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Comprehensive Evaluation of Photovoltaic Solar Plants vs. Natural Ecosystems in Green Conflict Situations

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Abstract: This study aims to develop a comprehensive method for evaluating the environmental cost/benefits of photovoltaic (PV) solar plant installation versus conserving natural ecosystems. First, the positive and negative impacts of installing PV solar plants in regions with natural ecosystems are reviewed. For focus and quantification, climate change mitigation and economic benefit were considered as benefits, and the loss of carbon sinks and biodiversity as well as disaster risk were considered as negatives. These items were also integrated as external costs using a life-cycle assessment method, and a ratio of positive versus negative impacts (P/N ratio) was developed, as part of our evaluation. The method was applied to a case study in Hyogo Prefecture, Japan, where 361 large PV solar plants have been installed in areas that previously supported natural ecosystems. Prior to the PV installation, 25.5% of the plants were cleared from the natural ecosystem. Consequently, the annualized benefits (costs) for these Hyogo plants were estimated to be 101.16 (73.88) million USD, which yielded a P/N ratio of 1.37, indicating that their benefits outweighed their costs. An economic benefit was found to be one of the parameters that significantly influenced the P/N ratio.

Keywords: green conflict; mega PV solar plant; natural ecosystems

1. Introduction

The trend toward decarbonization for climate change mitigation has been accelerating worldwide. For example, Japan has declared a medium-term reduction target for greenhouse gas (GHG) emissions of 26% compared to 2013, by 2030, and a long-term reduction target of 80% by 2050 [1]. This is a "promise" set by Japan, based on the Paris Agreement concluded in 2015, with other countries around the world committing to similar targets, and developing policy and work programs to meet them. One of the popular tools for achieving decarbonization, the broad adoption of renewable energy, has been widely promoted. Japan has also committed to increasing the ratio of renewable energy for power generation, from 16.1% in 2017 to 22–24% by 2030 [2].

Various renewable energy sources, such as wind and geothermal, are in use, and the introduction of photovoltaics (PV) systems has been progressing rapidly since initiation of the Feed-in Tariff (FIT) economic incentive scheme by Japan, in 2009. This commitment to the rapid transition to renewable energy received added impetus following the 2011 Fukushima Daiichi nuclear incident. Japan's total solar generation capacity in 2017 was 49,040 MW, which was approximately 14 times larger than it had been in 2010, before the Fukushima incident (3618 MW), and was the second largest solar generation capacity in the world, after China [3]. As of September 2018, there were 5536 mega PV solar plants (plants with a total generation capacity ≥ 1 MW) operating in Japan [4].

The FIT scheme targeted residential power generation systems, and since its introduction, both business solar PV use, such as that provided by mega PV solar plants, as well as residential use, have rapidly increased. For example, Japan's cumulative PV module shipments in 2010 accounted for 462 MW of capacity, which increased to 35,352 MW in 2018 [5]. This dynamic PV expansion is expected to slow down in due course, owing to the FIT scheme incentive payment reductions described further below, however PV is still expected to be promoted to achieve national decarbonization and renewable energy introduction targets.

PV has been referred to as having various benefits (positive impacts), such as climate change mitigation and economic benefit, however its potential and actual costs (negative impacts) should not be ignored. For example, when natural ecosystems, such as forests and moorlands, are cleared for PV solar plant installation, negative impacts occur, including loss of carbon sink due to forest and biodiversity removal. Other impacts include damage to PV systems caused by natural disasters.

Skogen et al. [6] declared that some of the proposals put forward to stem climate change, such as the installation of wind farms, hydro-power, solar plants, and biofuel systems, are met with resistance on the grounds that they threaten biodiversity and other natural values. The rapid construction and operation of PV solar plants has also met with opposition from local residents throughout the country. The Japan Ministry of Environment [7] has reported that there were 234 complaints regarding the environmental impact of PV plants between 2015 and 2018, with 57% of these related to the destruction of natural ecosystems, landslide risk, and landscape value loss. The national government requires a PV plant operator to produce an environmental impact assessment (EIA) when proposing a large-scale PV power plant, and many local governments have enforced ordinances to regulate environmental conservation measures and control PV plant locations, from the landscape protection and disaster prevention viewpoints.

There are, however, no laws or ordinances which regulate PV plant installation. In particular, damage to PV solar plants due to natural disasters, such as earthquakes and typhoons, has been reported by the Japan Ministry of Economy, Trade, and Industry [8]. There have also been problems such as illegal logging in national parks, and inadequate consensus building between residents and solar energy companies, prior to PV solar plant installation. Consequently, in some cases, PV solar plant installation plans have been forced to cease, and/or local residents have filed suits to suspend the actions of solar energy companies. National and local governments have also enforced laws and ordinances that include strict environmental regulations regarding PV solar plant siting [9].

The widespread adoption of renewable energy has been promoted by national and local governments as a key mechanism for climate change mitigation. However, the decision-makers need to conduct cost/benefit analyses for PV system installations on a case-by-case basis, to ensure that their decisions can weigh up the positive benefits and negative impacts of individual proposals. The conflicts and collisions caused by the mixture of benefits and impacts on natural ecosystems have been referred to as 'green conflicts'. As an example of a green conflict, it has been reported by the International Institute for Sustainable Development [10] that the rapid increase in demand for resources such as gallium and germanium, necessary for the manufacture of renewable energy equipment, has caused conflict and violence among stakeholders in resource-mining countries.

In the study reported here, conflict between the public interest, in promoting PV generation, and the preservation of natural ecosystems, has been defined as a green conflict related to PV generation. When a solar energy company plans to clear a natural ecosystem to install a PV solar plant, consensus building is performed among stakeholders, such as local government, residents, and the company—although this can be quite challenging under a green conflict situation. One of the issues has been that there are few methods by which the benefits and costs involved in green conflicts can be quantitatively and comprehensively evaluated. This situation makes reasoned consideration difficult for stakeholders and complicates decision-making over contentious PV plant proposals.

In our work, we aimed to develop comprehensive and quantitative methods for evaluating the benefits and costs of installing PV solar plants vs. preservation of natural ecosystems, under green conflict scenarios, to assist decision-making by national and local governments. To achieve this aim, we have described the costs and benefits of installing a PV solar plant when natural ecosystems have to be cleared. Methods for quantifying these costs and benefits, and for their comprehensive evaluation, have then been proposed. A case study involving assessing installation of mega PV solar plants in Hyogo Prefecture, Japan, was then conducted, using the methods developed in this study.

Solar energy industry national associations and organizations have published installation standards and/or guidelines for mitigating PV solar plant installation impacts—although the impact descriptions are generally limited to explanations of the applicable laws and/or regulations. Many studies have focused on PV solar plant installation costs and benefits, including climate change mitigation [11–13], reduced dependence on fossil fuels [14], landscaping [15,16], land use [17,18], and the disposal and recycling of PV wastes [19]. Some studies have also evaluated the external costs of the merits and demerits of environmental issues which cannot be expressed in monetary terms [20–24].

