean greenhouse gas reduction efforts (distinct from climate change adaptation measures, such as storm water management). We discuss interpretations of social equity and disaster resilience within the discussion.

These responses (while only a small n sample) provide clues as to local governments' preferences for energy policymaking and in what terms they perceive and value social equity within energy policy. This sample is not generalizable to the population, but instead is a sample of 100 of Japan's top 200 largest plants in terms of installed capacity. Additionally, the data used in our methodology (see Sects. "Evaluating important energy policy impacts from a social equity viewpoint" and "Survey findings, application to evaluation framework and results") do not need to be representative of the population of all mega-solar power plants to be useful. The value of this method is to show that specific plants have greater social equity

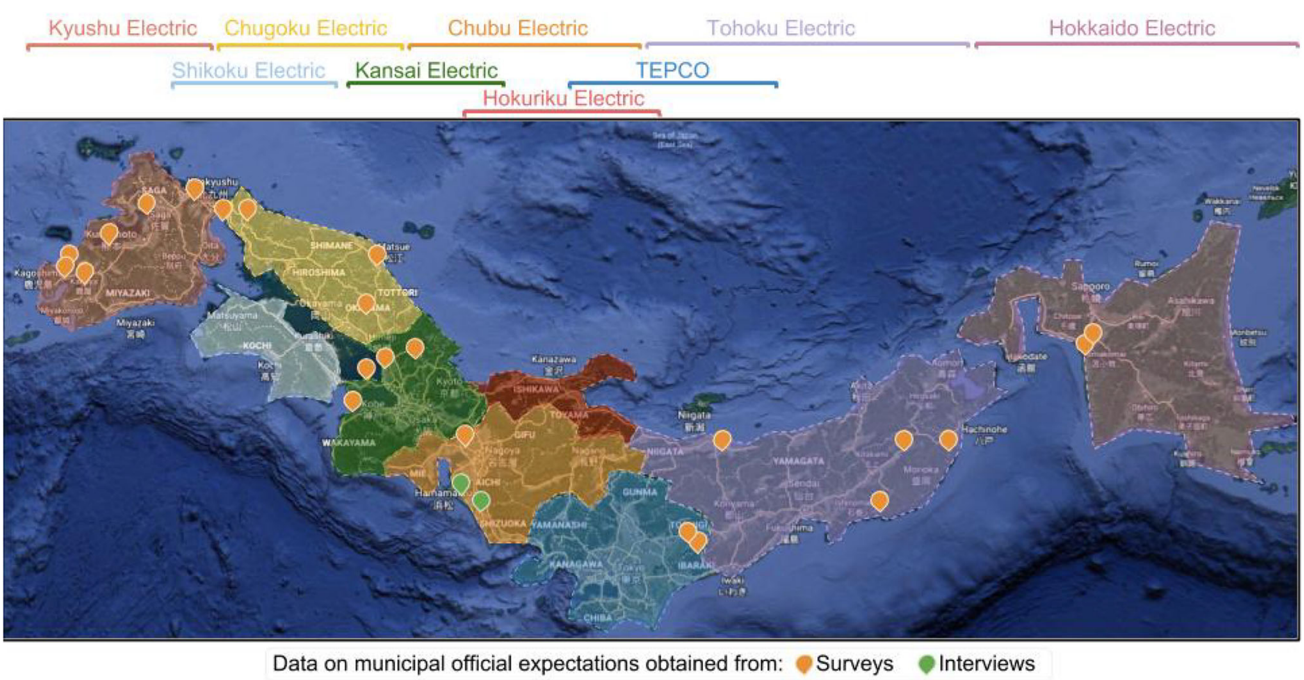

Fig. 1 Mega-solar power plant host municipalities surveyed

impacts than others (not to show variation in equity between a random sample of plants). Even without a representative sample, this study demonstrates important geographical differences in equity outcomes.

Evaluating important energy policy impacts from a social equity viewpoint

Following the establishment of an agreed set of important mega-solar siting energy policy impacts, the investigated mega-solar sites in Japan can be comparatively evaluated to demonstrate both sustainability and social equity outcomes. This evaluation encompasses data from the local, prefectural, and regional levels (within the affected city, prefecture or energy generation region, as detailed in Sect. "Mega-solar social equity and sustainability evaluation" for each assessed factor and the scale considered). In doing so, this evaluation assesses the overall impact of deploying mega solar in terms of the achievement of each municipality's energy policy goals.

To comparatively evaluate the described renewable energy approaches in terms of their overall sustainability the EPSEF (detailed in Chapman et al. 2016) is utilized. This framework allows for the combination of economic and environmental mega-solar siting outcomes to derive quantitative social equity and burden distribution outcomes (with factors and weightings guided by stakeholder feedback from the site-specific survey and interview responses). Social equity and burden distribution are calculated on a comparative basis for the year 2017 and expressed using a score out of 100 for each mega-solar site.

Salient formulae for determining equity and burden distribution scores are outlined below. First, to determine the energy policy factor value (EV; summarized in the results section) for each income level:

$$\mathrm{EV}_{(i,j)} = \mathrm{DV}_{(i,j)} \times \left\{ \frac{\mathrm{CV}_{(i,j)}}{\mathrm{MaxCV}_{(i,j)}} \right\}, \quad (1)$$

where EV is the energy policy factor value, to be calculated for each income level and energy policy factor, DV is the distribution value (i.e., how each factor considered is distributed across society, in some cases such as CO_2 distribution, this is considered equal, while in others, such as electricity price impacts, will vary according to income), CV is the comparison value (i.e., the proxy values used to represent each energy policy factor, such as the amount of CO_2 reduced, or the overall increase in the levelized cost of electricity, for example), i (="very low", "low", "average", "high", "very high") is the income quintile, and j (= 1, 2, 3, 4, 5) are the five energy policy factors, as detailed in Sect. "Mega-solar social equity and sustainability evaluation".

Using the derived energy policy factor values for each income level, comparative equity scores between income levels can be established thus:

$$\text{Comparative equity}_{(i)} = \frac{\sum_j \mathrm{EV}_{(i,j)} \times w_{(j)}}{\sum_j w_{(j)}}, \quad (2)$$

where w_j is the weighting assigned to each equity factor (identified as the level of importance in Table 1, Sect. "Mega-solar social equity and sustainability evaluation").

The level of social equity and resultant burden distribution can then be plotted for each income level. This is achieved using the x- and y-coordinates of income levels and comparative equity scores in an area-weighted approach, thus:

$$x = \frac{\sum c_{\mathrm{k}_x} A_{\mathrm{k}}}{\sum A_{\mathrm{k}}}, \quad y = \frac{\sum c_{\mathrm{k}_y} A_{\mathrm{k}}}{\sum A_{\mathrm{k}}}, \quad (3)$$

where is the C is the centroid and A is the area of individual rectangles (k), which are formed for each income level [i.e., income quintiles are plotted ordinally on the x-axis, and equity scores for each of these quintiles on the y-axis, creating five polygons whose y-value is the sum of weighted equity scores, and whose x-value is the cumulative width of the income quintiles from lowest to highest

Table 1 Distribution, comparison and importance of energy policy factors

Energy policy factor	Distribution value	Comparison value	Level of importance
1. Environmental conservation/climate change countermeasures	Assumed to be equal	% Carbon dioxide (CO_2) reduction within local grid	3.9
2. Pollution countermeasures	Assumed to be equal at the prefectural level	% Particulate matter (PM) reduction within local grid	4
3. Electricity prices	% Income spent on electricity	Change in energy price (LCOE impact of solar) in local grid	3.1
4. Community tax base/community development	Assumed to be equal (i.e. reinvested in community facilities)	Change in local tax revenue	3.4
5. Employment	Job allocation and salaries	Change in job numbers (RE jobs gained—Fossil jobs lost) locally	2.9

(e.g., 20, 40, 60, 80, 100)]. The overall polygon formed (i.e., the combined polygons of each income quintile) can be thought of to represent the 'shape' of society in terms of the distribution of benefits and burdens across income levels within society. The area weighted centroid of this polygon is representative of the overall social equity or net social benefit, and the sector of society which receives the majority of these benefits. Burden distribution is calculated by subtracting the derived x-values from an 'ideal' maximum value of 100, to determine whether the burden of deploying mega-solar in a locale is borne by higher (a burden distribution score > 50) or lower (a burden distribution score < 50) income households. The y-values represent the social equity score, normalized to a maximum of 100. A higher score is better in both cases, and outcomes can be compared across sites on a single graph.

