Environmental Balance of Agrivoltaics in Organic Rice Paddies

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1. Introduction

1) Importance of Countermeasures for Climate Change is Growing Rapidly

In recent years, climate change has become increasingly evident and is now recognized by the Intergovernmental Panel on Climate Change (IPCC) (*3)as being caused by rising concentrations of greenhouse gases (GHGs)(*1) in the atmosphere due to human activities. These gases include carbon dioxide, methane, and nitrous oxide, among others. In July 2023, UN Secretary-General António Guterres declared that "the era of global warming has ended; the era of global boiling has arrived." By December 2024, he further expressed a heightened sense of urgency, stating that we are now witnessing "climate collapse."

Following this shared understanding, the international community, led by the United Nations, continues to pursue concrete intergovernmental negotiations at annual COP meetings and is intensifying efforts to reduce emissions across all aspects of human activity. In the realm of economic activity, global corporations are increasingly joining initiatives such as RE100(*4), aiming for 100% renewable energy use. As a result, even small and medium-sized enterprises are feeling growing pressure to decarbonize in order to remain viable within the global supply chain.

While various global approaches to climate change mitigation are accelerating, methane emissions—particularly influenced by global warming—have increased by approximately 10% over the past 20 years (according to the website of the National Institute for Environmental Studies, 2020), indicating that effective control measures are still lacking. Although the expansion of renewable energy serves as a direct and effective countermeasure against global warming, the reduction of other greenhouse gas (GHG) emissions remains a major challenge.

All human activities, including those in agriculture and across the broader economy, now face an urgent need to be restructured and updated with climate change as a central premise. It is becoming increasingly clear—supported by findings such as those from the IPCC Sixth Assessment Synthesis Report: Summary for Policymakers—that the actions taken over the next ten years will have a decisive impact on the future of our planet.

(*The IPCC Sixth Assessment Synthesis Report: Summary for Policymakers/P36-C2/*/ chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.env.go.jp/content/000265059.pdf)

2） Agriculture

In agriculture, the conversion of natural vegetation such as forests and grasslands into farmland, along with long-term tillage practices, has led to the decomposition of soil organic matter and the release of large amounts of carbon dioxide into the atmosphere (Lal, 2004). Additionally, the extensive use of nitrogen fertilizers contributes to the emission of nitrous oxide. Methane is also emitted from ruminants and rice paddies. Furthermore, greenhouse gases (GHGs) are emitted from various other agricultural activities, including the use of fossil fuels in farming equipment, the fossil fuels consumed in the production of pesticides and chemical fertilizers, and the transportation of crops and agricultural materials.

As a result, greenhouse gas emissions originating from the agriculture and forestry sectors account for approximately 22% of total emissions from human activities worldwide. This indicates that agriculture and forestry must be prioritized as key sectors in the global effort to combat climate change (*according to the website of Japan’s Ministry of Agriculture, Forestry and Fisheries chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.maff.go.jp/j/seisan/kankyo/ondanka/attach/pdf/nakaboshi-1.pdf）

In Japan as well, the Ministry of Agriculture, Forestry and Fisheries (MAFF) has begun advocating for carbon farming.

Carbon Farming (Note 6) refers to agricultural practices that aim to sequester CO_2 from the atmosphere into the soil, thereby improving soil quality and reducing greenhouse gas emissions. It is often associated with what is called regenerative agriculture. (*Based on the MAFF website.)

However, the definition of “Carbon Farming” is not necessarily globally standardized, and it is broadly interpreted to include initiatives that reduce agricultural greenhouse gas emissions, such as methane (CH_4) emissions from rice paddies. Therefore, the methods employed in this study also fall under the definition of carbon farming.

*Reference: Communication document “Sustainable Carbon Cycles (COM(2021) 800 final)” published by the European Commission in December 2021.

*Reference link: MAFF website:

https://www.maff.go.jp/j/kokusai/kokkyo/platform/pdf/platform-172.pdf

Global GHG emissions from agriculture and forestry (2019)

(※)

Figure 1. Global GHG Emissions from1 the Agriculture and Forestry Sectors (2019).

Figure created by the author based on data from the Ministry of Agriculture, Forestry and Fisheries website.

Furthermore, according to a report released in August 2024 by the National Agriculture and Food Research Organization ※https://www.naro.go.jp/publicity_report/press/laboratory/rcait/163819.html, it was projected that, if no countermeasures are taken, the effects of global warming could lead to a decline of over 30% in rice yields by the year 2030. In addition to rice, many other crops, across a range of countries, regions, and varieties, are being increasingly pressured to adapt to a warming climate—an urgency that is accelerating year by year.

Therefore, it is essential that those directly involved in agriculture take climate change countermeasures seriously and proactively. In Japan specifically, methane emissions from rice paddies account for 27% of all agriculture-related GHG. (*according to the Ministry of Agriculture, Forestry and Fisheries website: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.maff.go.jp/j/seisan/kankyo/ondanka/attach/pdf/nakaboshi-1.pdf) Given that, an urgent need for effective countermeasures needs to be taken.

Methane in rice paddies is produced when the soil becomes anaerobic under flooded conditions, creating an environment in which methanogenic bacteria break down undecomposed organic matter such as rice straw (Kögel-Knabner et al., 2010). To reduce methane emissions, strategies such as cultivar improvement, adjustments to irrigation methods, and the removal of rice straw have been found effective (Qian et al., 2023).

One widely discussed mitigation technique is mid-season drainage (NAKABOSHI), which involves temporarily draining rice paddies during the growing season. Since 2023, extending the mid-season drainage period by one additional week has been officially recognized for generating carbon credits under Japan's J-Credit Scheme (※Reference Ministry of Agriculture、 Forestry and Fisheries：https://www.maff.go.jp/j/press/kanbo/b_kankyo/230301.html) However, this practice increases the burden on farmers and has raised concerns about its potential negative impacts on aquatic organisms such as dragonfly larvae and tadpoles.

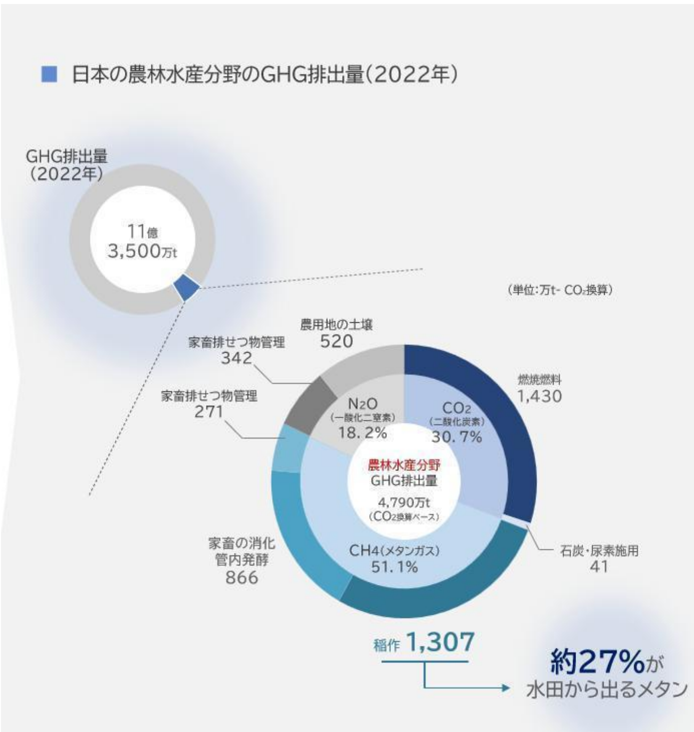


Figure 2. Breakdown of GHG Emissions from Japan’s Agriculture and Forestry Sectors (2022)

According to reports from the FAO, IPCC, and national greenhouse gas inventories, it is frequently estimated that methane emissions from rice paddies account for approximately 20% of all agriculture-related GHG emissions across Asia. In countries with a high proportion of rice cultivation, such as Vietnam and Bangladesh, methane from rice paddies has been reported to comprise around 30% to nearly 40% of total agricultural GHG emissions.

Methane reduction methods developed in Japan are being transferred to Southeast Asian countries such as Vietnam through major corporations involved in carbon credit trading. These initiatives are being implemented under the Joint Crediting Mechanism (JCM), and the scale of such activities has been increasing each year.

However, in Southeast Asia and similar regions, local climatic conditions, geographic characteristics, and farming practices often make it difficult to extend the mid-season drainage period. Against this backdrop, the development of methane reduction techniques within Japan continues to be highly anticipated.

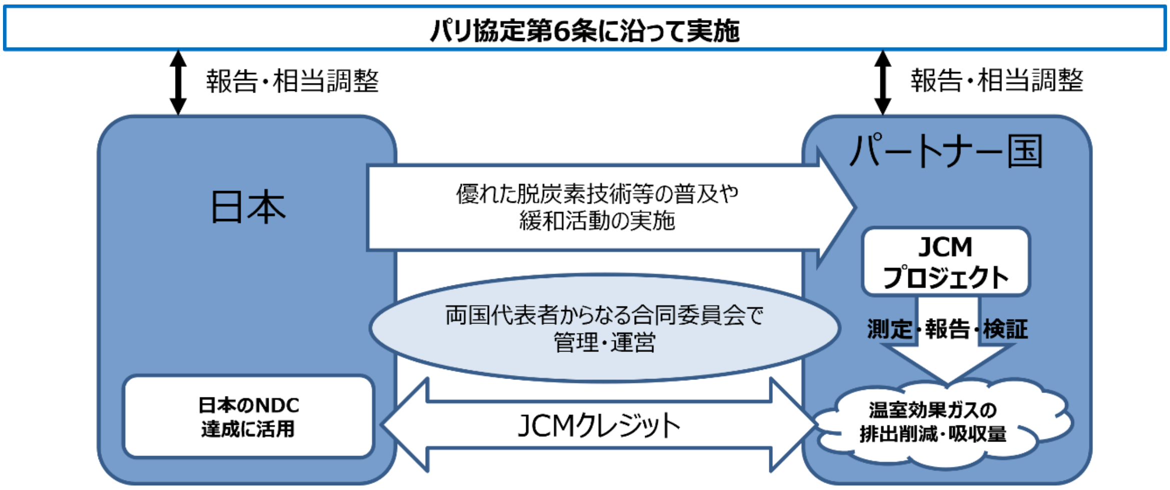


Figure 3/Quote/Ministry of Economy, Trade and Industry website：https://www.meti.go.jp/policy/energy_environment/global_warming/jcm/index.html

図4 Figure 4 (Japanese companies participating in the JCM project and domestic methane credits in Vietnam as of 2024)

Figure 5 (Japanese companies participating in the methane credit business in Japan as of 2024)

In addition to addressing climate change, a critical issue within Japan is the shortage of new entrants into the agricultural workforce. The average age of farmers now exceeds 68, and the total number of agricultural workers—including corporate entities—is projected to decline to 860,000 by 2030. In light of this situation, it is worth considering new sources of agricultural income, such as revenue from GHG credits and electricity sales through solar sharing, as part of a new model for sustainable agriculture.

For many individual farmers, it is becoming increasingly difficult to continue farming without relying on pension income. From an industrial perspective, this suggests a system on the verge of collapse. Therefore, urgent and fundamental reforms are needed—not only for the sustainability of the agricultural sector but also from the standpoint of national food security.

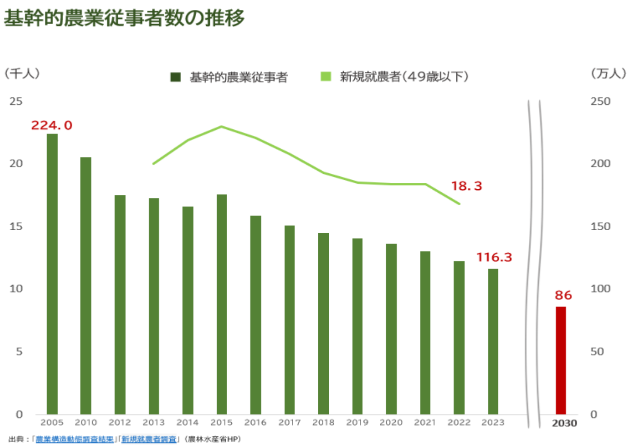


Figure 6 (Changes in the number of core agricultural workers in Japan)

※Figures taken from the Ministry of Agriculture, Forestry and Fisheries website/Drawn by the author　https://www.maff.go.jp/j/tokei/kouhyou/noukou/

3) Solar Sharing (Agrivoltaics)

Solar sharing, also known as agrivoltaics, is a method that enables simultaneous agricultural production and solar power generation on the same farmland (Abidin et al., 2021). One common approach involves installing narrow, flat solar panels at a height of approximately three meters, allowing for continued cultivation beneath using tractors and other farming equipment. This method was first patented in 2003 by Mr. Akira Nagashima in Japan and has since been made publicly available, enabling widespread use. With a light-blocking rate of around 30%, this system allows for the successful cultivation of rice, wheat, soybeans, and other crops beneath the panels. While varying in design, similar systems have now been adopted in many regions around the world.

As demand for renewable energy grows globally, Japan has already reached one of the world’s highest levels of solar power deployment on flat land. Consequently, the availability of additional flat land for large-scale solar installations is becoming increasingly limited. Furthermore, over 190 local municipalities across Japan have enacted regulations restricting solar installations in forested or mountainous areas, further reducing suitable sites.

Amid this social and regulatory background, solar sharing is gaining significant attention. Numerous large corporations have entered the field, and interest from government agencies is steadily increasing. In 2013, the Ministry of Agriculture, Forestry and Fisheries (MAFF) issued a directive conditionally allowing the implementation of solar sharing. In recent years, MAFF has also allocated subsidies for solar sharing, and from the FY2024 supplementary budget onward, grants have been extended to support research into plant growth under such systems.