There have also been studies in which the effect of PV on climate change mitigation, biodiversity loss, and other environmental impacts have been evaluated as external costs, using a life-cycle assessment (LCA) methodology. Fraser and Chapman [25] conducted an interview survey with Japanese local governments who operate mega PV solar plants. They determined that there was little social fairness involved, given that the solar energy companies rented land from local governments at low cost, a limited amount of their profit was returned to the local governments, and few local jobs were created.

A comprehensive evaluation of the costs and benefits of PV solar plant installation is desirable to assist decision-makers trying to determine their feasibility. Many studies have only evaluated one or two impacts however, and the comprehensive evaluations that have been performed have been elementary, using only the basic LCA unit—and most of these studies have been qualitative analyses, rather than quantitative. Originality of this study is to propose new approach that the costs and benefits of PV solar plant installation have been quantified, based on existing examples of plant installation and natural ecosystem clearance, using LCA, satellite information, and hazard maps. Another originality of this study is to propose a concept of the positive to negative impact ratio (P/N ratio) for new comprehensive evaluation considering economic value and external costs, to clarify whether individual project costs or benefits might be greater.

2. PV System Costs and Benefits

Decisions on PV power system installation apply national and local strategies with respect to environmental and economic perspectives. If a PV power system requires clearing natural ecosystems such as forests and moorlands prior to their installation, the costs and benefits of such installations need to be discussed. In Figure 1, we have illustrated the relationship between a PV system and natural ecosystems, using the arguments covered in Section 1. The positive impacts (benefits) of PV system operation include contribution to national climate mitigation and achieving renewable energy targets, stimulation to the national and local economies, and use of technological innovation. On the other hand, the installation of PV systems in forest areas and moorlands negatively affects (costs) natural ecosystems by destroying habitats and landscapes. This also causes loss of water-holding capacity when slopes become deforested, increasing the potential for landslides during heavy rainfall. Such events also involve a secondary effect, e.g., the collapsing of solar arrays as the land slips. Such potential costs can cause additional negative effects in areas where PV systems are installed, including decreased attachment by residents to the area and increased local disaster risk. These costs and benefits seem to be distinct. However, they are interrelated.

In this study, climate change mitigation and economic benefit were assigned as benefits (positive impacts), while loss of carbon sinks and biodiversity, together with increased disaster risk levels, were treated as costs (negative impacts), based on the relationship illustrated in Figure 1. These are factors which national and local governments should consider before allowing forest ecosystems to be cleared and PV plants to be installed, and are explained in more detail in the following sections.

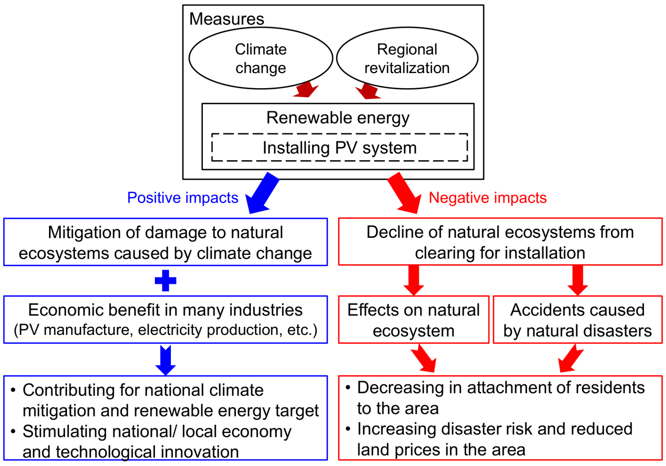

Figure 1. Relationship between a PV system and natural ecosystems.

2.1. Benefits (Positive Impacts)

2.1.1. Climate Change Mitigation

As explained in the introduction, many governments have identified climate change as a global concern. In use, PV solar arrays generate significantly less GHG emissions than thermal power production using fossil fuels such as coal or natural gas [26]. Significant PV array uptake and deployment can therefore make an important contribution to meeting GHG reduction targets.

2.1.2. Economic Benefit

The Mizuho Information & Research Institute, Inc. (Tokyo, Japan), [27] has forecast that PV could have an economic effect as large as 26 trillion JPY (247.0 billion USD; the exchange rate applied was 0.0095 USD = 1 JPY, as of 23 September 2020), affecting many industries in Japan, and based on the Japanese government outlook for renewable energy. There are a wide variety of industries involved in the various aspects of renewable energy adoption, including manufacturing, operating, distribution, and construction. PV manufacturing also involves various processes, from the production of materials to the assembly of panels. The construction of PV manufacturing plants and/or PV solar plant operations in areas where there has previously been no major industry can be expected to create both economic progress and new jobs.

Since 2008, Japan has been implementing an "Environmental Future City Initiative", with the aim of building environmentally, socially, and economically sustainable model cities [28]. 30 cities and regions have been selected as suitable candidates for action under this initiative, and many are implementing renewable energy programs to achieve environmental targets. Such strategies aim to achieve not only GHG emission mitigation, but also regional revitalization.

The existence of the Japanese FIT scheme has motivated many private companies to enter the solar energy industry. Under this scheme, if a renewable energy producer requests an electric utility to sign a contract to purchase electricity at a fixed price and for a long-term period guaranteed by the government, the electric utility is obligated to accept this request. In Japan, the full-scale FIT scheme started in FY2012 for the solar, wind, geothermal, biomass, and small hydro-energy industries. The purchase rate under the FIT scheme is reviewed annually, considering the introduction of various power sources. Table 1 shows the FIT purchase rate for power produced by mega PV solar plants. Under the FIT scheme, solar energy companies apply to the national government to receive approval for a usage plan, and if the plan is certified, the purchase rate for that year will continue to be applied for 20 years. For example, a solar energy company certified in FY2012 will have a purchase rate of 42 JPY/kWh (0.40 USD/kWh) for 20 years [29]. The highest purchase rate was set for various renewable energy sources when the full-scale FIT scheme was initially implemented, in a political decision which resulted in a significant increase in the amount of PV introduced, compared with other renewable energy sources.

Table 1. Power purchase rates for mega PV solar plants [30].

Fiscal Year (FY)	Purchase Rate [1] [JPY/kWh (USD/kWh)]	Fiscal Year	Purchase Rate [1] [JPY/kWh (USD/kWh)]
FY2012	42.00 (0.40)	FY2016	25.92 (0.25)
FY2013	37.80 (0.36)	FY2017	22.68 (0.22)
FY2014	34.56 (0.33)	FY2018	19.44 (0.18)
FY2015 (April 1 to June 30)	31.32 (0.30)	Since FY2019	Decided by tendering
FY2015 (From July 1)	29.16 (0.28)		

[1] Consumption tax is included.

The FIT PV power purchase rate has since been reduced annually, to motivate the increased introduction of other renewable energy sources. In addition, a tendering system, which will determine the purchase rate after FY2020, has been introduced, and overall, it is clear that economic benefit has functioned as the key motivating incentive for private company involvement with renewables.