Survey findings, application to evaluation framework and results

This section is divided into three parts, first identifying the critical social equity factors and their level of importance according to interviewees and survey respondents. These findings are then applied to the EPSEF, which enables a comparative social equity and sustainability evaluation between assessed mega-solar sites.

Mega-solar siting energy policy issue importance

The main findings for degree of importance of factors relevant to local energy policy according to local governments are detailed below. Surveys and interviews identified that the most important factor on average for local government officials is environmental conservation [4.5, with the lowest standard deviation (SD) of just 0.7 among all factors] with results confirming that officials are most united on the importance of this factor. Meanwhile, pollution countermeasures (4), community development (3.4), community tax base (3.4), climate change countermeasures (3.3), and electricity prices (3.1) ranked between "very important" (4) and "important" (3) with an average SD of 1.2. Finally, officials dubbed disaster resilience (2.9), employment (2.9), fair labor conditions (2.9), and social equity (2.7) as between "somewhat important" and "a little important" with an average SD of 1.4. Results are shown along with response SD's in Fig. 2. Responses for individual locations are summarized in Table 5 in "Appendix".

For environmental criteria, on average, the officials surveyed prioritize environmental conservation above all (perhaps because officials are conscious of potential negative landscape impacts of mega-solar, as described in Hori

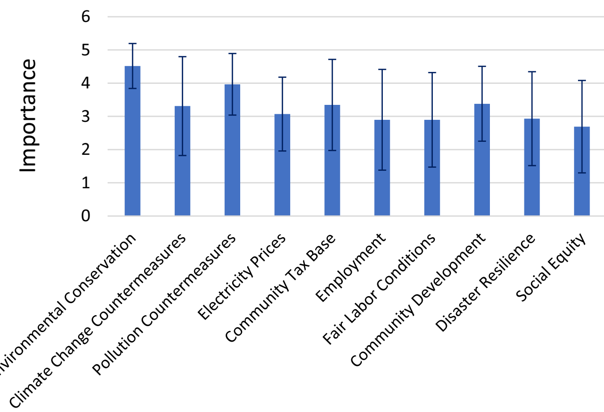

Fig. 2 Average degree of energy policy factor importance according to LG officials, with standard deviations

and Shibata 2017), but similarly prioritize pollution countermeasures and climate change countermeasures on average as between "very important" and "important." Despite this, climate change countermeasures ranked just above "important" on average (3.3) with the second highest SD among the results. This may reflect that economic development is more important than climate change countermeasures for officials or that some officials see the consequences of climate change as insignificant to their community. Even if respondents did interpret 'climate change countermeasures' as climate change adaptation instead of greenhouse gas reductions), these are still useful results, because they reflect how much officials are thinking of climate change countermeasures as a priority for their community. Since mega-solar's main contribution to both climate change adaptation and greenhouse gas emissions is offsetting fossil fuel demand, the contribution of mega-solar to greenhouse gas emissions reduction would help officials achieve their priorities more if those officials prioritize climate change countermeasures.

With regard to the local economy, results obtained suggest that local government officials surveyed slightly prioritize contributions of local energy policy to community development and community tax base over employment.

While disaster resilience constitutes a significant part of prefectural development plans for host communities that suffered from the 1995 Kobe Hanshin Earthquake (Hyogo Prefectural Government 2016) or the 2011 triple disaster (Miyagi Prefectural Government 2017; Mochizuki and Chang 2017), the concept is not as important to officials on average as environmental or economic issues. Similarly, social equity is perceived as the least important on average, suggesting that respondents conceptualize social impacts in different terms (e.g., community development, community tax base, or electricity prices), are unfamiliar with the concept of social equity, or genuinely are more focused on environmental and economic impacts (a common trend in energy analysis as identified by Been 1993; Tol 2001; Chapman et al. 2016).

Finally, no factors ranged between "a little important" and "not important" on average. This suggests that each of the factors hold some importance to officials, although officials' familiarity with the concepts and the degree to which researchers can quantify these factors vary.

Mega-solar social equity and sustainability evaluation

Building on the survey results, important energy policy factors can be incorporated into the EPSEF, which uses economic and environmental impacts distributed across income quintiles to quantify social equity outcomes, enabling a holistic sustainability evaluation (expressed in terms of equity level and burden distribution) of energy policy approaches. Of the ten important issues identified in the survey, seven are suitable for incorporation into the EPSEF (some combined), detailed in Table 1, including the factors utilized for distribution and weighting of these impacts, and the average reported level of importance (as summarized in Fig. 2, with raw results shown at Table 5 in "Appendix").

The qualitative factors of fair labor conditions and disaster resilience cannot be quantified utilizing environmental or economic inputs and are excluded in our evaluation. Social equity is expressed as a result of all EPSEF energy policy factor calculations, detailed below, with regional variables summarized in Table 8 in "Appendix".

Environmental conservation/climate change countermeasures (ΔCO_2)

To evaluate the environmental conservation and climate change countermeasure impact, the reduction of CO_2 compared to business as usual is measured in the mega-solar hosting city. For each site assessed, the reduction in CO_2 due to electricity generated from mega-solar sites is offset against the CO_2 from energy production. These figures are derived from data on each regional electricity provider's average CO_2 emissions, obtained from the Energy Information Center (2017). These figures also incorporate the lifecycle CO_2 emissions of solar PV systems, 38 grams per kilowatt hour (g/kWh), calculated by the Federation of Electric Power Companies of Japan (2016).

Pollution countermeasures (ΔPM)

The proxy used for pollution countermeasures is particulate matter (PM), considering the type and scale of PM-emitting power stations in assessed locations. We use the regional average tons of PM per annum due to electricity generation based on data from the Ministry of the Environment (2014), divided by the annual prefectural electricity generation, according to the Agency for Natural Resources and Energy (2017). Mega-solar is assumed to reduce PM for every unit of conventional power generation (TWh per annum) offset. This assumption seeks to evaluate pollution countermeasures at the prefectural level and does not take into account the fact that lower-income households often bear a greater share of pollution concentrations (Marmot Review Team 2010). Studies which focus on individual prefectures or municipalities at the singular, local level could further investigate pollution distribution across income levels for Japan.

Electricity prices (ΔLCOE)

The impact on electricity prices is calculated according to the amount of large-scale solar power deployed using an LCOE of 21 yen/kWh (excluding policy costs) based on the calculations of the Institute of Energy Economics Japan (2015). We then adjusted those figures for prefectural generation based on irradiation levels, using data from Japan's New Energy and Industrial Technology Development Organization (NEDO 2014). This impact is then applied to the average monthly expenditure for electricity in each Japanese region, using data from the energy market research company Enechange (2014), distributed by the percentage of income spent on electricity for each income quintile, based on data from the Ministry of Internal Affairs and Communications (2017).

Community tax base/community development (Δtax revenue)

Impacts on community development are established by estimating the change in fixed asset tax revenue, the most important direct financial impact of mega-solar plants on host communities across cases (Fraser and Chapman 2018). We average fixed asset tax revenue voluntarily disclosed by companies or local governments, at the rate of 1,090,245 JPY/MW of solar capacity,[1] as reported in Mainichi Shimbun (27 August 2012), the Ministry of Economy, Trade and Industry (2013), and several confidential survey respondents. Generally speaking, rates of revenue per MW for larger mega-solar plants are lower than for smaller plants because of land-use efficiencies of scale, mitigating fixed asset taxes. However, we opted for the assumption of constant returns to the scale of plant for simplicity.