The Ministry of the Environment has likewise begun providing subsidies, recognizing agri voltaics as a valuable source of local energy production. A visit by the Minister of the Environment to a solar sharing site is scheduled for January 2025. Additionally, since the beginning of 2024, the Ministry of Economy, Trade and Industry (METI) has frequently discussed solar sharing in its committee sessions, indicating a growing level of inter-ministerial awareness and recognition.

Legally, farming under the installations is required to continue without reducing crop yields by more than 20%, and in most cases, a portion of the electricity sales revenue is distributed from the power generation operators to the farmers as compensation for farming. This can serve as a new source of income for farmers.

Additionally, as of April 2023, when certified farmers engage in farming and power generation on their own land, the electricity sales revenue is now counted as part of their agricultural income. In this case, the electricity itself is effectively treated as an agricultural product.

However, the 2024 Agricultural White Paper states that in about 20% of solar sharing projects, far ming is not being properly carried out. Previously, only administrative guidance could be provided because regulations were issued as “notifications” by the Ministry of Agriculture, Forestry and Fis heries (MAFF).

However, starting in April 2024, the regulations have been upgraded to a formal “ministerial ordin ance” (*MAFF website link:

https://www.maff.go.jp/j/nousin/noukei/totiriyo/attach/pdf/einogata-16.pdf),

making it legally possible to impose penalties.

In fact, in fiscal year 2024, for more than 300 facilities where farming was not properly carried out, a very strict penalty—revocation of the FIT (Feed-in Tariff) certification—was enforced.

(*METI website: https://www.meti.go.jp/press/2024/08/20240805002/20240805002.html)

This measure is considered a desirable response by many involved in legitimate solar sharing proje cts.

There is a strong expectation from solar sharing power generation operators as well to foster soun d agricultural management.

Figure 7 [Excellent equipment examples on the Ministry of Agriculture, Forestry and Fisheries website]

(Photo provided by: Citizen Energy Chiba Co., Ltd./Sosa City, Chiba Prefecture/June 2023)

This installation uses narrow solar panels with a shading rate of 35%, and it has been confirmed that various crops can grow healthily under these conditions. The photo shows the harvest of organic barley grown under JAS organic certification. The spacing between support columns is over 4 meters, allowing standard combines and tractors to operate without issue. Since 2021, no-tillage cultivation experiments have been conducted in collaboration with Patagonia Japan and the Komatsuzaki Laboratory at Ibaraki University.

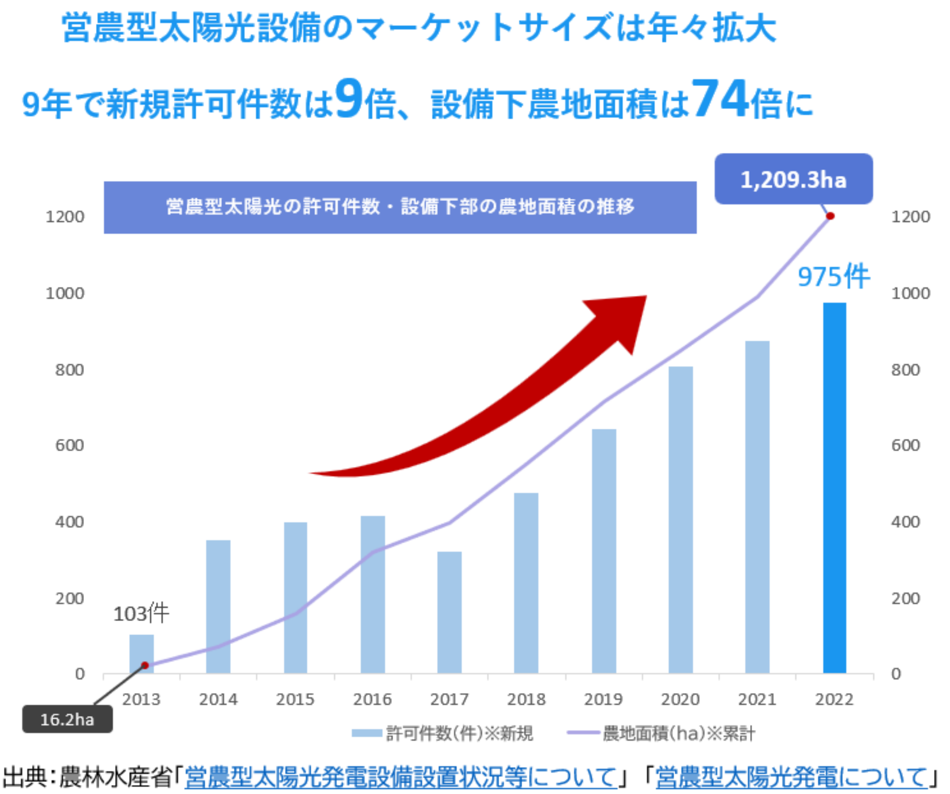


Figure 8: Changes in the number of permits for agricultural solar power generation

(*Chart created by the author based on figures from the Ministry of Agriculture, Forestry and Fisheries website)

Figure 9 [Upper image/Example of defective equipment]

※* Defective equipment cases published in the online edition of the Japan Agricultural News Minamisoma City, Fukushima Prefecture

Image source: https://www.agrinews.co.jp/society/index/237235

■【Comment by author】Figure 9 shows a case where the shading rate exceeds 90%, and there is no evidence of crop cultivation. The height below the diagonal braces also appears to be around 2 meters, making it difficult to operate tractors with 30 horsepower or more.

According to the 2024 White Paper on Agriculture published by the Ministry of Agriculture, Forestry and Fisheries （chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.maff.go.jp/j/wpaper/w_maff/r5/pdf/zentaiban_10.pdf） such substandard cases account for approximately 20% of all cases. These types of facilities exist nationwide and are contributing to a negative perception of solar sharing as a whole.

Even from the standpoint of those promoting sound solar sharing with a focus on agriculture, strict penalties for such substandard cases are considered a step in the right direction.

4) Solar Sharing in Rice Paddies as a Solution

No-till cultivation of rice paddies has been developed using methods such as direct sowing of unhulled rice (paddy seeds) in dry or wet fields. However, these methods are fundamentally reliant on herbicides, making them difficult to adapt for organic farming. On the other hand, no-till cultivation through seedling transplantation has also been developed (Reference: "Living Creatures and Nature-Rich Farming" by Nobuo Iwasawa, Somorisha Publishing), but the sale of rice transplanters has already been discontinued, making further expansion difficult.

By adopting no-till cultivation, rice straw from the previous year is not plowed into the soil, which is expected to reduce methane emissions. Additionally, the installation of solar panels reduces sunlight, which in turn suppresses the rise in soil temperature. Methanogenic bacteria in rice paddies typically thrive in soil temperatures of around 30-35° C, where they actively decompose organic matter and produce methane. Therefore, suppressing the soil temperature in this range could potentially reduce methane emissions.

Therefore, experimental plots were established in rice paddies with both tilled and no-till conditions, solar panels were installed, and comparisons were made between areas under the panels and those without panels. The objective was to observe the impact of no-till cultivation and solar panels on methane emissions.

The aim of this study is to examine sustainable agriculture from the perspective of environmental balance, develop improvement methods, and address the shortage of farm laborers by enhancing agricultural management practices. At the same time, it seeks to explore concrete methodologies for promoting decarbonization in the agricultural sector.

The inspiration for this research is based on a study that suggests a correlation between the latitude of rice paddies, the associated soil temperature, and the amount of methane emissions (Abidin, 2021).

In previous solar sharing trials on dry fields, although the temperature measurements under and outside the panels were taken irregularly and not as part of a formal academic study, it was consistently confirmed that the temperature under the panels was lower.

Therefore, it was hypothesized that in rice paddies as well, both water and soil temperatures would be lower under the panels, potentially leading to a reduction in methane emissions. This hypothesis served as the foundation for designing the experiment.

In terms of environmental sustainability, this approach must of course be viable. However, unless it is also sustainable from a farm management and economic standpoint, regenerative agriculture will neither continue nor spread. Thus, this study also includes an examination of the economic potential of solar sharing in rice paddies.

In this study, the term environmental balance specifically refers to the carbon dioxide (CO_2) balance. All other elements will be converted into their carbon dioxide (CO_2) equivalents for the purpose of calculation.

2. Research Location and Method

1) Study Area

The study was conducted at the farm of the Faculty of Food and Agriculture, Fukushima University, located in Maeda, Fukushima City, Fukushima Prefecture (Latitude: 37° 40′ 54″ N, Longitude: 140° 27′ 46″ E, Elevation: 156 m). The rice field used for the study was leased from a local farmer at the time of the faculty's establishment. Since 2022, this field has been cultivated without the use of pesticides. The study site is situated approximately a 15-minute walk from the Faculty of Food and Agriculture building.

Figure 10: [Location of the test plant and Fukushima University: December 2024](*From googleMap)

Figure 11 [Field conditions before the test plant was installed: December 2023]

Photo by author

※2* Farming has been carried out without the use of pesticides since 2022. The foreground of the photo is on the public road side, which has poor drainage and was known to cause poor rice growth, so this experiment was designed to not include this area.

2) Regarding the Test Plant

In early May 2024, 30 cm wide black cloth was installed at 70 cm intervals in a north-south orientation, at a height of 3 meters, to simulate solar panels. Initially, in the planning stage in December 2023, the plan was to install actual power-generating equipment. However, after several meetings with the Fukushima City Agricultural Committee, it became clear that installation could not be completed in time by April 2024. As a result, it was decided to conduct the experiment using dummy panels.

Regarding the installation method of the dummy panels, they were installed assuming the use of perovskite solar cells, with the long side of the panels oriented north-south - a direction that is 90 degrees different from the conventional orientation.

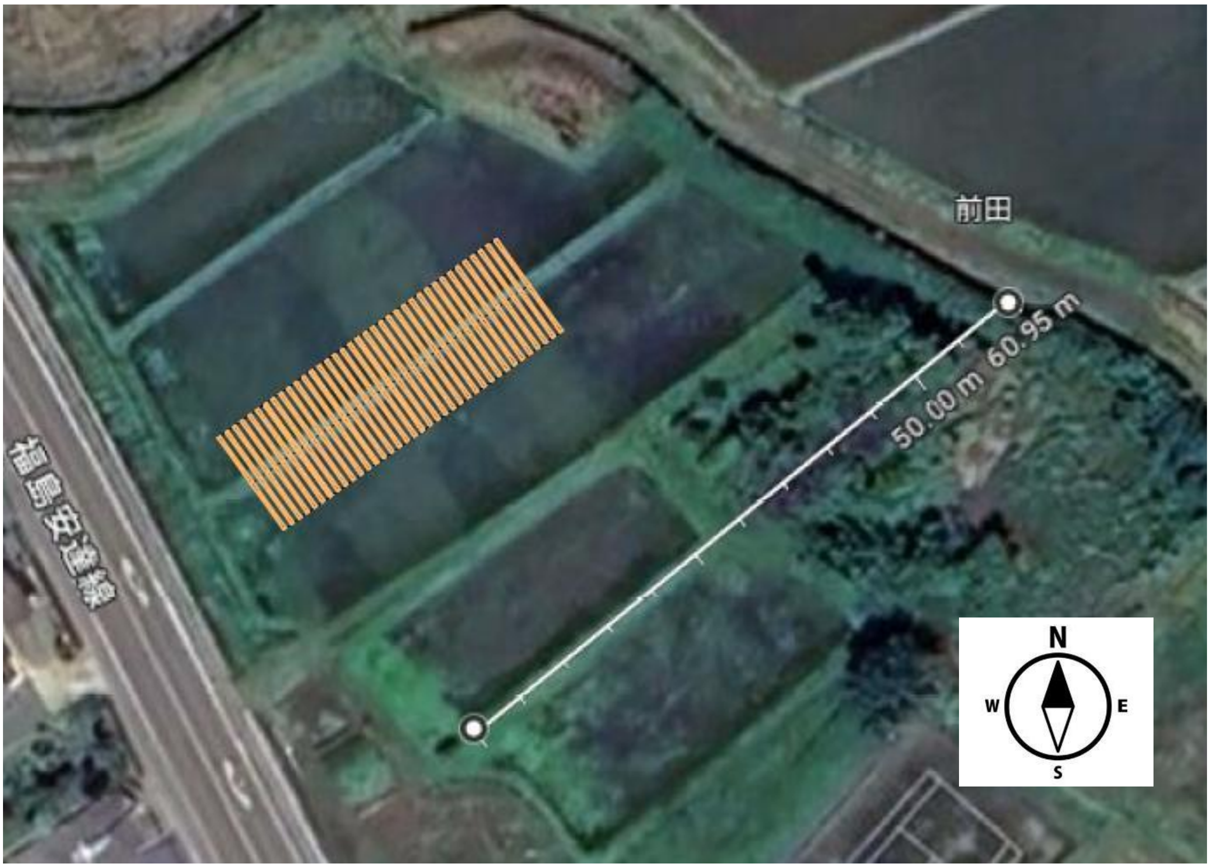


Figure 12 [Panel (Dummy Panel) Installation Layout] Drawn in March 2024

Installation Site Address:Maeda, Aza-Asakawa, Matsukawa Town, Fukushima City

[Reference] System Configuration in Case Actual Solar Panels Are Installed

·System Capacity: 165W x12 panels =19.8 kW (DC / direct current)

·Mounting Frame Post Spacing: East-West & North-South: 5m (center-to-center)

·Mounting Height: 3.2 m

•Installation Area:300㎡ (Short side 10 m × Long side 30 m)

·Shading Ratio: 34.3%

·Overload Ratio:133%

·Assumed Panel Tilt Angle: 25°

·Panel Azimuth Angle: Southeast-facing, 35.6° (due south = 0°)

·PCS (Power Conditioning System): 4.95 kW × 3 units = 14.85 kW (AC / alternating current)

·Estimated Construction Cost: 3.5 million yen (excluding connection costs and consumption tax)

Figure 13 [Test Plant Installation Scene ① Setting up the Posts: April 2024]

First, a simple survey was conducted, and stakes were driven into the ground. In an actual plant setup, screw piles would typically be driven about 2 meters deep using heavy machinery. However, for this case, they were driven about 1 meter deep using manual equipment.