2.2. *Costs (Negative Impacts)*

2.2.1. Loss of Carbon Sink

Ecosystems provide us with various services, including that of a carbon sink, which helps lock up carbon-based GHGs [31]. If forests are cut down to install PV solar plants, the CO_2 sink in the installation area will be lost. Figure 2 consists before and after mega solar plant installation Google Earth satellite images. In this case, 401,800 m^2 of forests and farmland were removed, to allow a 21.3-MW PV solar plant to be installed.

Figure 2. Satellite imagery for before (**left**) and after (**right**) installation of a collection of mega solar plants.

2.2.2. Biodiversity Loss

Biodiversity expresses the variety of life on earth. In our work, we focused on forest loss as a biodiversity loss. Figure 3 shows examples of forest loss associated with the installation of PV solar plants in a mountainous area. When ecosystems are cleared to install PV solar plants, vegetation is lost in the area, and animals which relied on that vegetation (for food and shelter, and so on) would have to relocate to another area. PV solar plant installation therefore contributes to regional biodiversity loss, as has been illustrated in Figure 4 which shows land use before mega solar plants were installed in Hyogo Prefecture, Japan, as reported by Electrical Japan [4]. Among the installations, we focused on 177 plants which had been constructed in areas for which the land use before installation was known. We were able to show that (1) rooftops of factories and the sides of buildings, (2) vacant, idle, and development land, and (3) landfill and land-reclamation sites accounted for approximately

20% of the total land use each, demonstrating that these mega PV solar plants had been installed in spaces that were generally not in use at the time. The results also revealed that approximately 20% of the plants led to the modification of forests or moorlands during their construction. This percentage was similar to the percentages of the three aforementioned land uses, showing that the amount forests and moorlands that had been cleared was not negligible.

(**a**) Near the housing (**b**) Near the construction company

Figure 3. PV solar plants installed on steep hillsides. Photography by author.

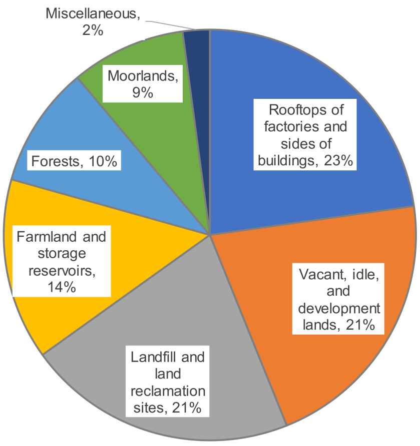

Figure 4. Land uses before installation of the mega solar plants.

2.2.3. Disaster Risk

When a PV solar plant is installed on a mountain slope, as shown in Figure 3, in a negative aftereffect associated with forest loss, the deforested slope loses its water-holding capacity, leading to the increase in landslide risk during heavy rainfall events. In such cases, secondary impacts, such as the collapse of the associated solar array, can also occur. This exact scenario has been captured in the imagery presented as Figure 5, and the Japan Ministry of Economy, Trade, and Industry [8] has reported that, in 2018, 48 such accidents were caused by natural disasters at Japanese PV solar plants.

(**a**) Distant view (**b**) Close view

Figure 5. PV system damaged by a landslide. Photography by author.

3. Materials and Methods

3.1. Cost and Benefit Quantification

The five cost and benefit factors discussed in Section 2 were targeted for quantification, and the evaluation methods applied to each have been discussed in the following sections. In this study, the denominator of the various positive and negative impacts, with the exception of economic benefit, was expressed using the unit m^{-2} to facilitate integration.

3.1.1. Climate Change Mitigation

PV contributes to power generation GHG mitigation, although GHGs are emitted in processes such as PV solar facility materials mining, element manufacturing, transportation, and construction. In this study, life-cycle GHG emissions, including CO_2, CH_4, and N_2O, were calculated using the LCA method. The equipment targeted included solar panels, mounts, and concrete foundations (Figure 6), which, as estimated by Imamura et al. [32], account for 76% of the life-cycle GHG emissions emitted from PV solar array development and installation. Contributions from other equipment, such as power conditioners and electric cables, and other processes, such as transportation and construction, were therefore neglected, because of their small contribution toward GHG emissions. PV system operating life was assumed to be 20 years, which allowed annualized GHG emissions to be calculated using the formula presented as Equation (1):

$$GHG = \frac{\sum_x (m_x \times \alpha_x) + \sum_x \beta_x}{y} - P \times \alpha_p, \quad (1)$$

where *GHG* stands for annual GHG emissions (as $kgCO_{2eq}/m^2$), m_x indicates the weight or area of material x (as kg/m^2 or m^2), α_x denotes the GHG emission intensity per unit of volume of material x (as kg CO_2/kg), and β_x shows the GHG emission intensity per unit of area of material x (kg CO_2/m^2). Symbol y represents the usage time (= 20 years), P stands for the estimated annual power generation in the grid power company (as kWh/m^2), and α_p indicates the overall CO_2 emission intensity of the grid power company (as kg CO_2/kWh).

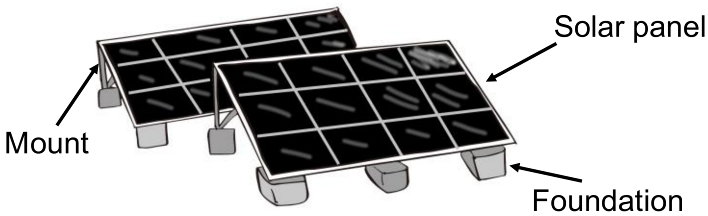

Figure 6. PV system elements prone to damage by landslides.

GHG emissions were calculated based on the weight or area of material used for the solar panels, their mounts, and their foundations, using the GHG emission intensities for the materials, as listed in Table 2. Weight and area data were collected from reports and statistics published by companies, national associations, and the national government through online surveys. GHG emission intensity was applied from the Japanese life-cycle inventory database "Inventory Database for Environmental Analysis (IDEA) version 2.2" [33]. In this study, the substitution effect of GHG emissions by PV generation was calculated by estimating the annual power generation and CO_2 emission intensity of the grid power company. The substitution effect refers to the substitution of fossil fuel-based power generation by the power company with PV solar array power generation.

Table 2. Fundamental data for calculating GHG emissions.

Product	Material	Weight or Area of Material		GHG Emission	
Mount	Steel	16.2	[kg/m^2]	2.16	[kg CO_{2eq}/kg]
	Aluminum foil	0.5	[kg/m^2]	12.6	[kg CO_{2eq}/kg]
Foundation	Concrete	107.7	[kg/m^2]	0.212	[kg CO_{2eq}/kg]
Solar panel	Glass	1	[m^2]	26.7	[kg CO_{2eq}/m^2]
	Aluminum frame	2.16	[kg/m^2]	11	[kg CO_{2eq}/kg]
	Plastic	2.44	[kg/m^2]	4.55	[kg CO_{2eq}/kg]
	Cell (Crystalline Silicon)	1	[m^2]	767	[kg CO_{2eq}/m^2]

The estimated annual power generation from the grid power company was calculated using Equation (2):

$$P = \frac{r \times d \times o \times l}{s}, \tag{2}$$

where r represents the annual average solar radiation (as kWh/m^2/day), d indicates the annual operating days (as days, and in this case = 365), o denotes the total output of the PV system (as kW), l stands for the loss factor, and s represents standard solar radiation intensity [kW/m^2].