[1] Based on two case studies from our own analysis and two external sources ranging from 2 MW to 49 MW, and 789,963 to 1,500,000 JPY/MW detailed in Table 9 in "Appendix".

Table 2 Mega-solar site equity and burden scores and rankings (highest scores bold underlined)

Site name	Equity score	Rank	Burden score	Rank
SOFTBANK Tomatō Abira Solar Park	**100**	**1**	50.6	28
Kagoshima Nanatsujima Mega Solar Power Station	48	2	52.4	17
Tahara Solar Wind Power Station	40.3	5	53.6	2
Kisoaki Reclaimed Area Mega Solar	37.8	7	**53.9**	**1**
SOFTBANK Hamamatsu Nakao Solar Park	42.2	4	52.2	20
SOFTBANK Tottori Yonago Solar Park	43.4	3	53.4	6
Tahara Solar Power Station 2	32.8	10	53.6	3
Tahara Solar Power Station 1	32.4	12	53.6	4
Eurus Tsunato Solar Park	32.7	11	53.2	7
Awaji Kifune Solar Power Station	28.9	13	53.2	8
Kumenan Mega Solar Power Plant	35.1	8	52	24
Fukuroda Solar Power Station	26.2	16	52.9	11
Arita Solar Power Station	40.2	6	51.8	25
Hioki Yōbo Power Station	19.7	22	52.4	18
Wano Solar Power Station	33.6	9	52.2	21
Smart Solar Yamaguchi Aki Power Station	24.9	19	52.5	15
Eastern Niigata Photovoltaic Power Plant	22.7	20	53.5	5
SOFTBANK Kumamoto Arao Solar Park	16.1	24	52.6	13
Ashikita Solar Power Station	15.4	25	52.6	14
US Power Solar Power Station	22.1	21	52.5	16
Takizawa City Mega Solar	28.2	14	52.2	22
Goyōzan Solar Power Station	27.4	15	52.2	23
Tochigi Solar Power Station	25.3	17	51.8	26
Kagoshima Kirishima Solar Power Plant	13.7	29	52.4	19
LS Nasu Nakagawa Power Station	25	18	51.8	27
DREAM Solar Fukuoka Miyawaka	15.3	26	52.9	12
Mukawa Solar Power Plant	17.1	23	50.6	29
NRE Yamanan Solar Power Station	14.9	27	53.2	9
Nikke Machinaka Power Station Akashi Tsuchiyama	14	28	53.2	10

Employment (ΔJobs)

Employment impacts are measured via two components. We assess the jobs gained in mega-solar power stations (using average job numbers from surveys, interviews, and case studies) at a rate of 0.46 jobs per MW of solar capacity.[2] Second, we assess the commensurate amount of full-time employees (FTE) lost in the fossil fuel sector, based on the reduced amount of generation jobs (31.7–52.1 FTE/TWh). These figures are derived from energy provider annual reports,[3] with the percentage of total jobs lost based on international precedents as reported by Payscale (2017) and the US Department of Energy (2017). The jobs gained and lost are distributed by salary across income quintiles, with solar jobs assumed to be electrical engineers (based on data from Electrical Engineer Qualification and Reports 2017), and with fossil fuel jobs assumed to be power plant operators (see Employment Case Studies 2017).

The normalized equity and burden scores and rankings for each mega-solar site assessed are detailed in Table 2.

Although the largest site assessed, the SOFTBANK Tomatō Abira Solar Park, located in Hokkaido scores highest in terms of overall equity improvement, the Kisoaki Reclaimed Area Mega Solar Plant, located in Mie Prefecture has the most desirable burden distribution outcome. All assessed sites achieve a burden score greater than 50, demonstrating that higher income groups are bearing the burden of mega-solar deployment.

To understand these results, and the impact of different energy policy and site-specific factors, further analysis was undertaken to better express the impacts of scale and region. Comparative burden scores for each site located within the same prefecture (thereby supplied by the same power company) were almost identical, and after accounting for scale (using equity per MW), the same was

[2] Based on nine case studies from our analysis ranging from 19 MW to 111 MW, and 0 to 5 Jobs/MW.

[3] TEPCO 2017, KEPCO 2017, Energia 2017, Kyuden 2017, Chuden 2017, HEPCO 2017, Tohoku-EPCO 2017.

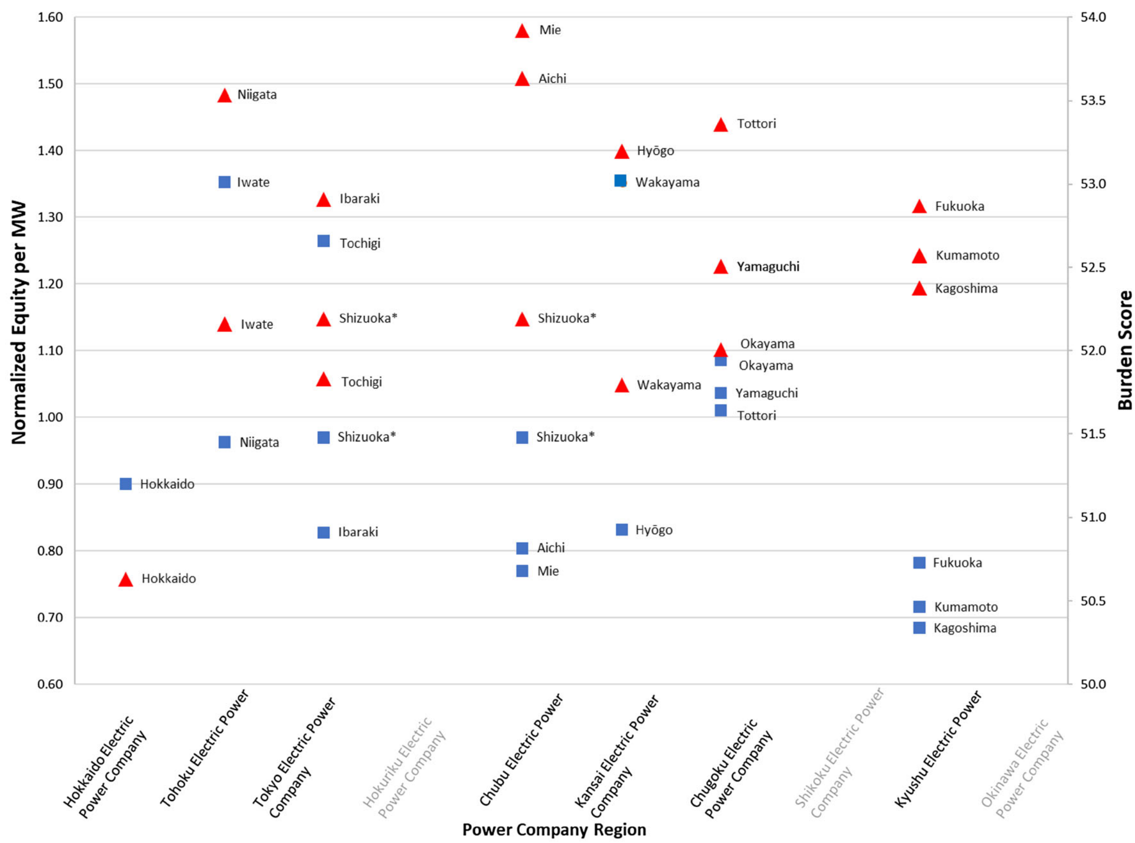

Fig. 3 Equity (blue filled square) and burden (red filled triangle) scores per power region and prefecture. Shizuoka prefectural results are reflected in both the Tokyo Electric and Chubu Electric Power Company Regions due to a shared supply arrangement. Hokuriku, Shikoku, and Okinawa Power Companies are not assessed

found to be true for comparative equity scores, demonstrated in Fig. 3. Plants located in the same towns and prefectures have nearly identical equity and burden values. For this reason, although Fig. 3 appears to feature 17 sites, the chart in fact displays results for all 29 plants.