Figure 14 [Test Plant Installation Scene ② Assembling the Prepared Mounting Frame: April 2024]

This time, we utilized commercially available scaffolding pipes (single pipes) and clamps for those pipes. In an actual plant, dedicated aluminum or steel mounting frames would be used. The wind resistance standard is 38 m/s. For a structure of this size, steps ① and ② can be completed by a team of three workers in 2 to 3 days.

Figure 15 [Test Plant Installation (3): Attaching Dummy Panels – April 2024]

This time, we struggled because the scaffolding was muddy. For rice fields, it is preferable to carry out installation during winter when the ground is more stable. This task also took about two to three days with a team of three people.
Normally, by using a lift and specialized mounting brackets, panel installation can proceed at more than twice the speed.

Figure 16 [Test Plant Installation (4): Dummy Panels Half Completed – April 2024]

This time, we realized that the initially planned method could not withstand the wind, which caused delays.
During maintenance in the winter of 2025, we plan to strengthen the structure further by using stainless steel wires.

Figure 17 [Condition of the Test Field After Installation (5) – July 2024]

During the experiment period, there were two instances where dummy panels became detached.
However, both were recovered within two weeks, and the experiment was able to proceed without major issues.

3) About Cultivation and Measurement

(1) Cultivation

On May 29th, in both the tilled and no-till plots, Koshihikari rice was transplanted using a rice transplanter. The tilled plot employed a shallow tillage method, cultivating the top 5 cm of soil. In the no-till plot, rye and weeds grown as cover crops were flattened using a roller crimper, followed by flooding of the field. The rice seedlings were then transplanted directly into the undisturbed soil.

Figure 18 [Division of tillage/no-tillage/reduced tillage]

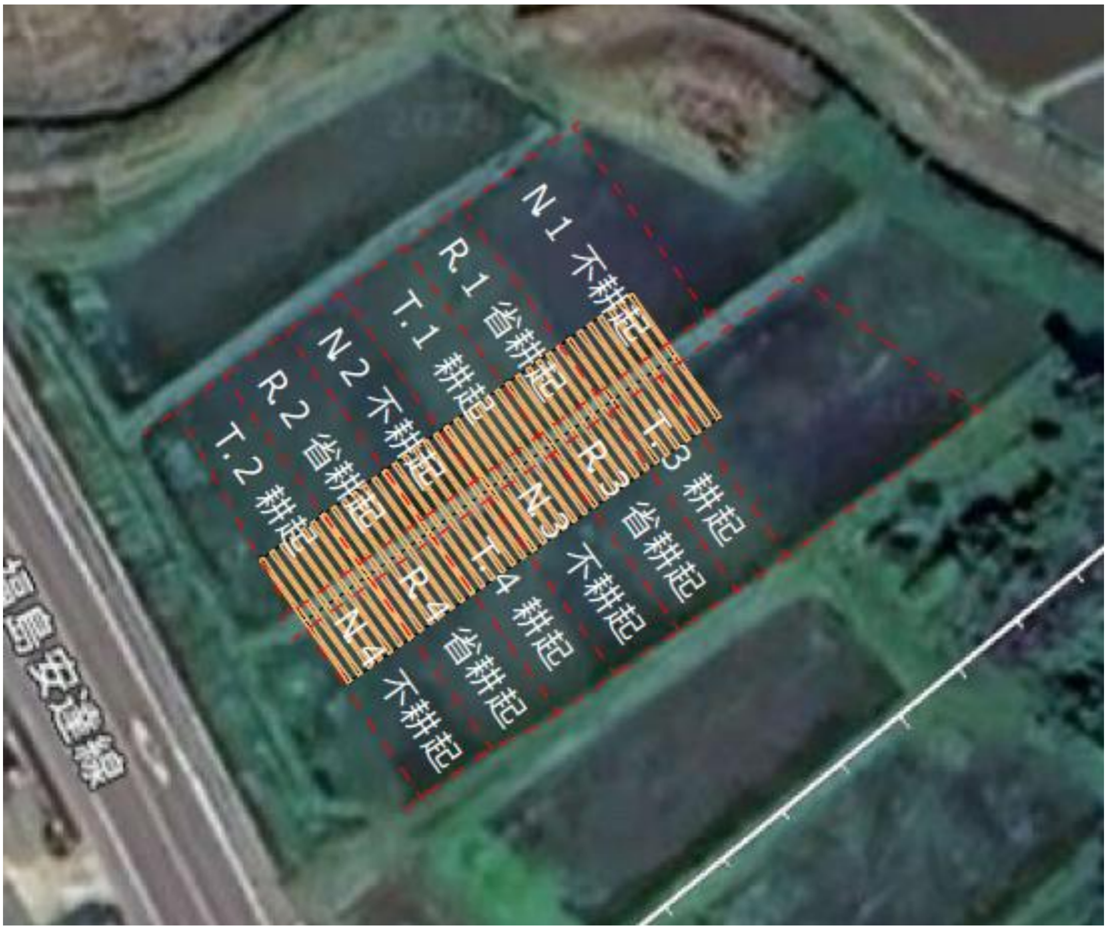


Figure 19 [Division of tillage/no-tillage/reduced tillage and location of test plants]

Cultivation and experiments were conducted using a randomized design that included tillage, reduced tillage, and no-tillage treatments, both with and without solar panel shading, while accounting for potential variations in soil fertility across different areas of the field.

Figure 20 [Hand-Pushed Roller Crimper: May 29, 2024]

※The crimper is designed to allow water to be added inside, enabling sufficient weight to be applied. The one in the photo was made by high school students and is approximately 50 cm wide. In the experimental field, an 80 cm-wide version made by

“Bizen” was used. There are also larger, heavier models about 2 meters wide that can be pulled by a tractor.

Figure 21 [Rice Planting Using a No-Till Transplanter at the Test Plant – May 29, 2024]

*On the right side of the photo is Professor Shoji from Kobe University.
We borrowed Professor Shoji’s original no-till rice transplanter, which is being used in joint research with Professor Komatsuzaki from Ibaraki University.
A demonstration and workshop were also held, inviting participants from across the country.

(2) Regarding the Measurements

To measure methane emissions, a transparent box-shaped chamber was placed over three rice plants. Gas samples of 30 ml were collected every 10 minutes, then quantitatively analyzed in the laboratory using gas chromatography. Based on this ,the emission rate (flux) per unit area per unit time was calculated.

A total of nine observations were conducted between May and September 2024.

Left / Figure 22 [Preparations for Gas Collection] **Right / Figure 23** [Professor Kaneko Explaining Gas Collection]

Even under light cloud cover, the rice paddies were extremely humid, making the experiment a high-risk task in terms of heatstroke.

Figure 24 [Preparations for Gas Collection]

The work takes about four hours in pairs, but it requires quick and continuous movement from one spot to the next.

Figure 25 [Equipment for Methane Measurement Installed at the Faculty of Food and Agricultural Sciences, Fukushima University]

Bottles containing the gas samples collected in the field were brought to the laboratory, where measurements and verification were conducted using the equipment shown above (Agilent 7697A Headspace Sampler and Agilent 8890 GC System).

During the experiment period, soil temperatures were measured by placing soil thermometers at a depth of 10 cm in both the area under the panels and in the panel-free rice field. Temperature data was recorded every hour using a data logger.

2024年	1回目	2回目	3回目	4.回目	5回目	6回目	7回目	8回目	9回目
観測日	5/14	6/5	6/19	7/3	7/17	7/31	8/14	8/28	9/11

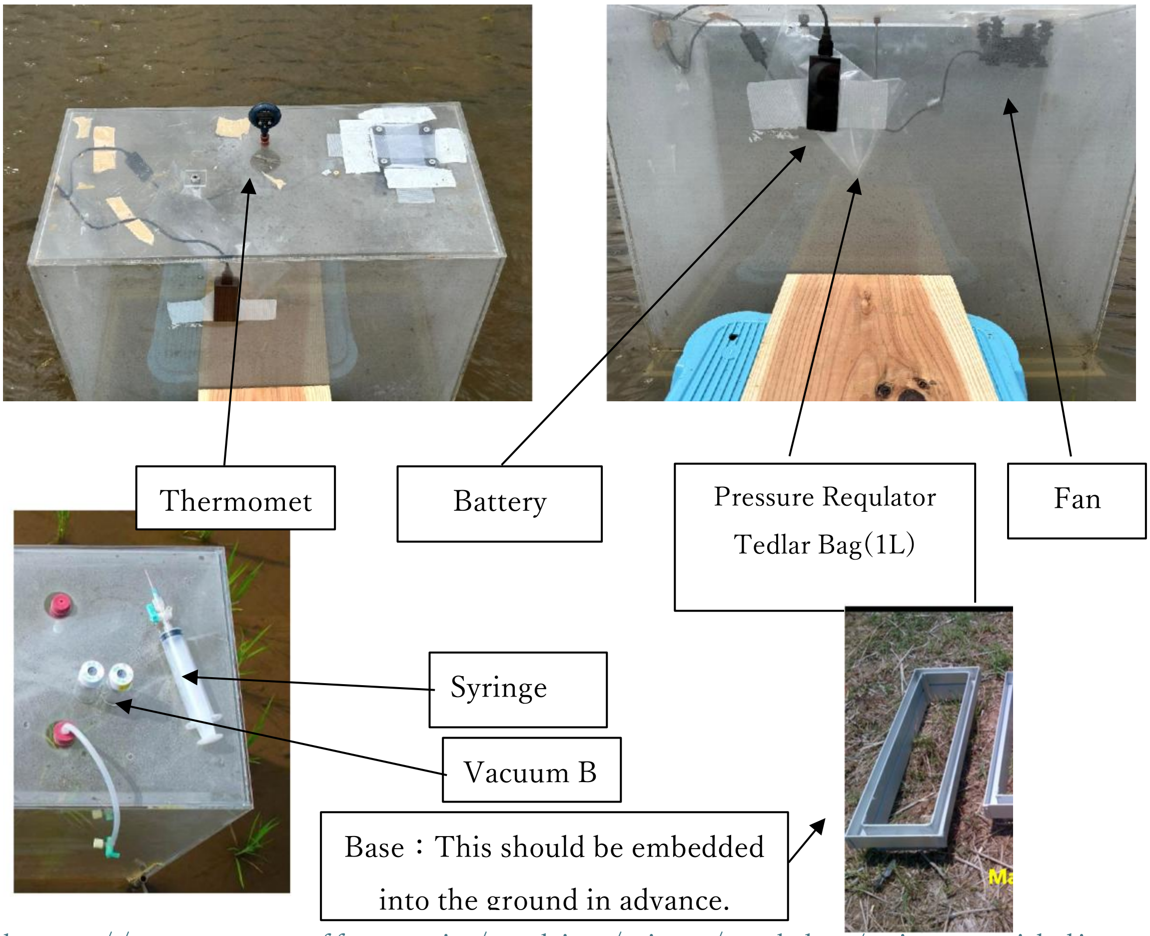
[2024 Observation Dates]

Soil temperature sensors were installed at a depth of 10 cm in both the areas under the panels and in rice fields without panels, and temperatures were recorded every hour using a data logger.

"Manual for Measuring Methane in Paddy Fields" *2 pages are quoted up to the next page.

Made by Yoshinori Watanabe

[Preparing the measurement chamber]



https://www.naro.affrc.go.jp/archive/niaes/techdoc/mirsa_guidelines.pdf

[Preparing a Pathway for Access to the Chamber]

・Create a bridge by placing boards over containers. Concrete blocks can also be used.

・This is to prevent the release of methane gas caused by stepping on the ground during measurement.

https://www.naro.affrc.go.jp/archive/niaes/techdoc/mirsa_guidelines.pdf

[Items to Prepare]

·100 vacuum bottles, 1 pressure gauge, two 50 ml syringes, 2 thermometers, 2 sets of recording sheets (see separate attachment), 2 folding rulers, 2 blowers

[Measurement Procedure]

More than one day before the measurement:

·Charge the battery for the fan

·Prepare the vacuum bottles (by depressurizing them using a freeze dryer)

⇩

The day before the measurement:

·Set up the chamber bases and extenders simultaneously in both the control and tre atment plots

·Reinforce the fan on the chamber top with tape

·Maintain a water depth of 5-10 cm in the rice field

⇩

The day of measurement:

·Use the blower to inject air into the Tedlar bag for pressure adjustment

·Set up the thermometers

·Install the chamber top

·0-minute sampling:

·Collect 30 ml of gas from inside the chamber using a syringe and inject it into a vacuum bottle

·Record the time, temperature, and internal pressure on the sheet

·10, 20, 30-minute samplings:

·Collect 30 ml of gas from the chamber at each time point using the same method as at 0 minutes

·Record the temperature

·Measure the height of the inner wall at two points inside the chamber using foldi ng rulers

⇩

After the experiment:

·Bring the sample bottles back to Fukushima University

·Measure the methane concentration in the sample bottles using a gas chromatograph (GC), aiming to complete the analysis within about one month

3．1)Results and Discussion

1) Reduction of Methane Emissions from Rice Fields

Under the panels, soil temperature on sunny days dropped by up to 3° C during the daytime and was about 1° C lower at night compared to areas without panels.

