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Evolution of Agrivoltaic Farms in Japan

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Abstract. Development of agrivoltaics in Japan started in 2004 in Chiba Prefecture initiated by Akira Nagashima. Today, 1,992 agrivoltaic farms (560 ha) exist throughout Japan except one prefecture out of 47 prefectures. Most agrivoltaics in Japan is small-scale less than 0.1 ha. It is estimated that total power generated by agrivoltaics is 500,000 to 600,000 MWh or 0.8% of the total power generated by photovoltaics in Japan in 2019. Farmland must be converted to non-agricultural use to install photovoltaics, in which agrivoltaics has an advantage over solar parks applicable to all 5 classes of farmland. Increase of devastated and abandoned farmland is a grave concern for the Japanese agriculture and agrivoltaics is expected to contribute to solve this issue. Over 120 crops are grown in agrivoltaics in Japan and for 69% of cases, cultivated crop is changed upon installation of agrivoltaics, which is causing concern that it may disrupt small, fixed markets of those crops. Shading rate in agrivoltaics ranges from 10 to 100% with its median at 30 to 40%. The choice of shading rate is made according to light saturation point of the crop, but a high shading rate is often determined first to maximize profit from electricity sale, because it is much greater than the one from agriculture itself, then suitable crop for that shading rate is chosen. Agrivoltaic development in Japan took off after the introduction of feed-in tariff (FIT) in 2012. FIT was significantly effective in policy impact compared to RPS system previously acquired in Japan, increasing renewable energy supply in Japan by 76% from 2012 to 2019. Photovoltaics has been a driving force increased from 7,600 GWh to 77,000 GWh during the same period. Two directives from the Ministry of Agriculture, Forestry and Fisheries (MAFF), one in March 2013 and another in May 2018, institutionalized agrivoltaics and promoted its development. The second amendment of FIT Law in June 2020, which will be enforced in April 2022, further paved the way for agrivoltaics preferentially treating it. Agrivoltaics is expected play an important role to revitalize the Japanese agriculture including reclamation of devastated or abandoned farmland, as being included in the above-mentioned policies. If all abandoned farmland were converted to agrivoltaic farms, 280 GW of electricity could be produced. The potential of agrivoltaics in 8 prefectures in Kanto region is estimated at least 15 to 39 GW. Emerging innovative agrivoltaics, such as one we see in a high value-added tea agrivoltaics in Shizuoka prefecture, is an economically and environmentally sound business model, which we may want to replicate elsewhere.

HISTORY AND CURRENT SITUATION

Origin

Development of agrivoltaic farms in Japan all started from Akira Nagashima's initiatives. He coined the term "solar sharing (synonymous to agrivoltaics)" in 2003 and made its patent free for public use in 2005. Narrow-width 24-cell PV module was devised by him to mitigate shading effect and splash erosion to the crops under the PV panels. The first agrivoltaic farm in Japan was established by him in Chiba prefecture in 2004. The book written by Nagasihma comprehensively described "solar sharing," originally published in Japanese[1] in 2015 (also available in English[2] in 2020), became a bible for the early adopter of agrivoltaics in Japan.

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The Number and Scale

As of March 2019, total number of 1,992 agrivoltaic farms (560.0 ha) is registered under the Ministry of Agriculture, Forestry and Fisheries (MAFF), spreading to 46 prefectures out of 47 throughout Japan, except Toyama prefecture (Table 1). Chiba Prefecture, the origin of agrivoltaics in Japan, has the largest number of 298 agrivoltaic farms (Table 1).

The most agrivoltaic farms in Japan are small-scale. Out of 755 agrivoltaic farms established by May 2018, 65% or 490 farms were less than <0.1 ha, followed by 0.1 to 0.3 ha (24% or 178 farms), 0.3 to 0.5 ha (4% or 27 farms), 0.5 to 1 ha (5% or 34 farms), and >1 ha (3% or 26 farms).[4] It is natural to see the scale is skewed towards the lower end, since most farms in Japan are small-scale. Some 623,900 or 52% of farm management entities out of 1,188,800 owns less than 1 ha of agricultural field, followed by 1 to 5 ha (38% or 457,400 farms), 5 to 10 ha (4% or 49,800 farms), 10 to 20 ha (1% or 11,500 farms), and more than 30 ha (2% or 18,800 farms).[5]