Data published by the New Energy and Industrial Technology Development Organization [34] were applied, varied as required with respect to region, to calculate annual average solar radiation. For example, the annual average solar radiation in the case study area, Hyogo Prefecture, Japan, has been listed as being 3.38 kWh/m^2/day. The loss factor was set at 73% [35], and the standard solar radiation intensity specified by Japanese Industrial Standards (1.0 kW/m^2) [36], was used to measure the characteristics of the PV cells and modules. The CO_2 emissions released during power generation by grid power companies were taken to be 0.35 kg CO_2/kWh, for FY 2018 [37].

3.1.2. Economic Benefit

The benefits obtained from the FIT scheme belong to PV companies, although they do create local jobs and return benefits to the region where the PV plant is operated—and so, from this perspective, the benefits obtained from the FIT scheme might be considered social benefits. In this study, it was assumed that profit from the FIT scheme was a benefit (positive impact).

The economic benefit obtained by operating the PV solar plants was calculated by estimating annual PV power generation, and combining this with the FIT scheme purchase rate, as shown in Equation (3):

$$B = P \times r_f, \tag{3}$$

where B indicates the annual economic benefit (in JPY), r_f represents the FIT scheme purchase rate, taking the approval year and month, f, into consideration (as JPY/kWh).

The PV solar plant approval year and month were obtained from a Japan Agency for Natural Resources and Energy database [38], and the total output from Japanese PV solar plants was obtained from an Electrical Japan [4] database. The purchase rate established when the approval year and month were applied can be seen in Table 1.

3.1.3. Loss of Carbon Sink

Each tree in a forest absorbs CO_2 from the atmosphere during photosynthesis and grows by storing carbon while generating oxygen. The Intergovernmental Panel on Climate Change [39] reports that agriculture, forestry, and other land uses are a significant net source of GHG emissions, contributing approximately 23% of total anthropogenic CO_2, CH_4, and N_2O emissions, which have been combined as CO_2 equivalents (CO_{2eq}) for 2007–2016. The ability of forests to serve as CO_2 sinks varies with species, location, and age [40], with variations in climate and vegetation varying by country and region, thereby varying their abilities to serve as CO_2 sinks. Vegetation surveys in each region are required to calibrate local CO_2 absorption amounts, so in this study, the Japanese average CO_2 absorption was calculated using Equation (4):

$$GHG^a = \frac{CO_2^a}{A} \times GWP_{CO2}, \tag{4}$$

where GHG^a shows annual GHG absorption by forests (as kg CO_{2eq}/m^2), CO_2^a indicates the annual CO_2 absorption by forests in Japan (as kg CO_2), A represents the total Japanese forested area (as m^2), and GWP_{CO2} indicates the global warming potential of CO_2 (=1.0).

3.1.4. Biodiversity Loss

Biodiversity is closely linked to locality and local climate, as is the case for carbon sink loss. Therefore, accurately measuring the biodiversity loss associated with the installation of a PV solar plant is difficult. In this study, the reduction in forest area caused by solar power plant installation was adopted as a proxy for biodiversity loss.

3.1.5. Disaster Risk

- Landslide hazard map

If PV solar plants are installed in landslide hazard areas, there is a risk of damage from landslides caused by earthquakes, typhoon rains, and so on (Figure 5). In this study, a PV solar plant location map was overlain onto a landslide hazard map, to identify PV solar plants located in high landslide risk areas (Figure 7). A geographic information system was then used to evaluate the overlay. PV solar plant locations were determined using address data from plants approved under the FIT scheme [38], while mapping published by the Japan Ministry of Land, Infrastructure, Transport, and Tourism [41] was used to identify landslide hazard locations.

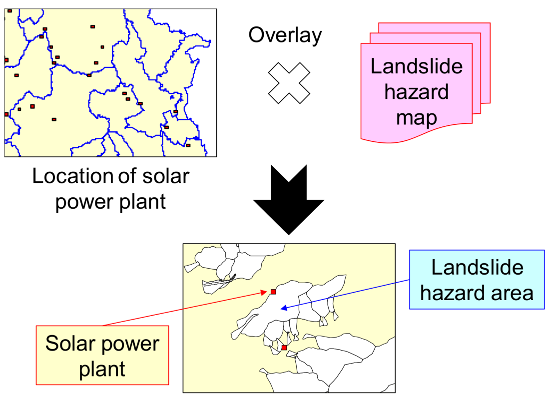

Figure 7. Overlaying mega PV solar plant locations and landslide hazard areas.

- PV solar plant damage

When a PV solar plant is destroyed by a landslide, all PV system materials are assumed to be lost, and the damaged material is rebadged as disaster waste. In this study, disaster risk has been expressed in terms of the quantum of potential disaster waste. This amount included damaged equipment such as solar panels, mounts, and foundations, and was calculated by multiplying the weight of each equipment element per installed area by the installed area per solar panel and the number of solar panels damaged, as shown in Equation (5):

$$W = \sum_y e_y, \tag{5}$$

where W represents the potential disaster waste derived from the PV solar plant (as kg/m^2), e_y indicates the weight of equipment y per installed area (as kg/m^2), and y represents all equipment (that is, solar panels, mounts, and foundations).

To calculate solar panel weight and area data, unit weight information was acquired from the catalogs of 12 major domestic industrial PV system manufacturers, in relation to product available for sale as of January 2019 (94 products in all). Mount and foundation weights were calculated using weight and installation area data published by the Japan Photovoltaic Energy Association [42], as a guideline for ground-mounted PV systems. The tilt angle of the array (the angle at which solar panels are aligned) was 20°, and it was assumed that the same unit weight and area intensity data could be used, irrespective of PV system installation location.

3.2. Case Study

A cost/benefit case study was conducted for mega solar plants in Hyogo Prefecture, Japan, where 361 plants had been installed as of September 2019, as shown in Figure 8 [4]. The combined nominal output from the plants was approximately 1040 MW, at an average of ~2.88 MW per plant. Clearing natural ecosystems, such as forests, moorlands, and agricultural land, was required prior to the installation of 92 (25.5%) of the plants. Using satellite imagery, the total area of natural ecosystem loss was estimated to be 3,226,100 m^2.