To examine regional trends, we utilize variation in burden scores and normalized equity per MW among cases. The latter value essentially equates to the equity potential of a community when hosting mega-solar. In terms of equity per MW, mega-solar sites in Iwate and Wakayama Prefectures performed best, while in terms of a preferable burden distribution, Mie and Aichi mega-solar sites (both in the Chubu Electric Power Region) performed best, followed closely by Niigata. It is of note that in all power company regions except for the Kyushu electric power region, the order of equity and burden score outcomes are reversed (i.e., the highest equity scoring prefecture has the lowest burden score). This anomaly is discussed within Sect. "Factors of variation in burden and equity per MW" of the discussion and may be related to exogenous and pre-existing environmental conditions within the Kyushu electric power region. The implications of our social equity conceptualization and the significance of plant size and geographical variation in interpreting these results is discussed below.

Discussion

This paper assessed equity, weighted by the preferences of host community officials and the distribution of burden among income quintiles for 29 of Japan's 200 biggest mega-solar power plants. In this discussion, we outline the meaning of these results in terms of methodological considerations taken regarding social equity, weighting preferences, and scale. Subsequently, we discuss the variation in our results. We outline the degree of variation in equity per MW and burden scores explained by each energy policy factor, outlier cases, and policy implications.

Methodological considerations: social equity

It is important to explain what may appear in our survey responses to be paradoxical results about the importance of social equity. Local government officials consistently identified social equity as the least important on average of all listed factors (scoring 2.7 out of 5 in importance, with a SD of 1.4). Simultaneously, these officials responded favorably about the holistic, multifaceted components of social equity which were evaluated in this analysis, including carbon emission reduction, pollution reduction, electricity prices, job impacts, and community development.

We suspect that the term social equity remains outside the lexicon of local officials, and that when surveyed, respondents consistently more readily connect with concrete terminology such as employment or electricity prices rather than complex yet vague ideas such as social equity (2.7) or disaster resilience (2.9), which was not quantified in this analysis (see Fig. 2). The results indicate difficulty in clearly defining and translating taken-for-granted concepts such as social equity and burden distribution, and future research should potentially reconsider and refine the Japanese terms used in this survey. The authors' experience in the field suggests that officials are quite conscious of the diverse impacts of this technology in their community and are committed to maximizing community gains from projects wherever able (see Fraser and Chapman 2018), even if they do not frequently use the term social equity itself.

Methodological considerations: weighting local preferences

It is also important to consider how the model's use of weighting preferences affects our results. Based on our survey results, local officials prioritize pollution countermeasures the highest, followed by our combined category of environmental conservation/climate change countermeasures, tax base, electricity prices, and employment. Consequently, as discussed below, pollution countermeasures (PM offset) is the strongest predictor of equity. If, in a subsequent iteration of this study, employment became the most important, or indeed electricity prices, previously identified as critical to social equity (Chapman and Pambudi 2018), cases with high employment outcomes (such as the Kisoaki Reclaimed Area Mega Solar Plant in Mie Prefecture) would receive higher overall equity scores due to preference weighting.

Consequently, in this study, the responses allowed us to assess equity outcomes in terms of the priorities that officials found most relevant to their community's needs, as opposed to those of outsiders or national policymakers. For this reason, when equity returns on mega-solar siting in some regions, such as Tohoku, far exceeded those in others, such as Kyushu, these results reflect that net equity changes in Tohoku better matched municipal officials' goals for mega-solar than they did in Kyushu.

Methodological considerations: scale of analysis

Scale plays a decisive role in our analysis and results. As shown in Fig. 4, we considered multiple scales of data to capture the importance of geography and local context in the distribution of costs and benefits of mega-solar deployment. This methodology serves to fill an important gap in the literature; a lack of site-specific studies of equity that encompass more than a handful of cases. We based our analysis on local empirical data gathered through surveys and fieldwork; prefectural data on each area's energy and environmental characteristics; regional data related to fossil fuel generation by regional utilities; national data on income and emissions; and international data for industry-wide norms. In each part of our analysis, we used the most specific data available.

This attention to scale has implications for our findings. Because our equity and burden scores incorporate significant amounts of data from the prefectural scale, among others, we can more reasonably claim that the equity or burden values for a single municipal case study, such as Abira, Hokkaido Prefecture may be generalizable to the prefectural level and not only to the local level. This is

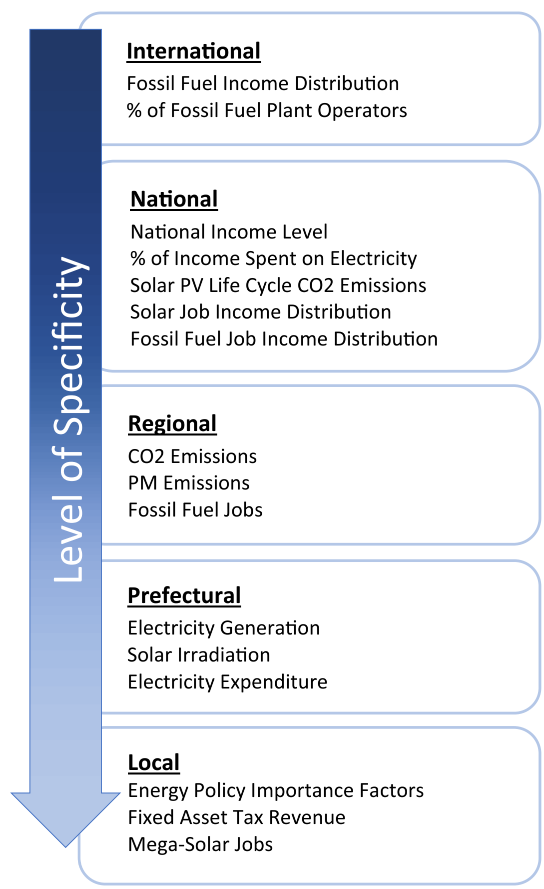

Fig. 4 Scale of factor specificity used to evaluate equity and burden

because our analysis draws from categories that remain largely consistent within prefectures, such as solar irradiation, energy generation related PM exposure, and the existing fossil fuel-related employment base.

Further, the consistent variation among regions and among prefectures within these regions adds weight to our findings that geography produces real, significant differences in equity outcomes for mega-solar. Future studies would do well to expand the external validity of our findings by randomly sampling an equal number of communities hosting mega-solar within each prefecture analyzed.

Next, we discuss the significance of plant scale and geographical variation among our results.

Variation by plant scale

Our findings confirm that, unsurprisingly, plant scale is positively correlated with equity outcomes in Japan (Fig. 5), as the larger a plant is, the more PM and CO_2 it will offset, and likely offer more employment opportunities within the region. Under the FiT, Japanese towns with more underutilized land to offer solar developers will make larger comparative equity gains. If installers adopt Japan's top-down, market-friendly approach involving a Feed-in Tariff and mega-scale projects, then planners should advocate for larger mega-solar plants, because larger plants offset more costs and health impacts from fossil fuels than smaller plants, although the additional benefit per MW tends to decrease as plant size increases. Alternatively, however, if installers of mega-solar adopt bottom-up initiatives such as local ownership of facilities and/or microgrids, in this case, plant size alone may not deliver the same kinds of equity gains anticipated from such economic innovations. Smaller, locally owned projects and vertically integrated, regional manufacturing of parts may be better for employment, tax revenue, and stakeholder engagement. These remain important considerations which are beyond the resolution offered within this study (see Fig. 4) and have not yet been quantified, but could be addressed through site-specific or comparative future studies.