TABLE 1. The number of officially registered agrivoltaic farms in Japan by prefecture[a]

AAB[b]	Prefecture	Agrivoltaic farms	AAB[b]	Prefecture	Agrivoltaic farms	AAB[b]	Prefecture	Agrivoltaic farms
Hokkaido	Hokkaido	6		Shizuoka	264	**Shikoku**	Okayama	9
Tohoku	Aomori	10	**Hokuriku**	Niigata	27		Hiroshima	31
	Iwate	13		Toyama	0		Yamaguchi	2
	Miyagi	29		Ishikawa	3		Tokushima	131
	Akita	12		Fukui	16		Kagawa	45
	Yamagata	34	**Tokai**	Gifu	46		Ehime	32
	Fukushima	75		Aichi	47		Kochi	6
Kanto	Ibaraki	111		Mie	36	**Kyushu**	Fukuoka	15
	Tochigi	19	**Kinki**	Shiga	17		Saga	6
	Gunma	196		Kyoto	17		Nagasaki	3
	Saitama	100		Osaka	4		Kumamoto	36
	Chiba	298		Hyogo	39		Oita	6
	Tokyo	4		Nara	30		Miyazaki	10
	Kanagawa	31		Wakayama	23		Kagoshima	9
	Yamanashi	67	**Chugoku**	Tottori	6	**Okinawa**	Okinawa	19
	Nagano	34		Shimane	18	**Total**		**1,992**

[a] Reference 3.

[b] AAB = Agricultural Administration Bureau

We can only infer the installed capacity of agrivoltaics in Japan since there is no official statistics available. A reasonable estimate would be 500 to 600 MW (or 500,000 to 600,000 MWh) based on the total installed area of officially registered agrivoltaic farms,[6] which is approximately 0.8% of 77,434 GWh, the total power generated by photovoltaics in 2019.[7]

Land Use

To conduct agrivoltaics, a part of farmland area where mounting foundation is constructed must be approved to be converted to "non-agricultural use" by local Agricultural Commission at municipality level (Table 2). Currently, there are 1,703 Agricultural Commissions in 1,724 municipalities.[8] Solar parks are constructed mainly in the second and the third class farmland because of ease in obtaining land conversion approval, while agrivoltaics takes place in all classes since it is meant for agriculture.

There are two grave concerns in the Japanese agriculture: aging population of farmers and increase in abandoned farmland. Agrivoltaics is expected to contribute to solve the latter issue. The acreage of the abandoned farmland is 423,000 ha from the latest national census in 2015, which is 9.4% of the total farmland area of 4,496,000 ha (Table 3). The conversion of farmland to photovoltaic use started from 2011 after the introduction of feed-in tariff (FIT) scheme. The cumulative farmland area converted so far to solar parks and agrivoltaics is 9,964 ha and 560 ha, respectively (Table 3).

Though there is no area-based statistics, 31% of approved cases of farmland conversion to agrivoltaics was in devastated farmland by 2018 (Table 2). This ratio was down to 15% in 2020 but the number of cases is increasing except a slight decline in the second and the third class farmland, from 21 to 17 cases and from 7 to 5 cases, respectively. This decline is most likely attributed to difficulty to continue farming in the low grade, devastated farmland, or conversion to more profitable land use due to the vicinity of urban area, which may include solar parks.

Some argues that the conversion of farmland, including devastated farmland, to agrivoltaics will accelerate while the conversion to solar parks will be declining, because convertible farmland to solar parks are saturating.[9] There is no statistical evidence to support the “saturation” but it is a likely scenario particularly considering policy guidance in the renewed FIT scheme to gear towards this change that is discussed later in Policy Framework.