During the observation period (May to August), methane emissions were slightly higher in n o-till plots compared to tilled plots, contrary to initial predictions.

On the other hand, the installation of panels reduced methane emissions to 49.9% in tilled pl ots and 59.9% in no-till plots compared to plots without panels, indicating that the panels had a methane reduction effect.

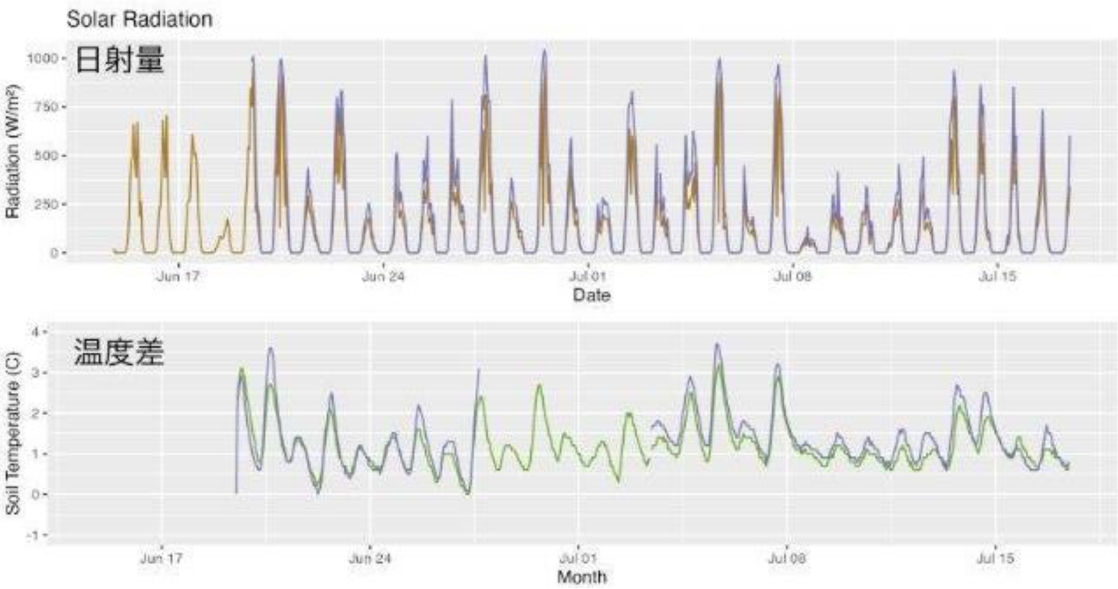
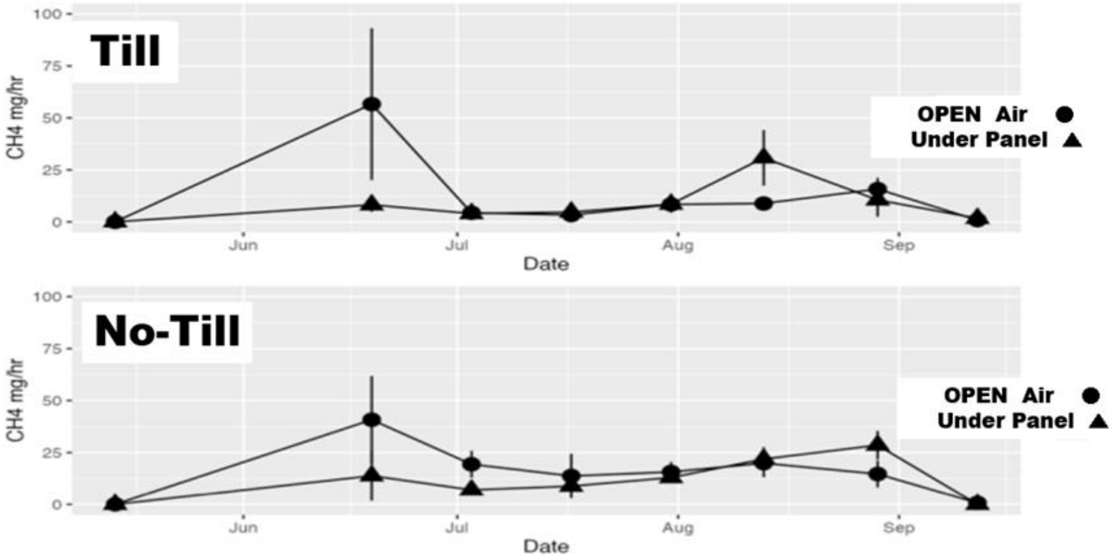


Figure 27 [Solar radiation and the associated temperature difference between under the panel and other areas]



水田からのメタンの発生

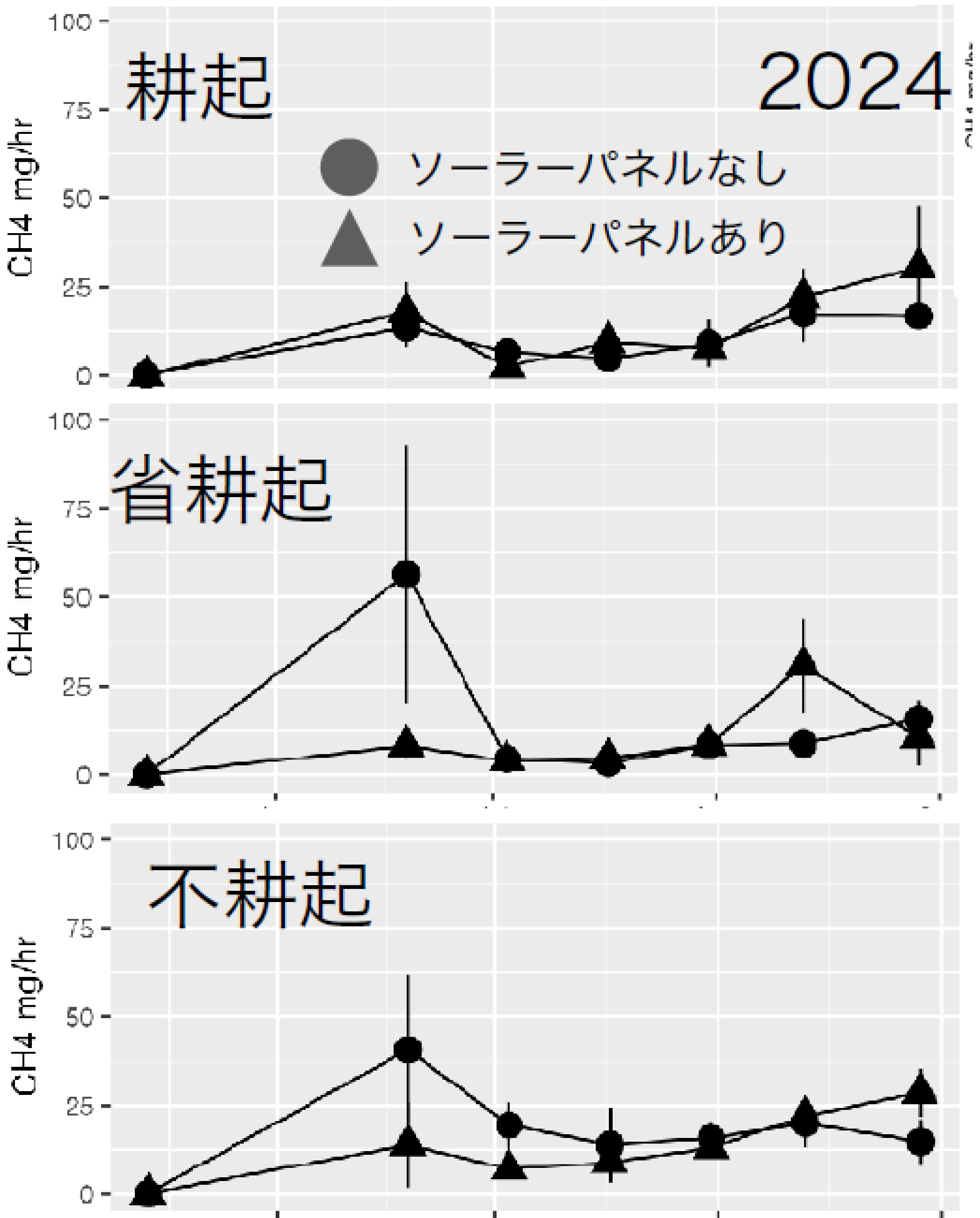
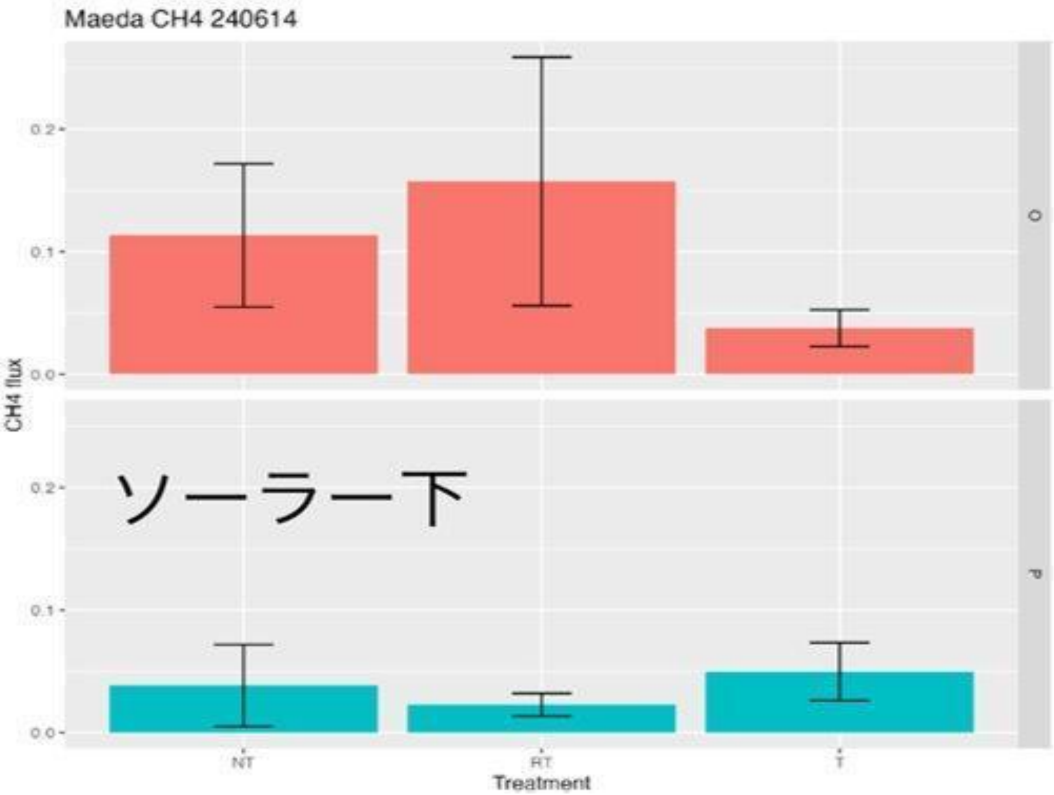


Figure 28 [Methane Emissions in Tilled, Reduced Tillage, and No-Tillage Areas - Comparing Under Panels and Non-Panel Areas]



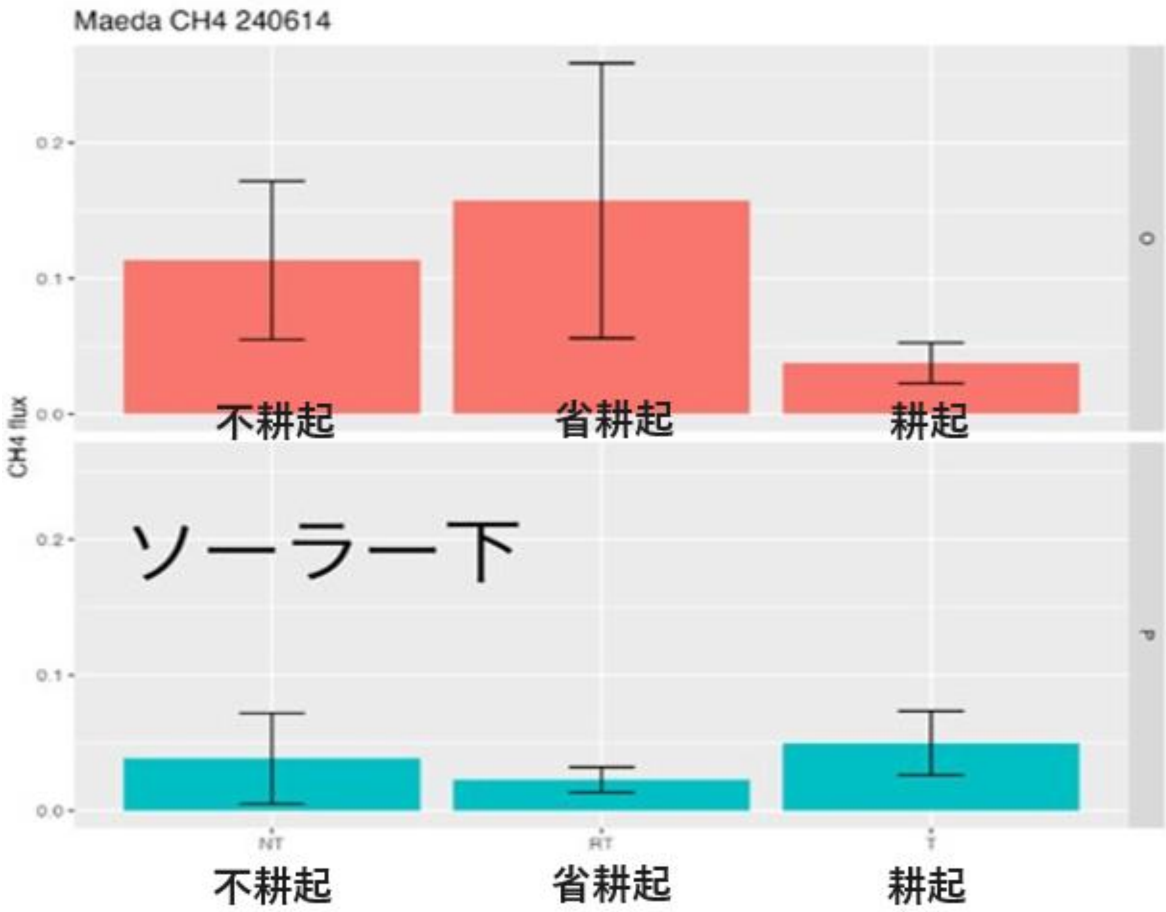


図29

Figure 29 [Methane Emissions in June Under Panels and in Non-Panel Areas for Tilled and No-Till Plots]

In June, as shown above, significant differences in methane emissions were observed. However, in July, water leaked from the rice paddies, resulting in almost no observable differences. It is essential to ensure that such issues are not repeated in coming years.