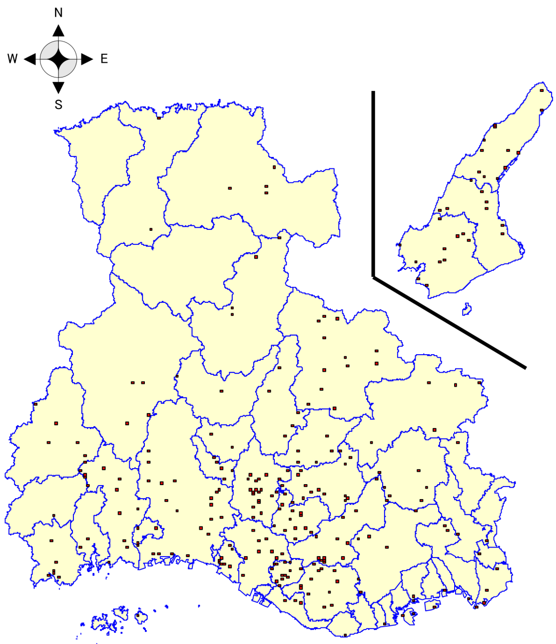

Figure 8. Mega PV solar plant locations in Hyogo Prefecture, Japan.

Costs and benefits were calculated as follows:

- Climate change mitigation

This benefit was calculated by multiplying the annual GHG emissions in Equation (1) by the area of natural ecosystem loss. In this study, for the sake of simplifying calculations, the area of natural ecosystem loss and area of the associated mega PV solar plant were assumed to be the same.

- Economic benefit

This benefit was calculated by summing the economic benefit of each mega PV solar plant from Equation (3). The total output and purchase rate (as determined based on the approval year and month that the mega PV solar plants were installed by clearing natural ecosystems) were identified using the database referred to in Section 3.1.2.

- Loss of carbon sink

This cost was calculated by multiplying CO_2 absorption (as identified for Equation (4)) by the natural ecosystem loss area.

- Biodiversity loss

The total area of natural ecosystem loss was used as a direct proxy in quantifying this cost.

- Disaster risk

First, the number of mega PV solar plants in high landslide risks was identified, using the overlay method described above, then their potential disaster waste was calculated, by multiplying the entire area of the natural ecosystem loss by the equipment weight data for each array.

- Integration of positive and negative impacts

The costs and benefits calculated by these methods were integrated as the external cost, using the EIA aspect of the LCA. In this study, the life-cycle impact assessment method based on endpoint modeling (LIME) Ver.2 (LIME2), the EIA method most utilized in Japan, was applied. LIME is a life-cycle impact analysis method in which the degree to which humans and the ecosystem suffer environmental impact is evaluated in monetary terms [43]. The indicator value is calculated by multiplying the environmental impact with the applicable LIME2 coefficient, as shown in Table 3 [33].

Table 3. LIME2 coefficients.

Item	Variable	LIME2 Coefficient	Unit
Benefit (positive impact)	Climate change mitigation	2.33 0.022	[JPY/kg CO_{2eq}] [USD/kg CO_{2eq}]
Cost (negative impacts)	Loss of carbon sink	2.33 0.022	[JPY/kg CO_{2eq}] [USD/kg CO_{2eq}]
	Biodiversity loss	7420 70.49	[JPY/m^2] [USD/m^2]
	Disaster risk	23.80 0.23	[JPY/kg] [USD/kg]

The external costs have been expressed in monetary units and can be summed for comparison with the economic benefit. The ratio was calculated by dividing the monetary value per unit estimated for the benefits by the monetary value per unit estimated as costs. In this study, this ratio was defined as the P/N ratio. If the benefits (positive impacts) outweighed the costs (negative impacts), the P/N ratio would be >1.0, and if less, the P/N ratio would be <1.0. By using this ratio, it was possible to determine whether the benefits or costs were greater for the test case mega PV solar plant installations.

4. Results and Discussion

4.1. Cost and Benefit Quantification Results

4.1.1. Climate Change Mitigation

GHG emissions released in manufacturing a PV system were calculated as 611 kg CO_{2eq}/m^2. This was annualized to 30.55 kg CO_{2eq}/m^2/year, and the annual substitution effect was estimated at 65.25 kg CO_{2eq}/m^2/year so that the annual GHG emissions were calculated as 34.70 kg CO_{2eq}/m^2. This result revealed that the substitution effect was greater than the GHG emissions released during the manufacturing process.

4.1.2. Loss of Carbon Sink

CO_2 absorption by Japanese forests was estimated at 60,854 kt CO_2, for FY 2017 [44]. The total forest area in Japan was calculated to be 250,480 km^2 in FY 2017 [45], and hence the CO_2 absorption per unit area was calculated to be 0.25 kg CO_{2eq}/m^2.

4.1.3. Disaster Risk

Table 4 shows the weight of PV equipment. The median, 25th and 75th percentiles of the weight of solar panels were calculated, because many manufacturers produce multiple types of cells and modules. Table 5 shows the estimated disaster waste derived from PV equipment, based on data from actual natural disasters. Photographs showing the damage status of the four cases shown in Table 5 are presented in Figure 9. The estimated disaster waste derived from the solar panels was 8.57% of the total, with the foundation forming the dominant component of this waste. For example, approximately 2910 t of disaster waste derived from households was generated by heavy rain in Tanba, Hyogo Prefecture (area: 493.2 km^2; population: 66,000), in 2014 [46]. This amount was similar to the estimated value of the disaster waste from Case 2, and indicates that the impact of the damage to PV solar plants was significant.

Table 4. Weight of PV equipment.

Solar Panel	Mount	Foundation (Concrete)	Total
11.60 (11.34–13.49) [1]	16.70	107.07	135.37 (135.11–137.26) [1]

Unit: kg/m^2. [1] The numbers in parentheses include the 25th percentile before the hyphen and the 75th percentile after the hyphen.

Figure 9. PV solar plant damage caused by natural events [8].

Table 5. Estimated disaster waste derived from PV equipment.

Specifications	Case 1	Case 2	Case 3	Case 4
Total generation capacity [kW]	750	6500	9990	1990
Land use [m^2]	217,000	270,000	150,000	N.A.
Location	Mountainside	Factory rooftop	Closed landfill	Holding pond
Solar panels	3534	28,160	36,480	9268
Disaster	Heavy rain	Typhoon	Typhoon	Typhoon
Damaged solar panels	1344	13,780	13,413	733
Potential disaster waste [t]	299 (268–343) [1]	3067 (2745–3512) [1]	2985 (2672–3419) [1]	34 (31–40) [1]

Source: Japan Ministry of Economy, Trade and Industry [8] except for potential disaster waste. [1] The numbers in parentheses indicate the 25th percentile before the hyphen and the 75th percentile after the hyphen.

4.2. Case Study

Figure 10 shows where mega PV solar plants have been installed in high landslide risk areas, with 182 plants, or approximately half of the total of 361 plants in the study area, located in high landslide risk areas. Other data showed that 42 plants, representing 45.2% of the 92 plants installed by clearing the natural ecosystems had been installed in high landslide risk areas. The total natural ecosystem loss area removed to allow installation of these 42 plants was estimated to be 2,041,600 m^2.