TABLE 2. Land conversion policy and approved farmlands for agrivoltaics by farmland classes[a]

Farmland classification	Farming conditions, urbanization situation	Approval policy	Survey year	Total (cases)	Total %	Devastated farmland (cases)	Devastated farmland % to total
Farmland within the agricultural district	Agricultural land designated as an agricultural land area in the Agricultural Promotion Area Development Plan	Not permitted in principle (There are exceptions based on the businesses subject to the Agricultural Land Law and Land Acquisition Law)	2018	537	71.1	161	30.0
			2020	1,425	74.5	205	14.4
First grade farmland	Farmland with particularly good farming conditions (Agricultural land, etc. that was the target of land improvement projects in urbanization control areas within 8 years)		2018	3	0.4	0	0.0
			2020	12	0.6	0	0.0
First class farmland	Farmland with good farming conditions (A group of farmlands with a scale of 10 ha or more / farmland targeted for land improvement projects, etc.)		2018	119	15.8	45	37.8
			2020	333	17.4	59	17.7
Second class farmland	Farmland that is expected to be in the city (Small group farmland with low productivity, such as a railway station within 500 m)	Permitted on condition (Cannot be located in other areas around)	2018	79	10.5	21	26.6
			2020	110	5.8	17	15.5
Third class farmland	Farmland in urban areas or areas with a marked tendency to urbanize (Railway station is within 300 m, etc.)	Permitted in principle	2018	17	2.3	7	41.2
			2020	33	1.7	5	15.2
		Total	2018	755	100.0	234	31.0
			2020	1,913	100.0	286	15.0

[a] Combined reference 4, 10 and 14.

TABLE 3. Total, devastated, abandoned, and converted farmland to photovoltaics in Japan[a]

Farmland JPY	Farmland (ha)	Devastated farmland Restorable (ha)	Devastated farmland Non-restorable (ha)	Devastated farmland Total (ha)	Devastated farmland Ratio to farmland (%)	Abandoned farmland Total (ha)	Abandoned farmland Ratio to farmland (%)	Converted farmland to solar parks (ha)	Converted farmland to agrivoltaics (ha)
1961	6,086,000								
1975	5,572,000					131,000	2.4%		
1980	5,461,000					123,000	2.3%		
1985	5,379,000					135,000	2.5%		
1990	5,243,000					217,000	4.1%		
1995	5,038,000					244,000	4.8%		
2000	4,830,000					343,000	7.1%		
2005	4,692,000					386,000	8.2%		
2008	4,628,000	149,000	135,000	284,000	6.1%				
2009	4,609,000	151,000	137,000	287,000	6.2%				
2010	4,593,000	148,000	144,000	292,000	6.4%	396,000	8.6%		
2011	4,561,000	248,000	130,000	278,000	6.1%			0.7	
2012	4,549,000	147,000	125,000	272,000	6.0%			264.6	
2013	4,537,000	138,000	135,000	273,000	6.0%			1,616.0	19.4
2014	4,518,000	132,000	144,000	276,000	6.1%			3,883.6	79.9
2015	4,496,000	124,000	160,000	284,000	6.3%	423,000	9.4%	5,464.4	151.8
2016	4,471,000	98,000	183,000	281,000	6.3%			7,019.3	331.0
2017	4,444,000	92,000	190,000	283,000	6.4%			8,268.8	413.1
2018	4,420,000	92,000	188,000	280,000	6.3%			9,964.3	560.0

[a] Compiled from reference 11, 12 and 13. Figures are rounded to the nearest thousand except those in the converted farmland.

Grown Crops

Over 120 kinds of crops have been grown in the Japanese agrivoltaic farms.[15] Top ten popular crops includes *mioga* ginger (65 farms), *Sakaki* or Japanese cleyera (41 farms), paddy rice (35 farms), *shiitake* mushroom (31 farms), and blueberry (20 farms), *fuki* or butterbur (18 farms), tea (15 farms), green onions (14 farms), pasture grass (13 farms), and pumpkin (13 farms) (Table 4). Paddy rice is ranked at the third as a popular crop in agrivoltaics not necessarily because it agronomically fits to agrivoltaics but mainly because it is a major crop grown in Japan. It is widely debated whether cultivation of some crops like Janapnese cleyera should be expanded just because it is shade-tolerant fitted to agrivoltaics. This plant is used in a *Shinto* ritual so that it has a fixed, small market. It is rational to introduce agrivoltaics to the existing Janapnese cleyera farms, however, it is worried that new introduction or expansion, particularly if it is large scale, may disrupt the existing market. The same debate applies to similar crops in religious plants, ornamental plants, or mushrooms groups.