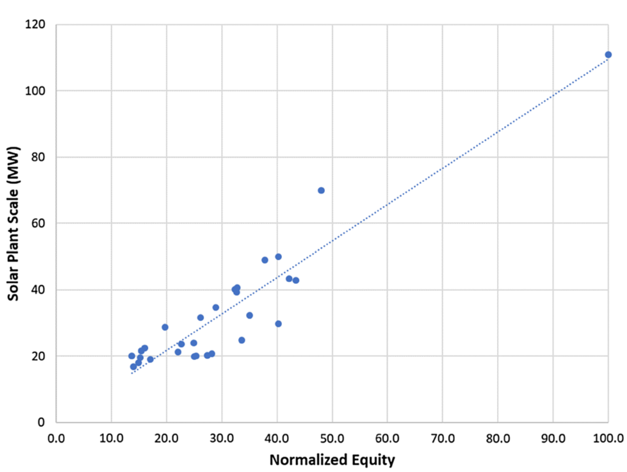

Fig. 5 Mega-solar plant scale and comparative equity scores from this study

Considering the results from Fig. 5, numerous cases deviate from the observed scale and equity line of best fit, suggesting that additional factors that need to be considered to explain equity outcomes. We discuss several factors which affect equity and burden variation below.

Variation by geography

One important implication of our study is that although size matters in equity, equity outcomes vary by geography. Numerous municipalities experience more or less equitable outcomes than what size alone predicts. Our research shows clear differences between the equity and burden scores among municipalities in different prefectures (see Table 2). Interestingly, we find that equity per MW and burden scores often vary even within regions.

This is noteworthy because there are numerous reasons why prefectures in the same region should instead share scores. First, solar irradiation, CO_2 intensity, and PM intensity extend across neighboring prefectural borders. Second, our calculations included several kinds of regional-level data from regional utilities, namely fossil fuel generation employment and electricity prices. Even so, as detailed in Table 3, prefectures within the same region can vary by up to 2.37 SD in equity per MW (Kansai) and 2.15 SD in terms of burden (Chubu). These figures are not comprehensive, because our study only considered 17 out of Japan's 47 prefectures, but they demonstrate the range of intra-regional variation in our results.

For example, in the Chugoku region, Okayama (1.09, 52.01), Yamaguchi (1.04, 52.51), and Tottori (1.01, 53.36) are within 0.34 SD of equity per MW of each other, but as far apart as 1.68 deviations of burden. In this case, Tottori's high net employment gains (0.51 jobs, at 1.84 SD above average) relative to Okayama (0.22 jobs, at 0.06 SD below average) may explain differences in burden. Our research showed that generation jobs generally go to lower income groups, thus tilting the burden of siting towards upper income groups. Meanwhile, Okayama owes much of its small equity per MW advantage over Tottori due to having a higher PM intensity ($0.4 > 0.24$ g/kWh), and therefore, more PM offset ($14.10 > 9.82$ megatons of PM/annum). The example of Chugoku clearly demonstrates how many characteristics can affect equity and burden scores. Therefore, policy solutions regarding mega-solar should consider the status of regional utilities, yet also be cognizant of individual prefectural characteristics.

Table 3 Variation in regional equity per MW and burden in terms of standard deviations

Region	Kyushu	Chugoku	Kansai	Chubu	Kanto	Tohoku	Hokkaido
Equity/MW	0.44	0.34	2.37	0.91	1.98	1.77	0.00
Burden	0.61	1.68	1.74	2.15	1.34	1.71	0.00

Factors of variation in burden and equity per MW

The factors which explain variation in prefectural equity and burden are clarified in this section. We assess how much energy policy factors and related variables in our analysis explain correlation with burden and normalized equity per MW scores. We outline the degree of correlation between factors in Table 4 in terms of their Pearson product moment correlation coefficient values, indicating the strength and direction of correlation. Below, we categorize variables in terms of statistical significance and relevance. The direction of causation is clearly established as these variables were used to derive site-specific burden and equity values.

The two factors which influence burden scores the most are the large amount of initial fossil fuel jobs in each locale ($r = -0.84$) and the net change in jobs after mega-solar siting ($r = 0.78$). The two factors which influence equity scores the most are initial PM intensity from prefectural generation, which impacts equity per MW very strongly ($r = 0.97$), as well as the amount of PM offset by solar generation ($r = 0.64$).

These findings suggest that the PM intensity of a prefecture is a better predictor of its equity per MW results than the amount of PM solar generation would offset. Because solar offsets the amount of demand for electricity from fossil fuel sources, areas with high-PM intensities make comparatively higher equity gains due to solar deployment compared with lower PM intensity areas. Furthermore, the relationship between megawatt-hours of solar power generated and PM offset does not vary geographically, unlike solar irradiation, CO_2 intensity, or fossil fuel generation-based employment. PM intensities remain within one standard deviation of the average in 22 of 29 cases and within 1.92 SD in the remaining seven cases. As a result, making a greater effort to offset PM emissions appears to improve local equity universally. This bodes well for local officials, who rate pollution countermeasures as their number one priority.

Additionally, a series of factors impart strong and statistically significant correlation with burden and equity scores. Unlike with equity, high initial PM intensities tend to adversely impact burden scores ($r = -0.55$), and high PM offsets decrease burden scores even more strongly ($r = -0.67$). This may be because communities with high PM intensity and subsequent offsets post siting are home to fossil fuel-based generation jobs, the demand for which declines in response to mega-solar deployment.

Table 4 Energy policy factors and correlation with burden and normalized equity/MW (bold, underlined values represent 'strong' relationships, where $r > \pm 0.5$)

Energy policy factors and related variables	Pearson product moment correlation coefficient (r)	
	Burden score	Normalized equity/MW
Environmental conservation		
CO_2 generation intensity (g/KWh)	− 0.43	0.20
CO_2 offset (MT/annum)	− 0.27	− 0.18
Pollution countermeasures		
PM generation intensity (g/kWh)	**− 0.55**	**0.97**
PM offset (MT/annum)	**− 0.67**	**0.64**
Electricity prices		
Reduction in tariff (Yen/kWh)	**0.66**	**0.54**
Scale of savings (Yen/Site)	0.47	0.00
Community tax base		
Fixed asset tax (Yen/annum)	− 0.13	− 0.24
Employment		
Fossil fuel jobs/TWh	**− 0.84**	0.16
New solar jobs	− 0.13	− 0.24
Net change in jobs	**0.78**	−0.13
Site-specific variables		
Scale (MW)	− 0.13	− 0.24
Solar irradiation (kWh/kW/annum)	− 0.02	**− 0.53**

Additionally, the loss of fossil fuel-based generation jobs disproportionately affects lower income groups.

For instance, Hokkaido hosts Japan's largest coal-fired power plant (Tomato-Atsuma). Not coincidentally, this prefecture's fossil fuel generation employment ranks 2.82 SD above the average at 198 FTE/TWh, resulting in one of the lowest burden scores of all assessed sites (50.64, 2.42 SD below average), in which upper income groups just barely shoulder more of the burden than lower income groups. This solar park ranks highest in terms of normalized equity due to high PM offsets (39.82 megatons, 3.59 SD above average) and considerable scale (111 MW). In spite of these factors, it ranks lowest among burden scores and among the lower half of equity scores per MW because of the high number of fossil fuel jobs lost.

Further, reducing electricity prices (customer tariffs) significantly improves burden scores ($r = 0.66$) and equity per MW scores ($r = 0.54$). In particular, burden distribution improves when electricity bills decrease because lower income groups benefit most from lower electricity prices, which constitute a higher percentage of their monthly expenses.