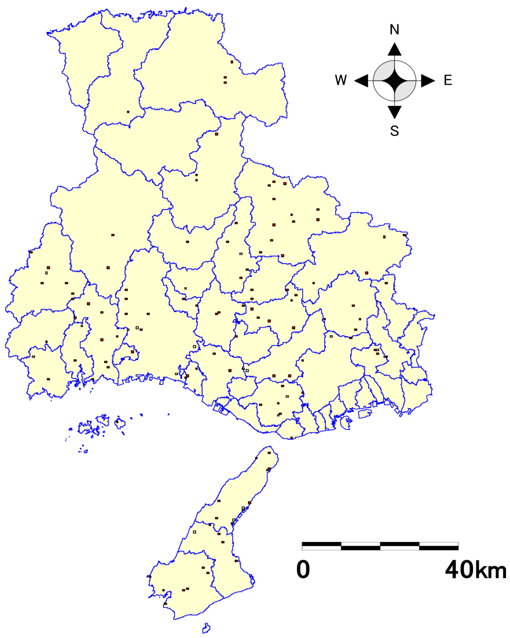

Figure 10. Mega PV solar plants installed in high landslide risk areas.

The annual economic benefit for the entire mega PV solar plant portfolio was calculated to be 34,755 million JPY (330.17 million USD); of this, the annual economic benefit from the 92 mega PV solar plants installed by clearing natural ecosystems was 10,387 million JPY (98.68 million USD).

Table 6 shows the integrated values calculated using LIME2, and the cost and benefit indicator values. The coefficient of biodiversity loss was annualized by divided by 20, considering the operating life of a PV solar plant. The original value was applied when calculating the coefficient of disaster risk, because it cannot be foretold just when a disaster will occur during the life of a PV solar plant.

The median value was used as the potential disaster waste quantum when calculating disaster risk. The results revealed that the mega PV solar plants installed by clearing natural ecosystems had an annual benefit (positive impact) of 10,648 million JPY (101.16 million USD), and an annual cost (negative impact) of 7776 million JPY (73.88 million USD), yielding a P/N ratio of 1.37. This result indicated that the benefits of PV solar array installation outweighed their costs, in terms of natural ecosystems loss.

The parameters that affected the P/N ratio the most were economic benefit, disaster risk, and biodiversity loss—with the other parameters having little discernible effect. Although the median value for potential disaster waste was used to calculate the disaster risk, substituting either the 25th or 75th percentile value made no difference to the outcome.

The effects of these changes on the P/N ratio were examined using sensitivity analysis, focusing on those parameters (economic benefit, disaster risk, and biodiversity loss) that most influenced the results. First, the values of each parameter shown in Table 6 were assumed as default values. The value of each parameter was then changed from 0 to 2.0, in increments of 0.2, and the P/N ratio was recalculated (with other parameter values fixed). For example, when economic benefits changed, other parameters were fixed.

Table 6. Annual indicator value.

Positive and Negative Impacts		Quantified Results [kg/m^2]	Integrated Value by LIME2 [JPY/m^2] ([USD/m^2])	Area [m^2]	(a) Economic Benefit [Million JPY] ([Million USD])	(b) Indicator Value [Million JPY] ([Million USD])	(a) + (b)
Benefit (positive impacts)	Climate change mitigation	34.70	80.85 (0.77)	3,226,100	-	261 (2.48)	261 (2.48)
	Economic benefit	-	-	-	10,387 (98.68)	-	10,387 (98.68)
	(1) Total	-	-	-	-	-	10,648 (101.16)
Cost (negative impacts)	Loss of carbon sink	0.25	0.58 (0.0055)	3,226,100	-	1.88 (0.018)	1.88 (0.0018)
	Biodiversity loss	-	371.00 (3.52)	3,226,100	-	1197 (11.37)	1197 (11.37)
	Disaster risk	135.37	3221.81 (30.61)	2,041,600	-	6578 (62.49)	6578 (62.49)
	(2) Total	-	-	-	-	-	7776 (73.88)
P/N ratio							1.37

The results of the sensitivity analysis have been presented in Figure 11. The P/N ratio remained >1.0, regardless of changes to biodiversity, while, when the economic benefit was reduced by 20% from the default value, the P/N ratio became <1.0. This showed that the mega PV solar plants retained their net positive impact, due to their economic benefits. If the economic benefits were decreased, the negative impact of clearing natural ecosystems could surpass the positive economic benefits.

With regard to disaster risk, the potential disaster waste quantum increased beyond the disaster risk default value because a damaged PV system was assumed to be converted 100% to disaster waste. In contrast, implementing disaster prevention measures, such as the adoption of landslide-resistant structures, could reduce potential disaster waste amounts, and may be a good way to reduce the P/N ratio significantly.

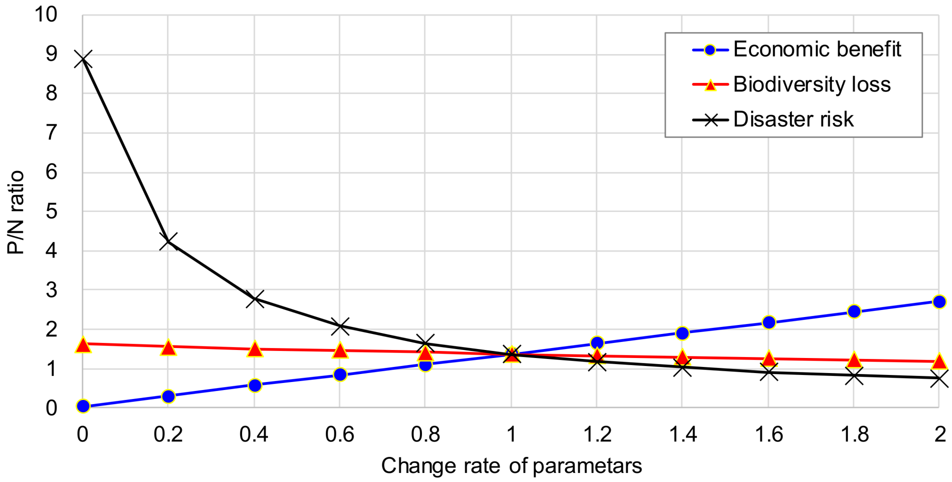

Figure 11. Sensitivity analysis.