The cultivated crops in agrivoltaics is categorized by crop classification by MAFF (Table 5). Future research may want to access these groups for economic, agronomical, environmental, and social feasibility and impact. Overall crop conversion rate is relatively high at 69%. Notable difference in the crop conversion rate is observed among different crop groups: (1) over 80% (vegetables, ornamental plants), (2) 50 to 70% (mushroom, flowers, fruit tree), (3) 30 to 50% (tea, pasture), and (4) at 10% level (land use crops) (Table 5). Unique crops (89% crop conversion rate) and *Mioga* (86% crop conversion rate) are sub-categorized since MAFF is concerned with its impact to a small, inflexible existing market as mentioned above. Some of the crop change is likely restricted within variety or cultivar level. Tea (43% crop conversion rate) is likely in this category, which requires 4 to 5 years of leading time after planting before the first harvest. Tea farmers may want to utilize an opportunity of installing agrivoltaics to replant a high-yielding or high value-added tea cultivar (this will be further elaborated later in a case study). The crop conversion rate of land use crops or cereals is distinctively low at 15%. They are often a major income source for farmers that is unlikely to be switched to other crops. Besides, in case of paddy rice, it requires certain period to prepare an ideal flooded field conditions and soil.

TABLE 4. Crops grown in agrivoltaic farms in Japan[a]