Finally, of the site-specific variables, prefectural solar irradiation (a factor indirectly relevant to equity, through its impact on PM and CO_2 reduction, as well as employment and electricity price outcomes) was shown to negatively impact overall equity per MW scores. In this case, higher solar irradiation does not make a community less equitable. Instead, this reflects the fact that prefectures in Kyushu, the sunniest of our regions considered, received the lowest values in equity per MW. This may be because Kyushu mega-projects lacked significant net change in jobs., i.e., the Kagoshima Nanatsujima Mega-solar Power Station generated 0.36 net jobs (0.87 SD above average), but reduced electricity spending by only 2.35 yen/kWh, some 0.96 SD below average while offsetting only 5.48 megatons of PM (0.44 SD below average). These lukewarm equity impacts are remarkable considering that the Nanatsujima plant is the second largest considered in our study at 70 MW, given that scale directly impacts net change in jobs and PM offsets. Such lackluster equity returns match with the findings of our previous study (Fraser and Chapman 2018). Kyushu's lower equity scores may be because some of these prefectures (namely Fukuoka) have already implemented aggressive environmental regulations, combatting local PM intensity and thus muting the amount of PM offset (see Fujikura 2001 and Low 2013). These pre-existing conditions may also explain the anomaly of equity and burden scores not being inverted as seen in other regions.

The following variables failed to display statistically significant correlation to equity per MW or burden scores: CO_2 generation intensity, CO_2 offsets, scale of savings in electricity prices, fixed asset tax revenue, new solar jobs, and scale. While plant scale did correlate with normalized equity alone, as described above, regression confirms that there is nothing innate about larger plants that makes them deliver greater equity outcomes. Instead, the statistically significant factors discussed above help explain deviations from the relationship between normalized equity and scale.

Outlier prefectures and policy implications

Recognizing that prefectural and municipal governments cannot adjust their regional characteristics to enhance the equity and burden outcomes of renewable siting, we identify outlier prefectures with unique characteristics for which mega-solar policy considerations are needed. We classify outliers as cases with unusually high values (standard deviations from the average greater than or equal to $\pm$ 1) in our four statistically significant energy policy factors: PM intensity, PM offset, reduction in tariff, fossil fuel jobs, or net change in jobs. This discussion point excludes solar irradiation because this criterion mostly highlights Kyushu prefectures' differences.

First, our analysis identified Iwate and Wakayama as high-equity score outliers. Iwate ties for first place in equity per MW at 1.35 (1.85 SD above average), propelled by high PM intensity (0.79 g/kWh; 1.92 SD above average), resulting in a below average burden score of 52.16 (0.53 SD below average). In terms of equity, Iwate officials' efforts at boosting renewable power capacity in the wake of the 2011 disaster have thus been well spent. This is good news for economic development in reconstruction era Tohoku.

Similarly, Wakayama ties for first place in equity per MW, largely due to high PM offset (25.62 megatons, 1.92 SD above average), linked to high PM intensity (0.78 g/kWh; 1.88 SD above average). Although Wakayama's burden score is 0.98 SD below average at 51.80, much like Hokkaido, Wakayama and Iwate demonstrate how siting in locations with high PM intensities can produce significant equity gains.

Second, our analysis identified Aichi and Mie as high-burden score outliers, accompanied by Tottori, Tochigi, and Ibaraki.

Aichi Prefecture has a high net change in jobs (0.42–0.52 jobs; 1.27–1.95 SD above average) and low fossil fuel generation employment (1.44 FTE/TWh; 1.61 SD below average), with the only downside being low electricity price reduction (1.84 yen/kWh; 1.37 SD below average). These lead to excellent burden scores (53.64; 1.30 SD above average) albeit meager equity per MW (0.81; 0.65 SD below average). Mie Prefecture shares similar characteristics (0.53 jobs, 144 FTE/TWh, and 1.84 yen/kW electricity price reductions, with especially low

PM intensity at just 0.04 g/kWh) with similar outcomes (53.93 burden and 0.77 equity per MW). These prefectures have natural advantages in terms of burden distribution because they lack significant fossil fuel infrastructure, but lag in terms of energy policy factors vital to equity.

Similarly, but less significantly, Tottori has a relatively high net change in jobs (0.51 jobs; 1.84 SD above average) and correspondingly mild fossil fuel generation employment (163 FTE/TWh; 0.05 SD below average), leading to an excellent burden score of 53.36 (0.96 SD above average), and a middling equity per MW score of 1.01 (0.29 SD above average). Consequently, Tottori appears to be a high value locale for siting mega-solar in terms of burden, preferable to neighboring prefectures such as Yamaguchi or Okayama.

Tochigi achieves a high reduction in electricity prices (5.13 yen/kWh, 1.27 SD above average) and also had high initial PM intensity (0.71 g/kWh; 1.61 SD above average), leading to a remarkable equity per MW score of 1.27 (1.44 SD above average), amidst a comparatively weak burden score of 51.84 (0.93 SD below average).

Ibaraki also achieves a high reduction in electricity prices (5.13 yen/kWh; 1.27 SD above average), leading to a strong burden score of 52.92 (0.41 SD above average), although equity per MW lags at 0.83 (0.54 SD below average).

Third, our analysis identified Hokkaido as a low burden and equity per MW outlier. Hokkaido, as discussed, has relatively high fossil fuel generation employment (198 FTE/TWh; 2.82 SD above average) and low net change in jobs (losing between 0.03 and 0.15 jobs; 2 SD below average), leading to the lowest burden score (50.64), although its high PM offset (3 SD above average) leads to only weak equity per MW (0.90). Although land is cheap on which to lease solar farms, burden and equity scores are naturally disadvantaged in terms of fossil fuel generation jobs lost. Hokkaido feels the *burden* of the solar transition more heavily than other prefectures. This may also relate to this region's history as an economically deprived region that experienced economic hollowing out as industries relocated into Japan's urban corridor (Edgington 2012; Wirth et al. 2016).

To summarize, the importance of PM intensity and offsetting in local preferences and equity impacts highlights how strongly pollution concerns continue to motivate perceptions of equity in Japanese energy policy. These findings hint at the lingering influence of the 1960s environmental movement and the 1970 pollution diet, which created the institutional architecture for the Ministry of the Environment and set precedents for environmental planning in local government offices (Avenell 2012). However, these findings also highlight an issue; because local officials in our study prioritized pollution countermeasures the highest on average, the most equitable cases (Wakayama and Iwate) lagged behind in terms of burden outcomes, which are not affected by PM, because low and high-income groups experience air pollution equally in the considered geographical region. This highlights the need for further research on how to reduce gaps between burden and equity outcomes.

Our findings suggest that it may be more beneficial to strategically deploy mega-solar en-masse first in areas such as Iwate and Wakayama that reap comparatively better equity outcomes than in Hokkaido. These findings suggest that a rural renewable energy revolution on Hokkaido's cheap, abundant land resources may not be as optimal a policy as scholars hoped (see, for example, Horio et al. 2015). Similarly, Aichi, Mie, Tottori, Tochigi, and Ibaraki offer highly competitive burden distribution due to significant electricity price reduction, high net change in jobs, and low fossil fuel generation employment. However, avoiding siting in areas such as Hokkaido could slow the transition to renewables and phase-out of fossil fuels in the region, leading local populations to miss out on long-term equity gains from solar job creation. Instead, regional equity and burden scores could be used to prioritize government financial support to ameliorate equity and burden imbalances.

Should future research prove this research's findings generalizable to Japanese municipalities, variables with strong and statistically significant correlation could constitute levers for selecting sites with better potential equity and burden distribution outcomes.

Policymakers could maximize equity per MW and burden outcomes by proactively encouraging facility siting in prefectures with high PM intensity, low electricity prices, or low fossil fuel generation employment attributes.

Alternatively, if municipal officials want to boost their burden distribution and equity outcomes, they could reactively offset the cost of electricity prices for lower income groups or design local schemes to transfer fossil fuel generation jobs into other sectors or vertically integrate manufacturing of parts for solar parks.

In the case of PM intensity, however, our equity policy factor correlations lead to a dilemma. If policymakers select sites with higher PM intensity and subsequent PM offset potential, our findings suggest that burden outcomes are weaker (although in every case assessed, a score of greater than 50 intimates that lower income groups' burden outcomes are positive overall). However, these sites experience better equity per MW outcomes. As discussed above, if, for example, companies site mega-solar plants in Hokkaido, which exhibits the highest PM intensity, host communities will consistently find these more equitable due to their perceived importance of PM reduction, however, due to lost fossil fuel jobs, burden distribution becomes sub-optimal. High PM intensity prefectures are likely to have greater concentrations of fossil fuel-based generation, meaning that replacement with mega-solar will have a large impact on this industry. This finding represents a major trade-off between equity and burden that policymakers need to consider.