Although reducing greenhouse gas emissions, unfortunately, climate change will not subside immediately. Therefore, continued high summer temperatures are expected. The installation of solar panels is anticipated to help mitigate heat stress in rice plants by lowering air and soil temperatures.

While this is based on one year of observation and the results are still preliminary, the installation of agrivoltaic systems (solar power integrated with farming) in rice paddies has shown a significant reduction in methane emissions. Moving forward, we plan to quantify the environmental balance of combining no-tillage rice paddies with agrivoltaic systems. This includes reductions in agricultural fuel usa ge due to no-tillage practices, the replacement of fossil fuels through the electrification of farming equipment, and changes in soil carbon content.

In the future, the methane reductions achieved through this method may become a new source of income for farmers as GHG credits. On October 1, 2024, a site visit was conducted by a section chief who played a key role in drafting the Ministry of Agriculture, Forestry and Fisheries' J-Credit regulations, which helped raise awareness of this method. Starting in fiscal year 2025, subsidies from the Ministry will support methane emission surveys in rice paddies equipped with solar sharing systems.

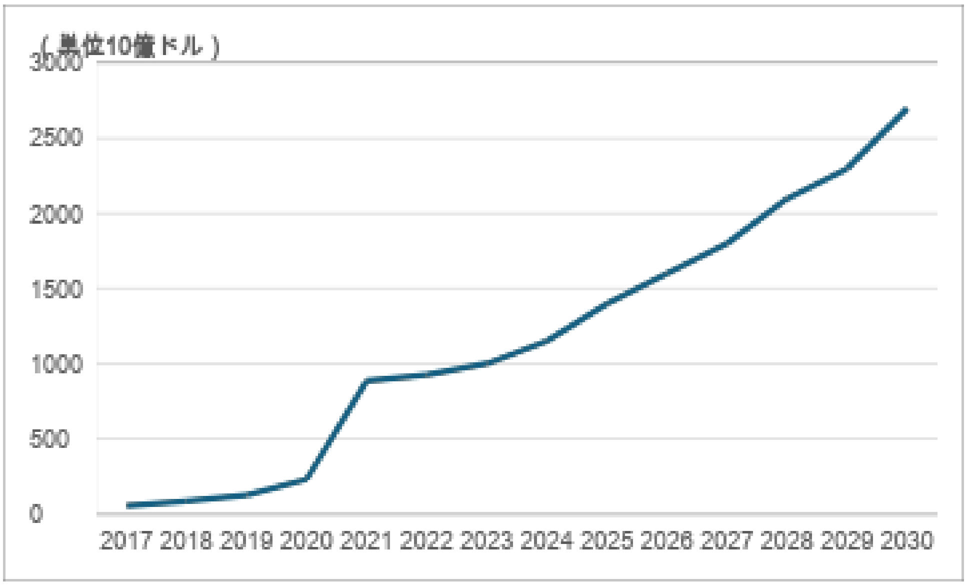


Figure 30 [Graph of Past Performance and Forecast of the Global Carbon Credit Market Volume]

[Prepared by the author based on data published by Refinitiv, BloombergNEF, Ecosystem Marketplace, etc.]

Based on past trends, the global carbon credit market is expected to continue growing—not only in trading volume but also in price per unit. By 2030, the market is projected to exceed 400 trillion yen (in Japanese yen). Given the results of this experiment, it is entirely feasible to leverage this trend to enhance agricultural income.

2) Adaptation to Heat Stress

In this experiment, the effectiveness of solar sharing was confirmed not only in terms of power generation but also in terms of crop adaptation to global warming.

The chart below shows the percentage of well-formed rice grains in both tilled and no-till plots, under the solar panel area and in other areas. It was found that the no-till cultivated areas had a higher percentage of well-formed rice grains, regardless of whether they were under the solar panels or not.

Additionally, the percentage of well-formed rice grains was higher under the solar panel area than in other areas. In other words, the highest percentage of well-formed rice grains was found in the no-till area under the solar panels, while the lowest was in the tilled area outside of the panel coverage.

In Japan, due to the effects of global warming, the ratio of second-grade rice has been increasing in all prefectures except Hokkaido, which has become a serious issue. According to the National Agriculture and Food Research Organization (NARO), if no countermeasures are taken, a yield reduction of over 11% is expected by 2050. (Japan Agricultural News, September 22, 2024)

This experiment suggested that installing solar sharing equipment in rice paddies could be effective as a measure to adapt to heat stress.

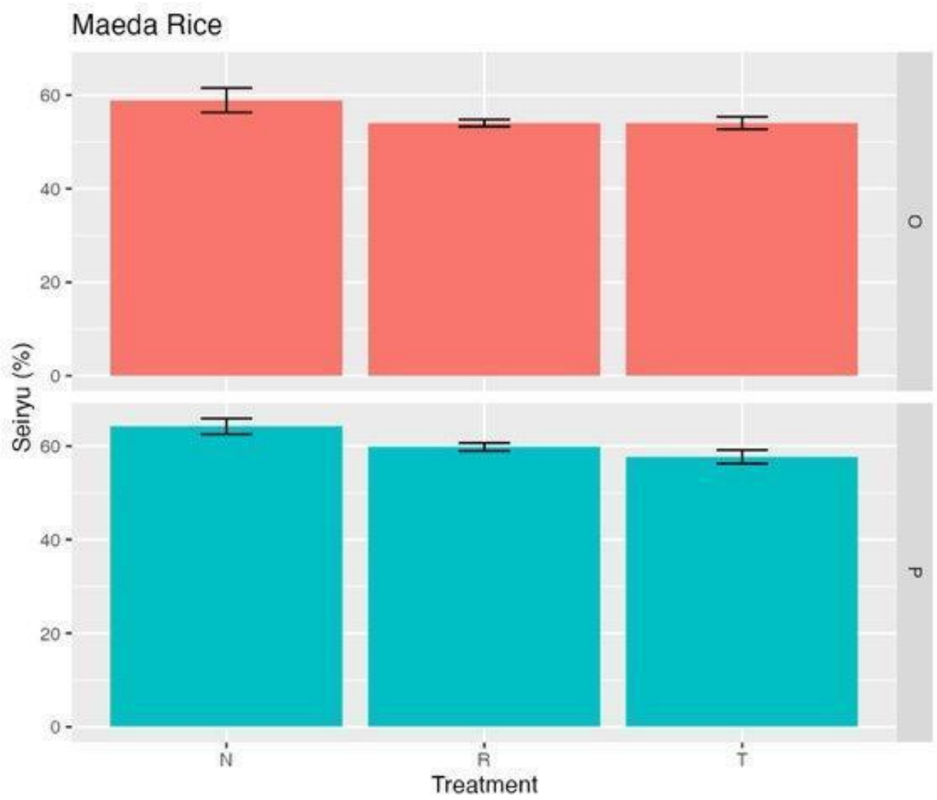
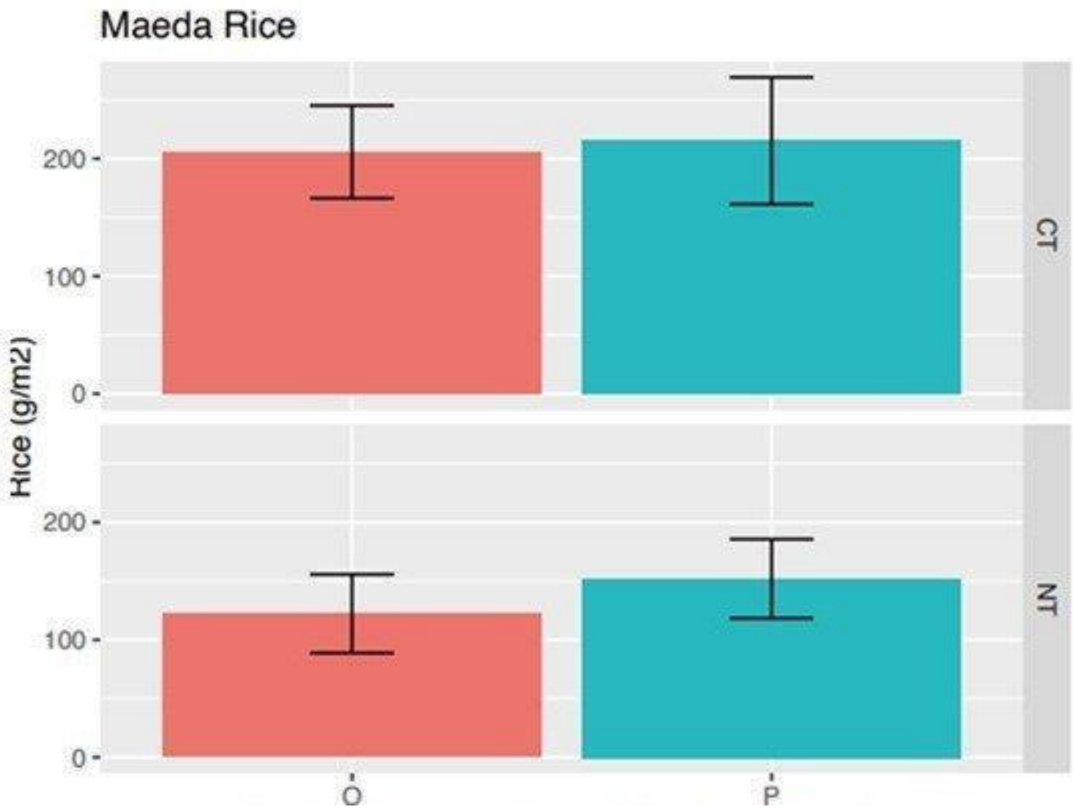


Figure 31 [Ratio of **well-formed rice grains** in tilled and no-tilled areas, below the panel and in othe
r areas]



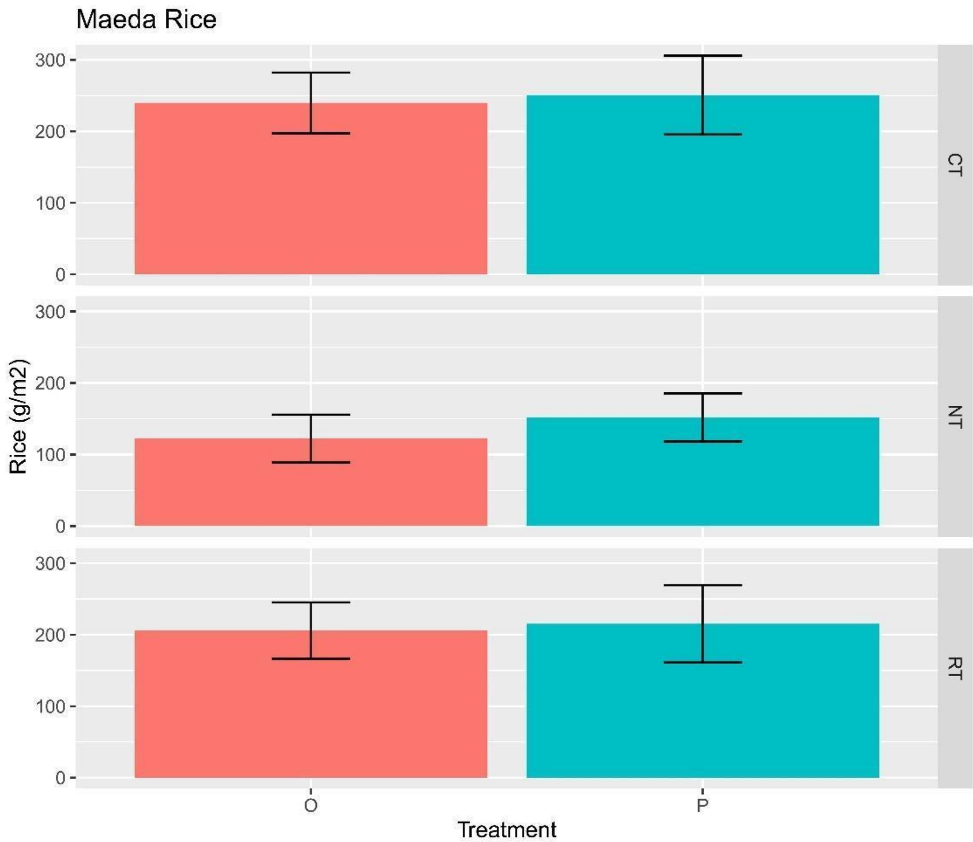


Figure 32 [Yield in Tilled, Reduced-Tillage, and No-Till Areas Under Panels and in Other Areas]

Although no statistically significant differences were observed, the average values indicate that the area under the solar sharing (SS) panels had higher yields. Comparing the tilled and no-till areas, the no-till areas showed approximately a 20% reduction in yield.