Number of cases	Common name (*Scientific name*) [number of cases]
>10	***mioga* ginger** (*Zingiber mioga Rosc.*) [65], **Japanese cleyera** (*Cleyera japonica*) [41], **paddy rice** (*Oryza sativa*) [35], ***shiitake* mushroom** (*Lentinula edodes*) [31], **blueberry** (*Cyanococcus spp.*) [20], ***fuki* / butterbur** (*Petasites japonicus (Siebold et Zucc.) Maxim.*) [18], **tea** (*Camellia sinensis (L.) O. Kuntze*) [15], **green onions** (*Allium fistulosum L.*) [14], **pasture grass** [13], **pumpkin** (*Cucurbita maxima*) [13], **sweet potato** (*Ipomoea batatas*) [11], **persimmon** (*Diospyros kaki*) [11]
9	**orange** (*Citrus unshiu*)
8	**soybean** (*Glycine max*), **potato** (*Solanum tuberosum L.*), **taro** (*Colocasia esculenta (L.) Schott*)
7	**asparagus** (*Asparagus officinalis L.*), **wood ear mushroom** (*Auricularia auricula-judae*), **lettuce** (*Lactuca sativa*), **peanut** (*Arachis hypogaeaii*)
6	**cabbage** (*Brassica oleracea L. var. capitata.*), ***senryu*** (*Sarcandra glabra*)
5	**bracken fern** (*Pteridium aquilinum (L.) Kuhn.*), **Japanese horseradish** (*Eutrema japonicum (Miq.) Koidz.*), **carrot** (*Daucus carota subsp. sativus*), ***ashitaba*** (*Angelica keiskei (Miq.) Koidz.*), **onion** (*Allium cepa*), **radish** (*Raphanus sativus var. hortensis*), **dwarf mondo grass** (*Ophiopogon japonicus 'Tamaryu'*), **tomato** (*Solanum lycopersicum*), **Chinese cabbage** (*Brassica rapa var. pekinensis*), **Japanese star anise** (*Illicium religiosum Siebold & Zucc.*), **garlic** (*Allium sativum*)
4	**Grape** (*Vitis spp.*), **Japanese chestnut** (*Setaria italica*), **young soybean** (*Glycine max*), **barroom plant** (*Aspidistra elatior*)
3	**buckwheat** (*Fagopyrum esculentum Moench*), **wheat** (*Triticum aestivum*), ***komatsuna*** (*Brassica rapa var. perviridis*), **citron** (*Citrus junos*), **spinach** (*Spinacia oleracea*), **Chinese chives** (*Allium tuberosum. Rottler ex Spreng.*), **chameleon plant** (*Houttuynia cordata*), **lemon** (*Citrus limon*), **kiwifruit** (*Actinidia chinensis*)
2	**fig** (*Ficus carica*), **mini tomato** (*Lycopersicum esculentum*), **potato** (*Solanum tuberosum L.*), **ginger** (*Zingiber officinale*), ***udo*** (*Aralia cordata*), **broccoli** (*Brassica oleracea var. italica*), **Japanese pepper tree** (*Zanthoxylum piperitum*), ***shiso* (Japanese basil)** (*Perilla frutescens var. crispa*), **cucumber** (*Cucumis sativus L.*), ***dekopon*** (*Citrus unshiu x reticulata Siranui*), **garden peas** (*Pisum sativum L.*), **sesame** (*Sesamum indicum*), **red clover** (*Trifolium pratense L.*)
1	**hascup** (*Lonicera caerulea var. emphyllocalyxi),* **maitake (hen-of-the-woods)** (*Grifola frondosa*), **Jerusalem artichoke** (*Herianthus tuberosus L.*), **garland chrysanthemum** (*Chrysanthemum coronarium L.*), **water convolvulus** (*Ipomoea aquatica Forsk.*), **leaf lettuce** (*Lactuca sativa var. crispa*), **Blackberry** (*Rubus fruticosus*), ***sudachi*** (*Citrus sudachi*), **ostrich fern** (*Matteuccia struthiopteris*), **Hydrangea** (*Hydrangea macrophylla*), **pak choi** (*Brassica rapa var. chinensis*), **Christmas rose** (*Helleborus spp.*), **turf grass** (*Zoysia spp.*), **bulb**, **black squirrel** (*Ilex rotunda*), **yacon** (*Smallanthus sonchifolius*), ***rakkyo*** (*Allium chinense G.Don*), **dichondra** (*Dichondra spp.*), **holly *nanten*** (*Mahonia japonica (Thunb.) DC.*), **rape** (*Brassica campestris L.*), **trefoil** (*Cryptotaenia japonica*), ***fukinoto*** (*Petasites japonicus (Siebold et Zucc.) Maxim.*), **cauliflower** (*Brassica oleracea var. botrytis*), **mugwort** (*Artemisia spp.*), **apple** (*Malus pumila var. domestica*), **high moss** (*Hypnum plumaeforme. Wilson.*), **currant** (*Ribes spp.*), **flowers**, **maize** (*Zea mays*), ***kiboshi*** (*Hosta spp.*), **strawberry** (*Fragaria ×ananassaDuchesne ex Rozier*), ***shimeji*** (*Hypsizygus marmoreus*), **moss**, **herbs**, **eggplant** (*Solanum melongena*), **watermelon** (*Citrullus lanatus*), **June berry** (*Amelanchier canadensis*), **prickly pear** (*Anredera cordifolia*), **Japanese apricot** (*Prunus mume*), ***jabara*** (*Citrus jabara hort. ex Y. Tanaka*), **moss phlox** (*Phlox subulate*), **coralberry** (*Ardisia crenata*), **plantain** (*Plantago asiatica*), ***shibuki*** (*Myrica rubra*), **turnip** (*Brassica rapa L.*), **okra** (*Abelmoschus esculentus*), **senna tea** (*Senna obtusifolia*), ***kiyomi* tangor** (*Citrus unshiu × sinensis*), **cherry** (*Prunus spp.*), **giant elephant ear** (*Colocasia gigantea*), **Chinese milk vetch** (*Astragalus sinicus L.*), **fodder**, ***hanashiba*** (*Illicium religiosum*), **mulberry** (*Morus spp.*), ***hyuganatsu*** (*Citrus tamurana*), **kumquat / cumquat** (*Citrus japonica / Fortunella japonica*), **Solomon's seal** (*Polygonatum spp.*), **dracaena** (*Dracaena spp.*), **coffee** (*Coffea spp.*), **bitter gourd** (*Momordica charantia*), **turmeric** (*Curcuma longa*)

[a] Modified reference 15.