This discussion has highlighted the importance of weighting local preferences and the assessment of multiple scales with regard to both burden allocation and social equity outcomes. Policymakers can use these findings to perform proactive, social equity and burden-aware mega-solar siting. Finally, this discussion identified Iwate and Wakayama as equity success cases, Aichi, Mie, Tottori, Tochigi, and Ibaraki as burden allocation success cases, and Hokkaido as an equity and burden challenge case, highlighting the need for policy responses to these challenges.

Conclusions

This research investigated mega-solar siting outcomes from a social equity point of view. The results clarified the equity and burden ramifications of siting, while identifying the underlying levers which influence these outcomes for each region analyzed. The results observed from the evaluation of 29 mega-solar sites across Japan are both meaningful and significant due to the methodology employed in conceptualizing social equity in this study. This methodology incorporated local officials' priorities into equity analysis, helping to create a more accurate picture of social equity desires in Japanese mega-solar host communities. The incorporation of local preference makes our model relevant to mega-solar hosting sites, and practical for the evaluation of future sites throughout Japan, identifying not only community desire but also realistic social equity outcomes which can be expected from mega-solar deployment.

Previous research regarding RE deployment and associated enabling technologies showed socially positive impacts including increased investment and localization of revenues, as well as positive behavioral changes including greater acceptance of RE projects, improved environmental awareness, and an increase in social capital and resilience to shocks (Mochizuki and Chang 2017; Motosu and Maruyama 2016; Abe et al. 2016; Hondo and Baba 2004; Raupach-Sumiya et al. 2015). This research digs deeper, identifying the underlying factors which are important to stakeholders, applying these factors and their perceived importance to an evaluation of social equity, and demonstrating individual factors' relationship to equity and burden outcomes at the local level.

This research has some limitations, identifying some opportunities for future work. First, the incorporation of storage, often considered necessary for the smooth integration of intermittent solar power to the grid, will impact upon our results, likely offering opportunities in some areas such as employment, while impeding others, namely cost. Additionally, it would be ideal to apply the framework established here to additional RE technologies under consideration for deployment in Japan, and abroad. Future efforts should also consider quantifying qualitative indicators such as disaster resilience and landscape degradation (Hori and Shibata 2017), as well as the consolidation of environmental conservation related factors, in line with survey and interview respondent's input. Further, while this research identified pollution countermeasures and environmental conservation as the most important energy policy factors of social equity, this preference may be related to national and cultural factors specific to Japan, identifying the need for further investigation of factors and their importance in other nations. Further, as this is the first attempt at capturing the social equity impacts of mega-solar deployment, a longitudinal study of preferences and deployment impacts could shed light on the ongoing impacts, taking into consideration technological learning curves and shifting preferences over time. Finally, the policy and social equity implications of a bottom-up approach to mega-solar siting could be investigated to specifically address the shortcomings of this research in terms of identifying the benefits of smaller, locally owned, vertically integrated projects when compared to their larger, top-down counterparts.

In addition to the limitations identified above, this research is a first attempt at identifying and quantifying the social equity impacts of mega-solar siting in Japan. Future work, including technological necessities, stakeholder engagement and scale and ownership issues need to be resolved before the proposed methodology may be used to conclusively justify the siting of mega-solar projects.

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Appendix

See Tables 5, 6, 7, 8, 9.

Table 5 Degree of importance for local energy policy according to local governments

Rank	MW	Prefecture	Municipality	Plant	Energy policy factor importance									
					①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
2	111	Hokkaido	Abira-cho	SOFTBANK Tomatō Abira Solar Park	4	5	4	5	3	1	1	3	1	1
4	70	Kagoshima	Kagoshima-shi	Kagoshima Nanatsujima Mega Solar Power Station	5	5	3	3	3	3	1	3	1	1
7	50	Aichi	Tahara-shi[a]	Tahara Solar Wind Power Station	5	5	5	1	1	1	2	2	2	2
8	49	Mie	Kisoaki-cho	Kisoaki Reclaimed Area Mega Solar	3	3	3	3	5	3	3	3	3	3
11	43.4	Shizuoka	Hamamatsu-shi[a]	Softbank Hamamatsu Nakao Solar Park	5	5	5	4	3	4	5	3	5	4
13	42.9	Tottori	Yonago-shi	SOFTBANK Tottori Yonago Solar Park	5	3	5	3	5	3	4	5	3	1
16	40.7	Aichi	Tahara-shi[a]	Tahara Solar Power Station 2	5	5	5	1	1	1	2	2	2	2
18	40.2	Aichi	Tahara-shi[a]	Tahara Solar Power Station 1	5	5	5	1	1	1	2	2	2	2
19	39.31	Hyōgo	Awaji-shi	Eurus Tsunato Solar Park	4	2	4	3	4	2	3	4	3	3
23	34.7	Hyōgo	Awaji-shi	Awaji Kifune Solar Power Station	4	2	4	4	4	2	3	4	3	3
29	32.26	Okayama	Kumenan-cho	Kumenan Mega solar power plant	5	3	5	2	5	3	3	5	3	3
30	31.6	Ibaraki	Daigo-cho	Fukuroda Solar Power Station	3	3	3	3	5	5	3	3	3	3
35	29.7	Wakayama	Arida-shi	Arita Solar Power Station	4	1	3	3	2	4	3	4	3	1
36	28.8	Kagoshima	Hioki-shi	Hioki Yōbo Power Station	5	4	4	3	3	5	3	3	3	3
47	24.79	Iwate	Hirono-cho	Wano Solar Power Station	5	4	5	5	3	5	5	4	5	5
52	24	Yamaguchi	Yamaguchi-shi	Smart Solar Yamaguchi Aki Power Station	5	4	3	3	3	3	3	4	3	4
53	23.55	Niigata	Agano-shi	Eastern Niigata Photovoltaic Power Plant	5	4	5	4	5	5	5	4	5	5
58	22.4	Kumamoto	Arao-shi	Softbank Kumamoto Arao Solar Park	5	2	2	5	4	4	3	5	4	3
62	21.52	Kumamoto	Ashikita-cho	Ashikita Solar Power Station	4	3	3	4	5	3	3	4	3	3
63	21.29	Yamaguchi	Ube-shi	US Power Solar Power Station	5	5	3	3	2	2	5	5	5	5
66	20.8	Iwate	Takizawa-shi	Takizawa City Mega Solar	4	4	4	2	4	4	4	5	3	3
69	20.2	Iwate	Ofunato-shi	Goyōzan Solar Power Station	5	5	5	3	1	4	5	5	5	5
70	20.01	Tochigi	Nakagawa-cho	Tochigi Solar Power Station	4	1	3	2	4	1	1	2	1	1
72	20	Kagoshima	Kirishima-shi	Kagoshima Kirishima Solar Power Plant	5	4	4	3	5	4	3	3	3	4
74	19.8	Tochigi	Nakagawa-cho	LS Nasu Nakagawa Power Station	4	1	3	2	4	1	1	2	1	1
80	19.5	Fukuoka	Miyawaka-shi	DREAM Solar Fukuoka Miyawaka	5	4	5	3	4	5	5	2	5	3
83	19	Hokkaido	Mukawa-cho	Mukawa Solar Power Plant	5	3	4	3	4	4	2	3	4	3
86	17.93	Hyōgo	Tanba-shi	NRE Yamanan Solar Power Station	5	1	5	5	1	1	1	1	1	1
92	16.82	Hyōgo	Inami-cho	Nikke Machinaka Power Station Akashi Tsuchiyama	3	0	3	3	3	0	0	3	0	0