3）Regarding Environmental Support

[Changes in Methane Emissions]

In many countries, including Japan, national greenhouse gas (GHG) emission inventories are often estimated using the IPCC Guidelines (2006 version and later revisions) for the agricultural sector. This study also followed those guidelines for estimation.

Basic Formula for CH_4 Emissions (Rice Cultivation):

¥text{CH_4 Emission} = A ¥times EF ¥times (1 - R) ¥times 10^{-3}

- A: Cultivated area (ha)
- EF: Emission factor (kg-CH_4/ha) – corrected based on factors such as duration of flooding, water management, and straw incorporation
- R: Recovery factor – reduction due to midseason drainage or multiple drainings
- 10^{-3}: Conversion factor to adjust units from kg to t (tons)

The emission factor (EF) is given a baseline value depending on conditions. For example, for "continuous flooding in a temperate region," the initial value is about 1.3 kg-CH_4/(ha·day), and adjustments are made based on actual flooding duration and whether rice straw is incorporated.

[GHG Reduction Effects of Renewable Energy Introduction]

When a 1,000 kW (1 MW) solar-sharing photovoltaic system is installed under typical conditions in Japan:

- Annual power generation: 1,300,000–1,350,000 kWh

(Based on 10 years of operational data from a Citizen Energy Chiba Co.,Ltd. – south-facing panels, 25°　tilt angle)

- CO_2 emission factor: 0.474–0.5 kg-CO_2/kWh

Using these values, the estimated annual CO_2 emission reduction is approximately 600–675 t-CO_2.

For a solar-sharing system with a 35% shading rate, a 1,000 kW solar panel system can be inst alled on 1.4 hectares.

Therefore, on 1 hectare, approximately 714 kW of panels can be installed.

As a result, the expected CO_2 emission reduction per hectare is approximately 428–482 t-CO_2 annually.

[LCA (Life Cycle Assessment)]

- To accurately evaluate how much CO_2 emissions can be reduced by solar power gen eration, it is necessary to consider emissions over the entire life cycle of the system — including "manufacturing→transportation→installation→operation→ disposal, and re cycling.
- The energy costs associated with manufacturing and recycling/disposal of so lar panels have been decreasing year by year. The energy payback time is of ten expressed as approximately 0.9 to 1.7 years, and it is generally consid ered to be around 1 to 2 years.
- In this study, to take a conservative approach, we assumed a 30-year servic e life for the solar panels and a payback time of 17 years, and thus applie d a correction factor of 0.94 to the emissions reduction coefficient.
- In Japan, it is legally mandated that all solar power systems over 10 years old must contribute to a recycling fund, and this requirement is already in effect. Since the technological methods for recycling are well established, further cost reductions, robust legal enforcement, and proper implementatio n will be needed moving forward.

[When a Portion Is Used for Agricultural Machinery]

Note: This experiment was based on simulation only.

The amount of fossil fuel and associated GHG emissions from agricultural machinery used in 1 he ctare of rice cultivation in Japan:

- Typical conventional rice farming uses around 40 to 80 liters of diesel per hectare annually.

  *This varies depending on the number of operations, machinery size, and fie ld conditions.

- GHG emissions (in CO_2 equivalent) considering the conditions above:
  Using a diesel emission factor of about 2.62 kg-CO_2/L, the emissions are estimated at approximately 0.10 to 0.21 t-CO_2/ha.

- If fuels and electricity for drying and processing are included, the emissions may be slightly higher.

[Annual GHG Emissions from Rice Cultivation in Japan]

The GHG emissions from 1 hectare of rice cultivation in Japan are typically around 2 to 4 t-CO_2eq/ha/year, and it is no exaggeration to say that 80–90% of these emissions come from methane.

[Conclusion Regarding Environmental Balance in GHG Equivalents]

1. The GHG emissions from 1 hectare of rice cultivation in Japan are approximately 2–4 t-CO_2eq/ha/year.
2. In this experiment, methane emissions were found to be reduced by about 50%. Taking a conservative approach, the following calculation was made:

   "2–4 t-CO_2eq/ha/year" × methane ratio (0.8) × methane reduction rate (0.5) = 0.8–1.6 t-CO_2eq/ha/year reduced.

3. Subtracting the estimated GHG reduction from reduced fossil fuel use in agricultural machinery (0.10–0.21 t-CO_2/ha/year) gives:

   0.6–1.5 t-CO_2eq/ha/year net GHG reduction from agriculture-related sources.

4. Installing solar sharing equipment provides an estimated GHG emission reduction of 428–482 t-CO_2/ha/year.
5. Accounting for environmental costs from manufacturing and disposal/recycling, a correction factor of 0.94 is applied.
6. An overwhelmingly positive environmental balance in GHG terms was confirmed.

Maximum impact: approximately 755 times greater (482 × 0.94 ÷ 0.6)

Minimum impact: approximately 268 times greater (428 × 0.94 ÷ 1.5)

7. As shown above, installing solar sharing greatly offsets GHG emissions generated from agriculture.
8. In other words, by installing solar sharing panels on just 2.85% of 1 hectare (i.e., 285 m^2), it is possible to completely offset the GHG emissions from rice cultivation on that hectare.
9. Furthermore, installing solar sharing panels on 33.2% of Japan's rice paddies would have the potential to cover the entirety of Japan's annual domestic electricity consumption.

■ **Calculation Example (Assuming annual power generation of 1,400 kWh per 1 kW system)**

1. Area of a Bifacial Solar Panel (per panel)

0.35m×1.95m=0.6825㎡

2. Panel Output per Square Meter

1÷0.6825×0.165=0.241kW

3. Annual Power Generation per Square Meter

0.241×1,400=337.4kWh

4. Area Required to Cover Japan's Annual Electricity Consumption

913.5 billion÷337.4=2.707 billion ㎡

5. Required Area Considering Solar Sharing with 35% Shading Ratio

2.707 billion ㎡÷0.35=7.734 billion ㎡= 773,400 hectares

6. Ratio to Total Agricultural Land Area

773,400 ha÷4,632,000 ha=16.7%

4) Economic Viability in Agricultural Management

[Items to Consider]

(1) Methane Credit Revenue

Extending the mid-season drainage period can reduce methane emissions by approximately 30%, while temperature reduction under solar sharing can reduce methane by about 50%.

- The market price for carbon credits from methane reduction through mid-season drainage is ¥8,000 to ¥15,000/ha/year.

Given that solar sharing can reduce methane 1.66 times more, the estimated credit revenue is: ¥13,280 to ¥24,900/ha/year

(2) Electricity Sales Revenue

Regarding revenue from selling electricity via solar sharing, three models can be considered from the farmer's perspective:

① The farmer becomes the power producer and continues farming themselves.

- All profits from the power generation business become the farmer's income.
- A 500 kW DC system can be installed per hectare, but construction costs exceed ¥75 million.
- If funding is secured, this can result in an additional income of over ¥2 million/ha/year.

(Note: figures vary significantly depending on subsidies and other conditions.)

② The farmer does not manage the power generation but continues farming beneath the solar panels.

- The farmer receives a portion of the electricity sales revenue.

- Typically, a 5% share of the sales is paid to the farmer.
- This results in approximately ¥600,000/ha/year, which is comparable to average rice field income.

③ The farmer neither farms nor generates electricity, but leases land to a power producer and a separate farmer.

- The only income is land rent from leasing the field.
- The revenue is estimated at approximately ¥150,000 to ¥200,000/ha/year.

(3) Fuel Cost Reduction through Electrification of Agricultural Machinery such as Tractors

- Due to global socio-economic trends, fossil fuel prices are expected to rise over the medium to long term, which in turn increases the operating costs of various types of agricultural management.

Transitioning to in-house renewable energy, such as through solar sharing, will contribute positively to the financial health of farming operations.

- Additionally, because the initial and operating costs of solar sharing systems are relatively fixed, the costs related to energy for machinery become stable, contributing to more predictable and sustainable agricultural management.
- Furthermore, as electric vehicles (EVs) become more common in general transportation, electrification of agricultural machinery like tractors is also expected to accelerate.

Companies such as Kubota and Iseki have already introduced such products, with Iseki launching EV equipment in the EU.

Figure 33 (left): Yanmar unmanned electric tractor

Figure 34 (right): Iseki electric mower

図35　㈱クボタHPより引用：https://www.kubota.co.jp/futurecube/tractor/

（4 Increased Income from Higher Yields

- In this experiment, no statistically significant superiority was observed, so numerical estimation has not been conducted at this stage.

However, the average yield was higher, likely due to adaptation effects against global warming.

If future demonstration experiments can quantify this effect, it may be possible to include it as a coefficient in agricultural income calculations.

- It is important to note that about 10% of the planting area is reduced due to the space occupied by solar sharing (SS) equipment columns.

Future equipment is expected to allow for a 60 cm gap with 6-meter column spacing, so the 10% reduction is a reasonable estimate.

(5) Increased Income from a Higher Ratio of Premium-Grade Rice

- Statistically significant superiority was observed here (see Figure 31).

Even with the same yield, a higher percentage of premium-grade (first-grade) rice leads to higher market prices, because distribution and production costs are the same for both first- and second-grade rice—thus, this directly impacts net profit.

- Additionally, while many rice farmers are switching to heat-tolerant varieties, if traditional varieties such as Koshihikari can continue to be grown under solar sharing, this adds scarcity value and could raise the selling price.

This contributes positively to competitiveness in agricultural management.

(6) Increased Income through Carbon Farming Branding

- Carbon farming refers to agricultural practices that aim to sequester CO_2 in the soil, improve soil quality, and reduce greenhouse gas emissions—commonly associated with regenerative agriculture.

(Source: Ministry of Agriculture, Forestry and Fisheries of Japan)

- However, the definition of "carbon farming" is not globally uniform.

In practice, it is interpreted to broadly include efforts to reduce agriculture-derived GHG emissions, such as methane reduction from rice paddies.

- Therefore, the methodology used in this study also qualifies as carbon farming under such interpretations.

Reference: European Commission Communication Document "Sustainable Cycles" (COM(2021) 800 final), published December 2021.

In the EU and other regions, agricultural products grown through carbon farming (carbon sequestration agriculture) are increasingly being distributed with consumer price incentives.

Even in Japan, there is a growing demand—particularly among environmentally conscious co nsumers—for decarbonized agricultural products.

The product shown in the photo is a miso made from soybeans cultivated under solar sharing, using no-tillage practices and certified JAS organic. It was commercialized by Patagonia,Inc, a company internationally recognized for its environmental efforts, and was sold in Patagonia's directly operated stores across Japan.

It was sold at a higher price than regular organic miso.

TERRA Co.,Ltd.,purchases organic barley grown under solar sharing and certified JAS organic from our affiliated farmland-holding company, Sosa Ohisama Farm Co., Ltd., at a price of 600 yen per kilogram (excluding tax) for use as a raw material in our solar beer.

Brand enhancement through carbon farming has the most immediate effect and may have a significant financial impact.

This synergy is particularly notable when solar sharing is implemented in collaboration with corporate partners.

•


Figure 36 [Example of a Carbon Farming Product / Solar Beer – Photo taken on 2024/11/6]

Miso made using no-till, organically grown soybeans cultivated under solar sharing conditions with JAS organic certification. The person in the right photo is Mr. Kondo,Provisions Leader at Patagonia J apan.

Figure 37 [Volunteer Farming Work at a Carbon Farming Field – Photo taken in August 2023]

Every year, more than 200 staff members from Patagonia Japan volunteer at this field, deepening their connections with the young members of the local agricultural corporation.

Figure 38 [Example of Carbon Farming Product Distribution / Solar Beer – Photo taken on 2024/8/6]

"Solar Beer" made using organically grown barley cultivated under solar sharing conditions with JAS organic certification. It is sold at a premium price of 800 yen.

(7) Cost Reduction by Omitting Water Overflow Cooling for High-Temperature Countermeasures

A web-based survey revealed that the cost and extent of implementing overflow irrigation for temperature control vary significantly by region and conditions. Therefore, this item is noted as a potential area for cost reduction, but no numerical estimate is provided at this time.

- Labor costs and fuel for opening and closing sluice gates
- Water usage fees

(8) Other Benefits

- Promotional impact from engaging in decarbonized agriculture
- Priority in securing new farmers through adoption of advanced agricultural practices
- Partial shading from solar panels may reduce worker fatigue during farming operations, potentially leading to lower relative labor costs

[Agricultural Management Calculations]

(1) Conventional Rice Farming Operations

■ Revenue per hectare:

Approximately ¥1,000,000 to ¥1,500,000 per hectare, though this varies significantly depending on rice prices and yield.

Expenses per hectare:

Including costs for materials, agricultural machinery, land lease, labor, etc., a general benchmark is around ¥500,000 to ¥700,000.

Net income (Gross Profit):

Estimated at around ¥500,000 to ¥800,000 per hectare.

For a 10-hectare operation:

This translates to an annual income of approximately ¥5,000,000 to ¥8,000,000.

(2) New Rice Farming Model with Solar Sharing

Farm Management Balance	Metahne Credit	Renewable Energy Income	Yield	First Class Rice Ratio	Brand Value	Total Income Increase	Income Increas /10ha/Total
	/ha/year	/ha/year	10%	3%	10%	/ha/year	/10ha/year
SS Installation	¥200	600,000	Decrease	Increased Revenue	Increased Revenue	¥630,000 or more	¥630,000 or more

※In terms of yield, rice growth per unit area is almost equivalent; however, due to the installation of pillars, the cultivable area is reduced by about 10%, leading to a corresponding decrease in total yield.