TABLE 5. Crops grown in agrivoltaics by classification[a]

Classification	Major crops	Number of cases	Ratio (%)	Number of crop change cases[b]	Crop conversion rate (%)
Land use crops	rice (*Oryza sativa*), wheat (*Triticum aestivum*), soybean (*Glycine max*), buckwheat (*Fagopyrum esculentum Moench.*)	173	9	26	15%
Vegetables	Vegetables: *komatsuna* (*Brassica rapa var. perviridis*), Chinese cabbage (*Brassica rapa var. pekinensis*), green onions (*Allium fistulosum L.*), pumpkin (*Cucurbita maxima*), etc.; Root crops	713	37	592	83%
Unique crops	mioga ginger (*Zingiber mioga Rosc.*), *fuki* / butterbur (*Petasites japonicus (Siebold et Zucc.) Maxim.*), *udo* (*Aralia cordata*), *ashitaba* (*Angelica keiskei (Miq.) Koidz.*), bracken fern (*Pteridium aquilinum (L.) Kuhn.*), chameleon plant (*Houttuynia cordata*), red clover (*Trifolium pratense L.*)	*403*	*21*	*358*	89%
mioga	mioga ginger (*Zingiber mioga Rosc.*)	*209*	*11*	*180*	86%

Classification	Major crops	Number of cases	Ratio (%)	Number of crop change cases[b]	Crop conversion rate (%)
Fruit tree	citrus (*Citrus spp.*), blueberry (*Cyanococcus spp.*), persimmon (*Diospyros kaki*), grape (*Vitis spp.*)	211	11	122	58%
Flowers	lily (*Lilium spp.*), pansy (*Viola × wittrockiana*)	12	1	8	67%
Ornamental plants	Japanese cleyera (*Cleyera japonica*), Japanese star anise (*Illicium religiosum Siebold & Zucc.*), senryo (*Sarcandra glabra*), dwarf mondo grass (*Ophiopogon japonicus 'Tamaryu'*), etc.	553	29	447	81%
Others	-	252	13	129	51%
Pasture	Italian ryegrass (*Lolium multiflorum*), sorghum (*Sorghum bicolor*), Chinese milk vetch (*Colocasia gigantea*)	*68*	*4*	*24*	35%
Mushrooms	shiitake mushroom (*Lentinula edodes*), wood ear mushroom (*Auricularia auricula-judae*)	*98*	*5*	*68*	69%
Tea	tea (*Camellia sinensis (L.) O. Kuntze*)	*65*	*3*	*28*	43%
	TOTAL	1,914	100	1,324	69%

[a] Modified reference 14.

[b] The number of cases where cultivated crops were changed upon introduction of agrivoltaics.

Shading Rate

Shade tolerance of a crop or shading rate is one of the major factors to determine agrivoltaic system.

According to MAFF's report in 2018,[4] the shading rate in agrivoltaic farms in Japan is widely distributed from less than 10% to 100%, with its median in 30 to 40% range (Figure 1). Approximately 20% of agrivoltaics has less than 30% of shading rate, 40% has less than 40% shading rate, 20% has more than 70% shading rate, and 10% has more than 80% shading rate. Unfortunately, this survey lacks associated crops to a particular shading rate.

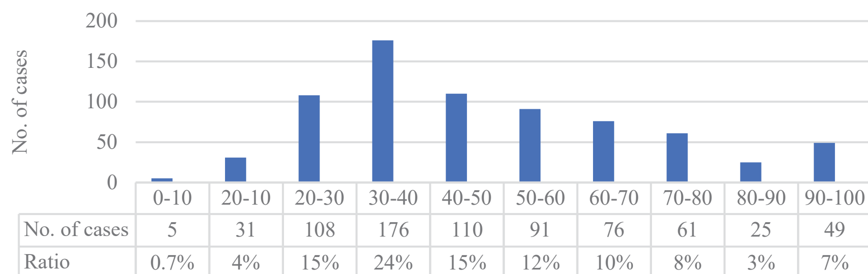

FIGURE 1. Shading rate distribution in agrivoltaic farms in Japan. Plotted from "Current status of agrivoltaic facilities."[4] n=732 out of 755 agrivoltaic farms granted the land conversion permit, for which a defined shading rate, (PV panel area/filed area), is known. Some 240 farms (32%) has more than 1,000 m^2 of cropping field.