Energy policy factors key: ① environmental conservation, ② climate change countermeasures, ③ pollution countermeasures, ④ electricity prices, ⑤ community tax base, ⑥ employment, ⑦ fair labor conditions, ⑧ community development, ⑨ disaster resilience, ⑩ social equity

[a]Data from in-person interview with local government representative

Table 6 Case municipality population characteristics (Source: Regional Statistics Database 2017)

Prefectures	Municipality	Pop. 2015	Taxable income 2015 (in 10,000 s of yen)	Arable land (ha) 2015	% of pop. employed	% workforce in agr/forestry 2011	% workforce in construction 2011
Hokkaido	Abira-cho	8148	14,728,726	7480	39.2	7.2	8.8
Hokkaido	Mukawa-cho	8596	9,361,549	6690	42.9	18.3	14.4
Iwate	Ofunato-shi	38,058	39,694,628	747	35.1	0.7	15.7
Iwate	Takizawa-shi	55,463	62,733,497	3460	24.7	1.6	12.5
Iwate	Hirono-cho	16,693	14,806,673	3010	22.2	8.5	21.6
Ibaraki	Daigo-cho	18,053	16,475,146	2180	37.9	1.7	15.6
Tochigi	Nakagawa-cho	16,964	17,793,230	2930	35.9	2.1	9.9
Niigata	Agano-shi	43,415	45,687,978	6850	37.8	4.4	16.6
Shizuoka	Hamamatsu-shi	797,980	1,203,489,359	12,600	46.4	0.5	6.5
Aichi	Tahara-shi	62,364	92,254,327	6330	53.0	2.7	6.0
Mie	Kisoaki-cho	6357	8,410,446	540	47.9	2.7	7.2
Hyogo	Tanba-shi	64,660	72,481,751	5640	40.8	0.4	8.0
Hyogo	Awaji	43,977	44,505,605	3240	38.7	0.8	7.7
Hyogo	Inami-cho	31,020	39,118,703	1610	45.3	1.0	5.1
Wakayama	Arida-shi	28,470	30,150,042	1310	38.6	1.3	11.8
Tottori	Yonago-shi	149,313	182,437,671	2990	44.8	0.2	7.9
Okayama	Kumenan-cho	4907	4,346,413	1190	25.9	4.4	9.1
Yamaguchi	Ube-shi	169,429	215,746,910	2690	42.9	0.3	8.2
Yamaguchi	Yamaguchi-shi	197,422	254,271,985	9220	43.9	1.1	7.5
Fukuoka	Miyawaka-shi	28,112	26,912,957	1780	69.9	0.4	3.8
Kumamoto	Arao-shi	53,407	49,617,730	1470	28.0	0.3	7.4
Kumamoto	Ashikita-cho	17,661	13,641,384	1620	30.7	1.3	11.4
Kagoshima	Kagoshima-shi	599,814	741,893,818	3380	46.3	0.2	7.0
Kagoshima	Hioki-shi	49,249	44,991,729	3270	35.6	1.1	8.7
Kagoshima	Kirishima-shi	125,857	130,139,984	6010	41.6	1.1	6.3

Table 7 Interview participants (further detailed in Fraser and Chapman 2018)

Municipality	Name	Sex	Position
Sapporo City, Hokkaido Prefecture	Yoshimichi Higashihara	M	Hokkaido Prefectural Government Office of Environment and Energy Rep.
Abira Town, Hokkaido Prefecture	(Confidential)	M	Abira Town Development Division Rep.
Tomakomai City, Hokkaido Prefecture	(Confidential)	M	Tomatō Corporation Reps.
Tomakomai City, Hokkaido Prefecture	(Confidential)	M	Tomakomai Business Official
Mukawa Town, Hokkaido Prefecture	(Confidential)	M	Mukawa Town Policy Division Rep.
Mukawa Town, Hokkaido Prefecture	Teruyoshi Ozawa	M	Mukawa Town Chamber of Commerce Rep.
Nagoya City, Aichi Prefecture	Masayuki Kawakami	M	CTECH Corporation Renewable Power Project Office Official
Tahara City, Aichi Prefecture	(Confidential)	M	Tahara City Hall Env. Policy Division Rep.
Tahara City, Aichi Prefecture	(Confidential)	M	Tahara City Business Rep.
Tahara City, Aichi Prefecture	Kiyotsugi Watarai	M	Tahara City Council Chairman
Tahara City, Aichi Prefecture	Masaaki Ōtake	M	Tahara City Council Vice Chairman
Tahara City, Aichi Prefecture	Hideo Kokubo	M	Tahara City Council Office Rep.
Hamamatsu City, Shizuoka Prefecture	(Confidential)	M	Hamamatsu City Hall Energy Policy Rep.
Awaji City, Hyogo Prefecture	Koichi Matsumura	M	Awaji Kifune Solar Power Plant Rep.
Awaji City, Hyogo Prefecture	Yasuhiko Kado	M	Awaji City Mayor
Awaji City, Hyogo Prefecture	Yuka Hirano	F	Awaji City Hall Public Relations Manager
Kagoshima City, Kagoshima Prefecture	Eiichiro Noguchi	M	Kagoshima City Council Member
Kagoshima City, Kagoshima Prefecture	Katsuhiro Taniguchi	M	Kagoshima City Hall RE Promotion Director

Table 8 Regional variables

Prefectures	Solar generation (kWh/kW/annum)	CO_2 from generation (g/kWh)	PM from generation (g/kWh)	Fossil fuel-generation jobs (FTE/TWh)[a]
Aichi	1121.75	482	0.09	31.68
Fukuoka	1049.75	528	0.14	36.52
Hokkaido	1087	676	0.33	43.56
Hyogo	1081.75	496	0.13	34.76
Ibaraki	1049.75	491	0.15	37.4
Iwate	996.5	559	0.79	36.74
Kagoshima	1119	528	0.07	36.52
Kumamoto	1095	528	0.09	36.52
Mie	1111	482	0.04	31.68
Niigata	946	559	0.23	36.74
Okayama	1092.5	700	0.40	35.75
Shizuoka	1145.75	486.5[b]	0.34	34.54[3]
Tochigi	1057.75	491	0.71	37.4
Tottori	954	700	0.24	35.75
Wakayama	1105.75	496	0.78	34.76
Yamaguchi	1044.5	700	0.32[c]	35.75
Data sources	Kitamoto (2017); NEDO (2017)	Federation of Electric Power Companies of Japan (2016); Energy Information Center (2017)	Ministry of the Environment (2014); Agency for Natural Resources and Energy (2017)	TEPCO (2017); KEPCO (2017); Energia (2017); Kyuden (2017); Chuden (2017); HEPCO (2017); Tohoku-EPCO (2017); Payscale (2017); DOE (2017); Electrical Engineer Qualification and Reports (2017); Employment Case Studies (2017); see footnote 2

[a]22% of all electrical utility jobs (based on international precedent)

[b]Shizuoka is serviced by Tokyo and Chubu power companies. The average CO_2 intensity and employment figures are used

[c]No PM data was available for Yamaguchi prefecture, so the average of the Chugoku region prefectures is used

Table 9 Employment and tax revenue data

No.	Plant size (MW)[a]	Plant jobs (full-time employees)	Plant tax revenue	Sources[b]
Average	40.1	1.44	¥15,871,513	
1	40–111	0		Fieldwork
2	40–111	2	¥40,986,050	Fieldwork
3	40–111	0		Fieldwork
4	30–40	4		Fieldwork
5	30–40	1		Fieldwork
6	24–30	5		Fieldwork
7	24–30	0		Fieldwork
8	20–24	0	¥17,000,000	Fieldwork
9	1–20	1		Fieldwork
10	1–20		¥2,500,000	Mainichi Shimbun (2012)
11	1–20		¥3,000,000	Ministry of Economy, Trade and Industry (2013)

[a]To preserve the confidentiality of our respondents, we indicate plants by the range of their size

[b]Since our list of interviewees has been published before, to protect the identities of any interviewees, we identify any response gathered either from survey or interviews as "fieldwork"

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