5. Conclusions

In the study described here, the authors intended to develop comprehensive and quantitative methods to evaluate the costs and benefits of installing PV solar plants as opposed to preserving the natural ecosystems at their sites, under green conflicts. The authors have also proposed various novel methods that facilitated cost and benefit evaluations. Using these methods, a case study for the installation of mega PV solar plants in Hyogo Prefecture, Japan was investigated, and its main findings may be summarized as follows:

1. The costs and benefits (negative and positive impacts) established for installing a PV system by clearing forests and moorlands have been described from environmental, social, and economic perspectives. The most influential benefits (climate change mitigation and economic benefit) and costs (loss of carbon sink, biodiversity loss, and disaster risk) were targeted for quantitative evaluation.
2. Climate change mitigation was calculated using GHG emissions released during PV system manufacturing, and applying substitution values for GHG emissions (determining CO_2 equivalents for all GHGs) for PV array development and installation. The economic benefit was calculated based on the FIT scheme subsidies gained by plant operation. Carbon sink loss was calculated based on estimates of CO_2 absorption by forests, and biodiversity loss was calculated based on the forest area lost to facilitate plant installation. Disaster risk was calculated using map overlays to determine whether PV solar plants were located in landslide hazard areas; it was assumed that such plants would eventually be damaged by landslides, and that all parts of such facilities would become waste, needing suitable disposal.
3. A comprehensive evaluation was conducted, using the EIA process from the LCA method. The P/N ratio was also defined to compare the cost and benefits (positive and negative impacts).
4. When this text was drafted, there were 361 mega solar plants installed in Hyogo Prefecture, Japan, of which 92 were installed by clearing natural ecosystems, such as forests, moorlands, and agricultural land. The natural ecosystem area cleared to install these 92 plants was estimated at 3,226,100 m^2 using satellite imagery, and 42 of these were found to be located in high-landslide-risk sites. The natural ecosystem area cleared for these 42 plants was calculated to be 2,041,600 m^2. We estimated that the mega PV solar plants installed by clearing natural ecosystems had an annual economic benefit of JPY 10,648 million JPY (101.16 million USD), and an estimated annual cost of 7776 million JPY (73.88 million USD). These estimates resulted in a P/N ratio of 1.37, indicating that, by using the methods applied here, the PV solar array economic benefits outweighed their costs, in terms of effects on natural ecosystems.

5. We found that economic benefit, disaster risk, and biodiversity loss were the parameters with the greatest influence on the P/N ratio, and reviewed the effect of changes to these parameters on the P/N ratio, using sensitivity analysis. We found that the P/N ratio did not go below 1.0, irrespective to any changes in biodiversity value estimates, while, if the economic benefit was reduced by 20% from the default value, the P/N ratio would become <1.0—that is, the costs would outweigh the benefits. We also found that applying disaster prevention measures to reduce disaster risk could be a good way to increase the P/N ratio significantly.

Conservation of natural ecosystems in their region is a major concern for residents. PV solar plant projects are developed and operated by private solar energy companies, while it is local governments who have the authority to permit projects involving changes in natural ecosystems. It can be difficult for local government decision-makers to determine whether to promote development or conserve natural ecosystems, and our method should contribute guiding principles or a methodology that could be applied to establish consensus among stakeholders.

We used five cost and benefit parameters in this study. If local government decision- or policy-makers think other parameters should be considered, they should feel free to decide what impacts to consider. They can then quantify these additional factors, and recalculate the P/N ratio accordingly.

One limitation of this study has been that it is not clear how much of the benefit obtained from the FIT scheme the PV owner/operator companies are returning to the region. This benefit is expressed in terms of local job creation, by PV operation and maintenance involving local companies, and so on, but data supporting such claims are not readily available. This is an issue that needs to be addressed in the future.

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References

1. Japan Ministry of Environment. Long-Term Low-Carbon Vision. Available online: https://www.env.go.jp/earth/report/h30-01/ref02.pdf (accessed on 23 September 2020).
2. Outlook of Long-Term Energy Demand in Japan. Available online: https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/mitoshi/pdf/report_01.pdf (accessed on 23 September 2020).
3. International Renewable Energy Agency. Renewable Capacity Statistics 2019. Available online: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Mar/IRENA_RE_Capacity_Statistics_2019.pdf (accessed on 23 September 2020).
4. Electrical Japan, Visualization of Electricity Demand and Supply. Available online: http://agora.ex.nii.ac.jp/earthquake/201103-eastjapan/energy/electrical-japan/ (accessed on 23 September 2020). (In Japanese).
5. Japan Photovoltaic Energy Association. Statistics for PV Cell Shipment. Available online: http://www.jpea.gr.jp/document/figure/index.html (accessed on 23 September 2020). (In Japanese).
6. Skogen, K.; Helland, H.; Kaltenborn, B. Concern about climate change, biodiversity loss, habitat degradation and landscape change: Embedded in different packages of environmental concern? *J. Nat. Conserv.* **2018**, *44*, 12–20. [CrossRef]
7. Japan Ministry of Environment. Report on Environmental Impact Assessment for PV Plants. Available online: http://www.env.go.jp/press/files/jp/110948.pdf (accessed on 23 September 2020). (In Japanese)