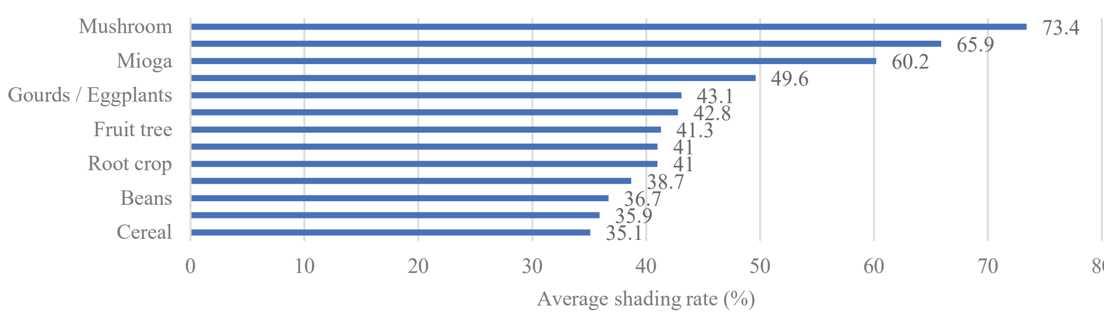

FIGURE 2. Average shading rate by crop classification. Plotted from reference 15. n=1,174 out of 1,465 (80.1% response rate). 100% shading rate for shiitake mushroom (*Lentinula edodes*), ginseng (*Panax ginseng*), and bracken fern (*Pteridium aquilinum (L.) Kuhn.*) and some shiitake mushroom farm with photovoltaic panel installed at 60 cm above ground reported.

Actually used shading rate in agrivoltaic systems were surveyed by another study (Figure 2).

Average shading rate ranges from 31.1% for rice to 100% for mushroom, ginseng, and bracken fern. The choice of the shading rate is often made using light saturation point as a benchmark, which was suggested by Nagashima.[1, 2]

However, choice of the shading rate comes first rather than crops in many cases, since farmers or investors to agrivoltaics seek a way to maximize their income from electricity sale under FIT scheme, which is much higher than their agricultural income, then choose a suitable crop for that shading rate. This explains why the crop conversion rate is particularly high for mostly shade tolerant crops in the unique crops and the ornamental plants category (Table 5) and they are ranked in the upper tier of popular agrivoltaic crops (Table 4).

POLICY FRAMEWORK

A number of governmental policies have been instrumental in promoting agrivoltaics in Japan (Table 6).

In 2011, FIT scheme was finally institutionalized in Japan, which final legislation process coincided with the Great East Japan Earthquake in March 2011 that caused Fukushima Daiichi Nuclear Power Plant disaster. FIT was originally proposed in 2000 by bipartisan parties but Japan acquired Renewables Portfolio Standard (RPS) system instead in 2003. RPS was marginally effective only doubling the renewable energy supply under RSP scheme from 4,000 GWh in 2003 to 8,000 GWh in 2009,[17] which did not result in overall increase in the national renewable energy supply during the same period, that was 117,000 GWh to 105,000 GWh.[7] Japan had to wait to see significant increase in renewable energy supply until the enforcement of FIT scheme in 2012. It increased by 76% from 2012 to 2019, from 110,000 GWh to 195,000 GWh, respectively.[7] Photovoltaics has been a key driving force in this increase to see ten times increase in this period from 7,600 GWh to 77,000 GWh.

On March 31, 2013, official directive was issued by the director of Rural Development Bureau, MAFF to the head of Regional Agricultural Administration Offices nationwide stipulating the procedure and conditions to permit farmland conversion for agrivoltaic use (Table 6), which applies to “Farmland within the agricultural district,” “First grade farmland,” and “First class farmland.” Once it is approved, the applicant can perform agrivoltaics in the applied lot of farmland for maximum of 3 years. The application is to be filed through local Agricultural Commission. The major conditions are as follows: (1) mounting structure is only temporary and easily removed, (2) elected photovoltaic panel should not hinder growth of crops so as to secure enough sunlight penetration for plant growth and enough at least 2 m of above ground height of the panel for agricultural machinery operation, (3) the installment should not hinder agricultural practice in surrounding areas including agricultural drainage system nor adversely affect the implementation of “Agriculture Promotion Area Maintenance Plan,” and (4) annual yield must be reported and yield reduction should not exceed 20% of the one before agrivoltaic installation.