※For renewable energy income, conservative (lower-bound) estimates were used. For methane credits, the average value was applied in the table.

※The total in the above table does not include potential income increases from a higher proportion of premium-grade rice or from enhanced brand value, as these are difficult to quantify.

By introducing solar sharing to a conventional 10-hectare rice farming operation—which previously generated ¥5 to ¥8 million in income—an additional income of over ¥6.3 million is expected. This would raise the total income to approximately ¥11.3 to ¥14.3 million.

This projection presents a highly promising business model for the next generation of Japanese farmers.

4) About Utilization of Perovskite Solar Cells

(1) Benefits of a New Installation Orientation Using Perovskite Solar Cells

This demonstration experiment was conducted using dummy panels simulating "perovskite solar cells," a next-generation solar panel technology developed in Japan (Note *53).

As shown in the figure below, by installing the panels at a 90-degree orientation from conventional setups, sunlight reaches the crops in a more natural way.

Since rice plants are classified as species without a light saturation point, it is considered favorable for shadows to pass over them in short intervals.

Particularly for rice, which lacks a light saturation point, it is expected that shading under improved conditions will be more beneficial.

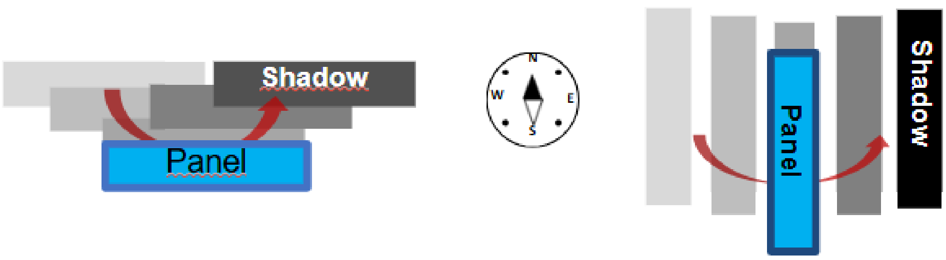


Figure 39 Cloud Movement When Solar Panels Are Installed Facing North-South

This is a type of installation made possible specifically by the unique characteristics of perovskite solar cells: they can be *flexible*, *maintain high power generation efficiency even under low light*, and *are not significantly affected by partial shading*. In contrast, silicon-based panels experience a significant drop in power output when installed at an angled position in the same (north-south) direction to prevent dust accumulation. Therefore, this installation method is unique to perovskite solar cells.

(2) Economic and Social Benefits and Challenges of Using Perovskite Solar Cells

- Perovskite solar cells can be produced at low temperatures, and their main material—iodine—can be sourced domestically. Combined with their lightweight nature, this leads to shorter payback times and a positive environmental impact.
- Furthermore, since they can be manufactured entirely within Japan, the introduction of solar sharing systems can proceed without being affected by exchange rates or international market trends, contributing to business stability.
- However, because they contain trace amounts of lead, strict management is required to prevent leakage into the natural environment. Specifically, any malfunctioning units should be promptly replaced. At the same time, it is crucial to develop legal frameworks and establish recycling systems.

Figure 40[Top image / Lens-shaped perovskite solar cell exclusively for solar sharing, photographed on 2024/8/6]

In Seisa City, Chiba pref. Known as a hub for solar sharing, TERRA Co.,Ltd. has launched a joint demonstration experiment with Sekisui Chemical Co.,LTD., TERRA holds patents related to this shap e (in Japan, the U.S., and China). The cross-section has a lens shape and is designed to withstand l arge typhoons that are expected in the future. Additionally, Sekisui Chemical Co.,Ltd.maintains a dominant lead in both technology and production when it comes to perovskite solar cells.


Figure 41 [Top image / Lens-shaped perovskite solar cell test plant exclusively for solar sharing, pho tographed on 2024/8/6]

Scene from the joint demonstration test by TERRA Co.,Ltd.and Sekisui Chemical Co.,Ltd. TER RA Co.,Ltd.aims to achieve the world's first grid connection in the first half of 2025. General sales a re also targeted for December 2025.

(3) Potential Use of Perovskite Solar Cells in Solar Sharing

[Reduction in Number of Components]

Since farming beneath the installation is essential in solar sharing, a minimum height of 2.5 meters is required. The lighter the upper structure, the simpler the frame can be, which reduces the number of components and construction labor, thereby lowering costs.

[Improved Agricultural Workability]

With wider spacing between pillars and sufficient height—around 4.5 m—agricultural operations become easier to carry out.

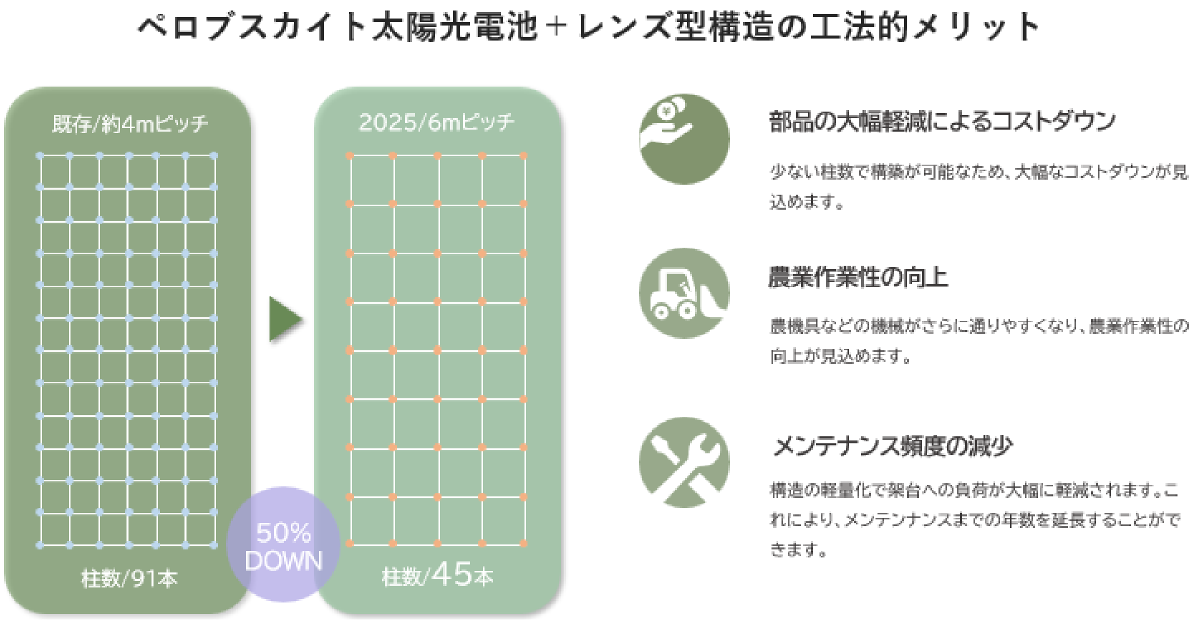


Figure 42 Diagram of Equipment Pillars with Perovskite Solar Cell Application

(4) Subsidies and Grants Related to the Use of Perovskite Solar Cells

With the establishment of FIT and FIP systems specifically for perovskite solar cells, along with various budgetary measures from the Ministry of Agriculture, Forestry and Fisheries, the Ministry of the Environment, the Ministry of Economy, Trade and Industry, and local governments, it is understood that these will be advantageous for farmers looking to adopt the technology.

In addition to support for the use of perovskite solar cells, a variety of subsidy programs for agrivoltaic (solar-sharing) systems are available from the same ministries and local governments. While these programs are expected to continue, they typically cap subsidies at 50% and involve several sp ecific eligibility requirements. Therefore, subsidy programs specifically targeting perovskite solar cells are likely to offer more favorable conditions.

(３）-1 Support Measures from the Ministry of Economy, Trade and Industry

The Ministry of Economy, Trade and Industry (METI) has already announced the creation of new FIT and FIP categories for facilities utilizing perovskite solar cells. The final pricing for the initial year is scheduled to be announced by the end of March 2025.

Once the FIT/FIP systems are implemented, they are expected to significantly benefit agricultural workers seeking loans from financial institutions, making financing more accessible. In addition to this measure, subsidies for construction costs are also under consideration.

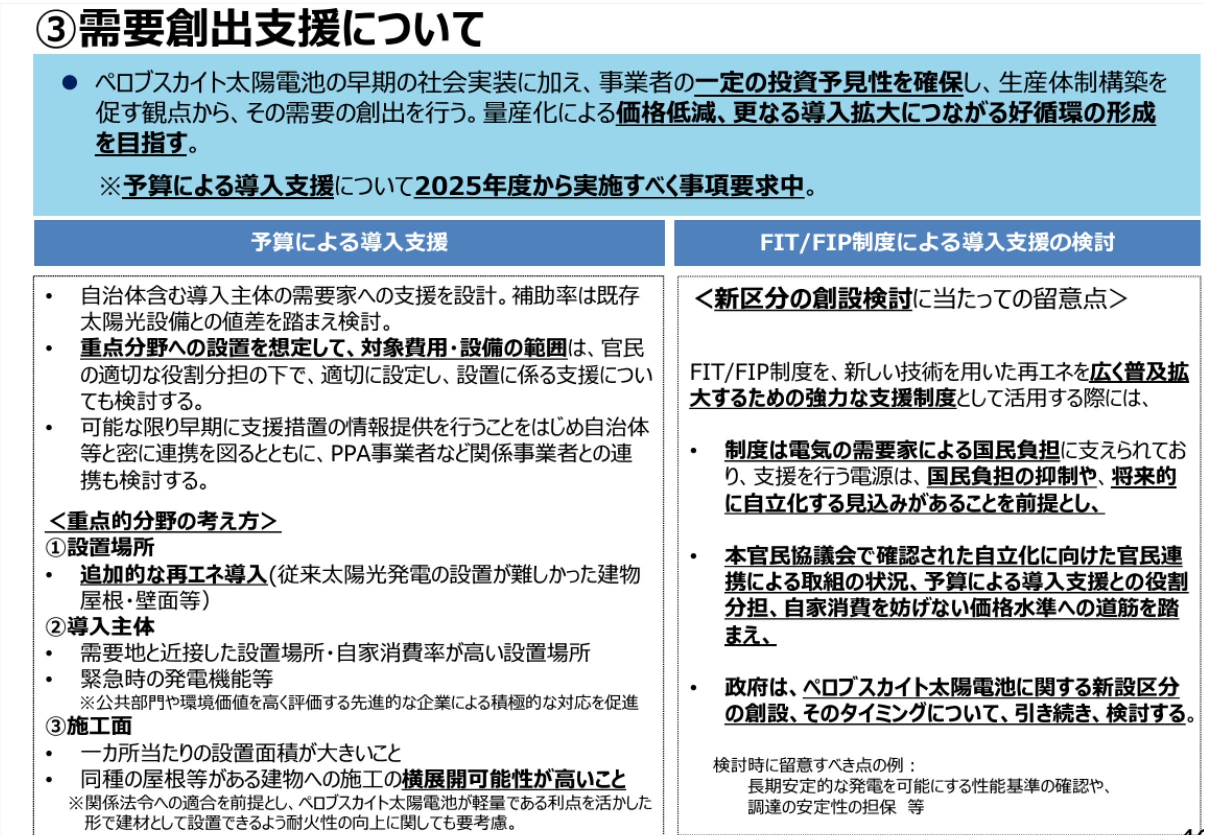


図43　Excerpt from the Ministry of Economy, Trade and Industry Website / Description regarding FIT/FIP (November 2024)

chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/
https://www.meti.go.jp/shingikai/energy_environment/perovskite_solar_cell/pdf/20241128_1.pdf

(3) -2　Support Measures from the Ministry of Agriculture, Forestry and Fisheries

Although specific details such as subsidy amounts, rates, and budget allocations are yet to be announced, the Ministry of Agriculture, Forestry and Fisheries has made an initial announcement. While it is easy to imagine that the Ministry of Economy, Trade and Industry and the Ministry of the Environment would be actively involved in the national promotion of perovskite solar cells, the participation of the Ministry of Agriculture and the Ministry of Land, Infrastructure, Transport and Tourism—along with the wide variety of available subsidy programs—strongly indicates that this is being promoted as a national policy initiative.