8. Japan Ministry of Economy. Trade and Industry, Characteristics of Accidents of PV Systems in Summer. 2018. Available online: https://www.meti.go.jp/shingikai/sankoshin/hoan_shohi/denryoku_anzen/newenergy_hatsuden_wg/pdf/014_01_00.pdf (accessed on 23 September 2020). (In Japanese)
9. PV Owner Network, Japan, Report on Ordinances of Municipalities for PV Plants in Japan. Available online: http://www.greenenergy.jp/wordpress/wp-content/uploads/2015/08/PVlocal-regulation.pdf (accessed on 23 September 2020). (In Japanese).
10. International Institute for Sustainable Development. Green Conflict Minerals: The Fuels of Conflict in the Transition to a Low-Carbon Economy. Available online: https://www.iisd.org/library/green-conflict-minerals-fuels-conflict-transition-low-carbon-economy (accessed on 23 September 2020).
11. Liu, S.-Q.; Mao, X.-Q.; Gao, Y.-U.; Xing, Y.-K. Life cycle assessment, estimation and comparison of greenhouse gas Mmitigation potential of new energy power generation in China. *Adv. Clim. Chang. Res.* **2012**, *3*, 147–153.
12. Ito, M.; Kodo, M.; Nagura, M.; Umeda, Y.; Tsuno, Y.; Kurokawa, K. A life cycle assessment of the Hokuto mego-solar plant. *Sol. Energy* **2013**, *39*, 51–60. (In Japanese)
13. Guo, X.; Lin, K.; Huang, H.; Li, Y. Carbon footprint of the photovoltaic power supply chain in China. *J. Clean. Prod.* **2019**, *233*, 626–633. [CrossRef]
14. Nwaigwe, K.N.; Mutabilwa, P.; Dintwa, E. An overview of solar power (PV systems) integration into electricity grids. *Mater. Sci. Technol.* **2019**, *2*, 629–633. [CrossRef]
15. Koura, A.; Akizuki, H. Planning issues in the conflicting public interests of landscape and renewable energy. *J. City Plan. Inst. Jpn.* **2017**, *52*, 1171–1176. (In Japanese)
16. Bevk, T.; Golobič, M. Contentious eye-catchers: Perceptions of landscapes changed by solar power plants in Slovenia. *Renew. Energy* **2020**, *152*, 999–1010. [CrossRef]
17. Denholm, P.; Margolis, R.M. Land–use requirements and the per-capita solar footprint for photovoltaic generation in the United States. *Energy Policy* **2008**, *36*, 3531–3543. [CrossRef]
18. Sakamura, K.; Kaneko, T.; Numata, M.; Nakai, N. Study on the site character of the ground standing photovoltaic power generating system. *J. City Plan. Inst. Jpn.* **2014**, *49*, 633–638. (In Japanese)
19. Faircloth, G.C.; Wagner, K.H.; Woodward, K.E.; Rakkwamsuk, P.; Gheewala, S.H. The environmental and economic impacts of photovoltaic waste management in Thailand. *Resour. Conserv. Recycl.* **2019**, *143*, 260–272. [CrossRef]
20. Noda, H.; Okuno, Y.; Itsubo, T. The estimated impacts of photovoltaic power systems on varieties of Japanese forest vegetation. *J. LCA Jpn.* **2015**, *11*, 172–188. (In Japanese)
21. Corona, B.; Cerrajero, E.; López, D.; Miguel, G.S. Full environmental life cycle cost analysis of concentrating solar power technology: Contribution of externalities to overall energy costs. *Sol. Energy* **2016**, *135*, 758–768. [CrossRef]
22. Guerin, T. A case study identifying and mitigating the environmental and community impacts from construction of a utility-scale solar photovoltaic power plant in eastern Australia. *Sol. Energy* **2017**, *146*, 94–104. [CrossRef]
23. Mahlandu, N.; Thopil, G.A. Life cycle analysis of external costs of a parabolic trough Concentrated Solar Power plant. *J. Clean. Prod.* **2018**, *195*, 32–43. [CrossRef]
24. Mahmud, M.A.; Huda, N.; Farjana, S.H.; Lang, C. Life–cycle impact assessment of renewable electricity generation systems in the United States. *Renew. Energy* **2020**, *151*, 1028–1045. [CrossRef]
25. Fraser, T.; Chapman, A.J. Social equity impacts in Japan's mega-solar siting process. *Energy Sustain. Dev.* **2018**, *42*, 136–151. [CrossRef]
26. Bauer, C.; Hirschberg, S.; Bäuerle, Y.; Biollaz, S.; CalbryMuzyka, A.; Cox, B.; Heck, T.; Lehnert, M.; Meier, A.; Prasser, H.-M.; et al. Potentials, Costs, and Environmental Assessment of Electricity Generation Technologies. Available online: https://www.psi.ch/sites/default/files/import/lea/HomeEN/Final-Report-BFE-Project.pdf (accessed on 23 September 2020).
27. Mizuho Information & Research Institute, Inc. Actual Situation and Future Outlook for Renewable Energy in Japan. Available online: https://www.mizuho-ir.co.jp/publication/report/2018/mhir15_saiene_01.html (accessed on 23 September 2020). (In Japanese).
28. Promotion Council for the "FutureCity" Initiative, Future City Initiative. Available online: http://future-city.jp/en/ (accessed on 23 September 2020).

29. Japan Agency for Natural Resources and Energy. Feed-In Tariff Scheme in Japan. Available online: https://www.meti.go.jp/english/policy/energy_environment/renewable/pdf/summary201207.pdf (accessed on 22 October 2020).
30. Japan Agency for Natural Resources and Energy. FIT Scheme in Japan. Available online: https://www.enecho.meti.go.jp/category/saving_and_new/saiene/kaitori/fit_kakaku.html (accessed on 23 September 2020). (In Japanese)
31. Costanza, R.; D'Arge, R.; de Groot, R.; Farberll, S.; Grassot, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neilltt, R.V.; Paruelo, J.; et al. The value of the world's ecosystem services and natural capital. *Nature* **1997**, *387*, 253–260. [CrossRef]
32. Imamura, E.; Iuchi, M.; Bando, S. Comprehensive Assessment of Life Cycle CO2 Emissions from Power Generation Technologies in Japan. Available online: https://criepi.denken.or.jp/jp/kenkikaku/report/detail/Y06.html (accessed on 23 September 2020). (In Japanese).
33. The Research Institute of Science for Safety and Sustainability, National Institute of Advanced Industrial Science and Technology and Japan Environmental Management Association for Industry, LCI Database "IDEA Version 2.2". Available online: http://idea-lca.com/features/?lang=en (accessed on 23 September 2020).
34. New Energy and Industrial Technology Development Organization. Database for the Quantity of Solar Radiation. Available online: https://www.nedo.go.jp/library/nissharyou.html (accessed on 23 September 2020). (In Japanese).
35. New Energy and Industrial Technology Development Organization. *Guidebook for Installing Electric Power Generation*; New Energy and Industrial Technology Development Organization: Tokyo, Japan, 2000; 180p. (In Japanese)
36. Japan Industrial Standards Committee. JIS C8960 "Words and Terms for Photovoltaic Power Generation". Available online: https://www.jisc.go.jp/pdfa6/PDFView/ShowPDF/WgAAAOcGcqCKzXYGolxq (accessed on 23 September 2020). (In Japanese)
37. Kansai Electric Power Co. Inc. Environmental Data. Available online: https://www.kepco.co.jp/english/corporate/list/environmental/data/pdf/en2019_e_00.pdf (accessed on 23 September 2020).
38. Japan Agency for Natural Resources and Energy. Electronic Applications for Renewable Energy in FIT Scheme. Available online: https://www.fit-portal.go.jp/ (accessed on 23 September 2020). (In Japanese)
39. Intergovernmental Panel on Climate Change, Special Report Climate Change and Land. Available online: https://www.ipcc.ch/srccl/chapter/chapter-2/ (accessed on 23 September 2020).
40. Anwar, A. Does the Age of a Tree Affect Carbon Storage? Available online: https://icp.giss.nasa.gov/research/ppa/2001/anwar/ (accessed on 23 September 2020).
41. Japan Ministry of Land, Infrastructure, Transport and Tourism. National Land Numerical Information Download Service. Available online: https://nlftp.mlit.go.jp/ksj/index.html (accessed on 23 September 2020). (In Japanese)
42. Japan Photovoltaic Energy Association. Guideline for Ground-Mounted PV Systems. Available online: http://www.jpea.gr.jp/topics/guideline.html (accessed on 23 September 2020). (In Japanese).
43. Itsubo, N.; Sakagami, M.; Washida, T.; Kokubu, K.; Inaba, A. Weighting across safeguard subjects for LCIA through the application of conjoint analysis. *Int. J. LCA* **2004**, *9*, 196–205. [CrossRef]
44. Greenhouse Gas Inventory Office of Japan, National GHG Inventory Report of Japan. Available online: http://www-gio.nies.go.jp/aboutghg/nir/2019/NIR-JPN-2019-v3.0_GIOweb.pdf (accessed on 23 September 2020).
45. Japan Forest Agency. 2019 Forestry Statistics. Available online: https://www.rinya.maff.go.jp/j/kikaku/toukei/youran_mokuzi2019.html (accessed on 23 September 2020). (In Japanese)
46. National Institute for Environmental Studies. Disaster Report for Heavy Rain in Tanba. 2014. Available online: https://dwasteinfo.nies.go.jp/archive/grep/special_141226tamba.pdf (accessed on 23 September 2020). (In Japanese)