Figure 44 Excerpt from the Ministry of Agriculture, Forestry and Fisheries Website / Description regarding subsidies for agrivoltaic projects using perovskite solar cells (November 2024)

Quoted from the Ministry of Agriculture, Forestry and Fisheries Website: /chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/
https://www.maff.go.jp/j/kanbo/smart/attach/pdf/houritsu-44.pdf

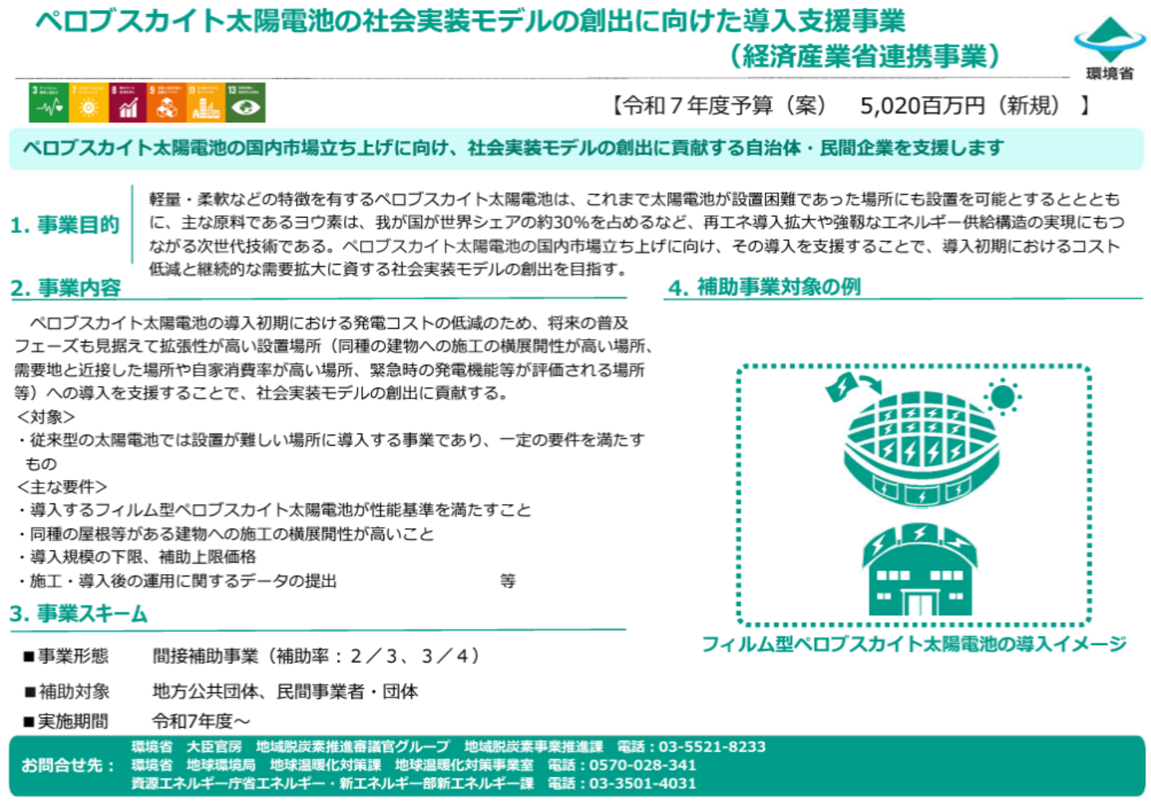
※About information on the Ministry of Land,Infrastructure,Transport and Tourism,see page 10 below.

chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/

https://www.mlit.go.jp/sogoseisaku/environment/content/001743556.pdf

（3）-3　Support Measures from the Ministry of the Environment

Although details such as the minimum and maximum amounts per project have yet to be announced by the Ministry of Agriculture, a substantial budget exceeding 5 billion yen has already been announced. Compared to the typical subsidy rate of 50%, this program offers an exceptional rate of two-thirds or even three-quarters, clearly reflecting the Ministry of the Environment's strong commitment to the initiative.



ペロブスカイト太陽電池の社会実装モデルの創出に向けた導入支援事業
（経済産業省連携事業）

環境省

【令和７年度予算（案）　5,020百万円（新規）】

ペロブスカイト太陽電池の国内市場立ち上げに向け、社会実装モデルの創出に貢献する自治体・民間企業を支援します

1. 事業目的

軽量・柔軟などの特徴を有するペロブスカイト太陽電池は、これまで太陽電池が設置困難であった場所にも設置を可能とするとともに、主な原料であるヨウ素は、我が国が世界シェアの約30%を占めるなど、再エネ導入拡大や強靱なエネルギー供給構造の実現にもつながる次世代技術である。ペロブスカイト太陽電池の国内市場立ち上げに向け、その導入を支援することで、導入初期におけるコスト低減と継続的な需要拡大に資する社会実装モデルの創出を目指す。

2. 事業内容

ペロブスカイト太陽電池の導入初期における発電コストの低減のため、将来の普及フェーズも見据えて拡張性が高い設置場所（同種の建物への施工の横展開性が高い場所、需要地と近接した場所や自家消費率が高い場所、緊急時の発電機能等が評価される場所等）への導入を支援することで、社会実装モデルの創出に貢献する。

<対象>

・従来型の太陽電池では設置が難しい場所に導入する事業であり、一定の要件を満たすもの

<主な要件>

・導入するフィルム型ペロブスカイト太陽電池が性能基準を満たすこと
・同種の屋根等がある建物への施工の横展開性が高いこと
・導入規模の下限、補助上限価格
・施工・導入後の運用に関するデータの提出　　　　等

3. 事業スキーム

■事業形態　　間接補助事業（補助率：２／３、３／４）
■補助対象　　地方公共団体、民間事業者・団体
■実施期間　　令和7年度～

4. 補助事業対象の例

フィルム型ペロブスカイト太陽電池の導入イメージ

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Figure 45 Quoted from the Ministry of the Environment website / Description regarding the introduction of perovskite solar cell utilization, November 2024

/chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.env.go.jp/content/000278971.pdf

6) Conclusion

[Summary]

・Through the installation of solar sharing systems, positive outcomes were comprehensively obtained in terms of environmental balance, such as: ① a decrease in ground temperature, ② a significant reduction in methane emissions, ③ no decrease in crop yield (with an increase in average yield), and ④ an increase in the ratio of well-formed rice grains. In addition, positive results were also observed in terms of the agricultural business balance. This study confirmed that the methodology for promoting a decarbonized society from the agricultural sector—its primary objective—can significantly reduce methane emissions from rice paddies.

However, in terms of paddy field management, water drained from the fields in July—when methane emissions are typically highest—resulting in near-zero methane emission measurements under all conditions. Therefore, the data cannot yet be considered fully conclusive.

This fiscal year, we plan to significantly strengthen farm operation and field management as we enter the second year of the experiment. Regarding heat damage to rice caused by climate change, the method of shading under various conditions has proven effective. Furthermore, the results clearly confirmed that this approach holds promise for establishing sustainable agriculture through methane reduction. Moving forward, it is important to further validate these findings by conducting similar tests at multiple locations, including overseas, and over multiple years.

[Continuation and expansion of research]

In 2025, similar experiments are scheduled to be conducted at two national agricultural universities in Vietnam—located in lower latitudes and hotter regions—in collaboration with MAAD and the Ministry of Agriculture, Forestry and Fisheries of Vietnam.

Additional plans include a collaborative experiment in Sosa City, Chiba Prefecture, Japan, involving Chiba Prefecture and Chiba University, as well as a demonstration trial on Awaji Island in Sumoto City, Hyogo Prefecture, conducted jointly with IGES, Hyogo Prefecture, Sumoto City, and Ryukoku University.

Although Fukushima Prefecture, situated at a high latitude with relatively low average summer temperatures, has been part of the study, greater methane reduction and mitigation of heat-related crop damage are anticipated in higher-latitude areas experiencing higher summer temperatures.

The results so far have exceeded our expectations, reinforcing the value of continuing these experiments across multiple locations and over multiple years. In addition, we have received collaboration requests from several major companies interested in supporting the initiative.

We intend to continue the project privately for several more years and, if proven effective, aim to collaborate with Japan's Ministry of Agriculture, Forestry and Fisheries to explore its potential application toward J-Credit certification. We also see merit in evaluating the approach in combination with extended mid-season drainage practices.

[Thoughts]

Climate change has brought us to a pivotal crossroads in human civilization. I believe it is essential to approach sustainability not only with short-term urgency but with a long-term perspective that spans several decades, even up to a century.

In the near future, global warming will make it harder to import food. Japanese agriculture is already facing a critical situation, but rather than viewing this solely as a crisis, I see it as an opportunity for renewal and transformation.

During the Edo period, farmers sustained themselves by producing and selling charcoal in the off-season. While charcoal is not a food item, it was a product of agricultural resources—highlighting how flexible and resourceful agricultural practices once were. In the same spirit, I believe we must adopt a broader, more adaptive mindset today. Recognizing renewable energy and carbon credits derived from rural resources as new forms of agricultural output may be key to revitalizing Japanese agriculture in a sustainable way.

[Acknowledgment]

This research was carried out with the financial support of TERRA Co.,Ltd., JA Mitsui Leasing,Ltd., The Norinchukin Bank,JA Mitsui Energy Solutions Co.,Ltd., Sertas Holdings Co.,Ltd., and a grant from Chiba Prefecture . We would like to express our sincere gratitude once again.

4. 7) References

Abidin, M.A.Z., Mahyuddin, M.N., Zainuri, M.A.A.M., 2021. Solar Photovoltaic Architecture and Agronomic Management in Agrivoltaic System: A Review. Sustainability 13, 7846.

Kögel-Knabner, I., Amelung, W., Cao, Z., Fiedler, S., Frenzel, P., Jahn, R., Kalbitz, K., Kölbl, A., Schloter, M., 2010. Biogeochemistry of paddy soils. Geoderma 157, 1–14.

Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food security. Science (1979).

Qian, H., Zhu, X., Huang, S., Linquist, B., Kuzyakov, Y., Wassmann, R., Minamikawa, K., Martinez-Eixarch, M., Yan, X., Zhou, F., Sander, B.O., Zhang, W., Shang, Z., Zou, J., Zheng, X., Li, G., Liu, Z., Wang, S., Ding, Y., van Groenigen, K.J., Jiang, Y., 2023. Greenhouse gas emissions and mitigation in rice agriculture. Nat Rev Earth Environ.

Pearcy, 1990; Chazdon & Pearcy, 1991

The Importance of Sunflecks for Forest Understory Plants: Photosynthetic machinery appears adapted to brief, unpredictable periods of radiation

Robin L. Chazdon, Robert W. Pearcy *BioScience*, Volume 41, Issue 11, December 1991, Pages 760–766, https://doi.org/10.2307/1311725 **Published:**01 December 1991

Final Report on Carbon Farming – March 2023 Eurovision& Associates (2023)

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https://www.maff.go.jp/j/kokusai/kokkyo/platform/pdf/platform-172.pdf

NARO Report (2024) https://www.naro.go.jp/publicity_report/press/laboratory/rcait/163819.html

5. 8) Definition of Terms

(Note *1) Greenhouse Gases (GHG):

Greenhouse gases are substances present in the atmosphere that trap part of the heat from the sun as it reaches the Earth's surface, thereby increasing the planet's temperature. Major greenhouse gases include carbon dioxide and methane.

(Note *2) Methane Gas:

Methane is a potent greenhouse gas produced by processes such as livestock digestion and waste decomposition. It has more than 25 times the greenhouse effect of carbon dioxide in the atmosphere and contributes significantly to global warming.

(Note *3) IPCC:

The IPCC (Intergovernmental Panel on Climate Change) is an international organization established to assess scientific knowledge related to climate change, including global warming, and to provide objective and comprehensive information to governments around the world.

IPCC Website: https://www.ipcc.ch/

[Background of Establishment]

- Year Established: 1988
- Founding Organizations: United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO)
- Purpose: To provide scientific information on climate change, its impacts, and countermeasures to national governments as a basis for policy-making.

[Main Activities of the IPCC]

- Preparation of ***Assessment Reports (AR):

Comprehensively evaluates the latest scientific research and observational data, and publishes them approximately every 5 to 7 years as "Assessment Reports."

The most recent is the Sixth Assessment Report **(AR6).

- Publication of **Special Reports:

Prepares reports focused on specific topics, such as the Special Report on Global Warming of 1.5°C, the Special Report on the Ocean and Cryosphere, and the Special Report on Climate Change and Land.

- Provision of **Methodology Reports:

Provides guidelines for countries to calculate and report greenhouse gas emissions.

[Foundation for Policy Decision-Making]

Used as a key reference for global and national environmental and energy policies, including greenhouse gas reduction and climate change adaptation strategies.

(Note *3) RE100:

RE100 is a global initiative aiming to power business operations with 100% renewable energy. The name comes from the phrase "Renewable Energy 100%."

(Note *4) Perovskite Solar Cells:

A next-generation solar cell technology invented by Professor Tsutomu Miyasaka of Toin University of Yokohama. These cells are resistant to distortion and lightweight, making installation possible in places unsuitable for traditional silicon solar panels. They can be mass-produced through coating or printing processes, which could significantly reduce costs. With energy conversion efficiency comparable to silicon cells, they are expected to see full-scale practical implementation.

(Note *4) Carbon Farming:

Carbon farming is a sustainable agricultural practice aimed at reducing greenhouse gas emissions by capturing CO_2 from the atmosphere and storing it in the soil, thereby improving soil quality. It refers to what is often called regenerative agriculture.

(Source: Ministry of Agriculture, Forestry and Fisheries website

https://www.maff.go.jp/j/kokusai/kokkyo/platform/pdf/platform-172.pdf)

However, the definition of "Carbon Farming" is not globally standardized. It is often interpreted broadly to include efforts to reduce agriculture-related greenhouse gas emissions, such as methane (CH_4) from rice paddies.

(Note *7) GHG Credit Market:

A market where credits generated from projects aimed at reducing or absorbing greenhouse gases (GHGs) are traded. Companies can trade within their emission allowances and purchase credits to meet their reduction targets.

In Japan, there is a system called the J-Credit Scheme, which certifies the amount of CO_2 and other emissions reduced through the introduction of energy-saving equipment or the use of renewable energy, as well as the amount of CO_2 absorbed through appropriate forest management, as tradable credits.

・On-site PPA: A system in which a power producer (PPA provider) installs solar power equipment on the customer's premises at the provider’s expense, owns and maintains the equipment, and supplies the electricity generated from it to the customer.

・Off-site PPA: A system in which a power producer (PPA provider) supplies electricity to a specific general customer via the public power grid. Off-site PPAs are not limited by the space available on the customer's property, making it easier to increase power generation and offering greater scalability compared to on-site PPAs.

6. Acknowledgement

This research was carried out with the financial support of TERRA Co.,Ltd., JA Mitsui Leasing,Ltd., The Norinchukin Bank,JA Mitsui Energy Solutions Co.,Ltd., Sertas Holdings Co.,Ltd., and a grant from Chiba Prefecture . We would like to express our sincere gratitude once again.