On May 15, 2018, a revised directive was issued (Table 6), which included a major policy update: the permit is to be granted for 10 years, instead of 3 years, if (1) a farmer can demonstrate his competence in agricultural practices and management, (2) agrivoltaics takes place in “Devastated farmland,” or (3) agrivoltaics takes place in “Second class farmland” or “Third class farmland.” Applications which do not apply to any of these conditions are treated as before with the maximum permit period of 3 years.

On June 12, 2020, the second amendment of FIT Law was promulgated which will be enforced on April 1, 2022 (Table 10). It contains several key changes in policy including (1) introduction of feed-in premium (FIP) scheme, (2) requirement for a large-scale solar parks to make an external reserve for costs for dismantling photovoltaic equipment, and (3) requirement for a small-scale (10 to 50 kW) photovoltaic facilities to fulfill “regional use requirements” to obtain a FIT certificate.

The last requirement applies to most agrivoltaic farms and the law provides added preferential treatment to agrivoltaics to encourage its further development. There are three “regional use requirements:” (1) self-consumption rate must be at least 30%, (2) there must be a way to confirm the actual self-consumption, and (3) generated electricity must be usable during disaster (a PCS or inverter with at least 10 kW operational capacity should be self-operatable without external power supply to provide at least 1.5 kW output during disaster). For agrivoltaics, however, the first requirement of compulsory self-consumption is waived if all the following three conditions are fulfilled: (1) its capacity is within 10 to 50 kW, (2) it already obtained a farmland conversion permit for 10 years, and (3) it is agrivoltaics.

TABLE 6. Key policy guidance to stimulate development of agrivoltaic farms in Japan

Time	Law / Policy
August 2011 (Enforced in July 2012)	Japanese government introduced a renewable energy feed-in tariff (FIT) scheme, which made it mandatory for electric power companies to buy electricity from renewable sources at fixed prices for 10 to 20 years (“Act on Special Measures Concerning Procurement of Electricity from Renewable Energy Sources by Electricity Utilities”).
March 2013	Temporary conversion of farmland for agrivoltaic use for the maximum of 3 years is officially permitted for the first time by MAFF Notification No. 24 Noushin Article 2657.[17]

Time	Law / Policy
Nov. 2014	"Act on the Promotion of Renewable Energy Electric Power Generation Harmonized with Sound Development of Agriculture, Forestry and Fisheries" is enforced.[18]
April 2017	"Act on Special Measures Concerning Procurement of Electricity from Renewable Energy Sources by Electricity Utilities (FIT Law)" was revised, enacted in March 2016 and enforced on April 1, 2017.
May 2018	The temporary conversion period will be extended to ten years from three years, if a farmer proves his competence in farming or uses devastated farmland (MAFF Notification No. 30 Noushin Article 78).[19]
June 2019	Cabinet council recognized agrivoltaics as means to build a powerful agriculture structure and to develop human resources despite a declining population, stipulating "Farming-photovoltaics, where photovoltaics equipment is installed above farmland, will be expanded nationwide." in "Follow-up on the Growth Strategy."[20]
June 2020	Enacted revised FIT Law renamed as "Act on Special Measures Concerning Promotion of Use of Renewable Energy Electricity," which will be enforced on April 1, 2022.[21]

FURTHER POTENTIAL AND BEST PRACTICE

Revitalizing the use of abandoned farmland is a prime interest in the agricultural policy in Japan.

The total area of abandoned farmland in Japan reported in the latest agricultural census is 423,064 ha as of 2015 (Table 3).[22] Converting all this area to agrivoltaic farms, we can potentially produce 280 GW of electricity. The maximum potential of agrivoltaic farms to be established in Kanto Region (8 prefectures) alone is estimated at 65.1 GW (69,188 GWh year^{-1})[23] or more modestly 15.2 to 32.6 GW,[24] both of which estimates use a standard unit capacity of agrivoltaics, 0.05 kWh m^{-2}.

Tea is proven to be one of the most suitable crops for agrivoltaics. It is the 7th popular agrivoltaic crop cultivated in at least 65 farms (Table 4). Agrivoltaic tea farming provides numerous solutions to the problems that farmers faced in the conventional tea farming, while offering added economic and environmental values. A case study from an agrivoltaic tea farm in Shizuoka Prefecture gives us insight suggesting the future direction of agrivoltaics.

Almost one tea cultivar, *Yabukita* (*Chanorin* no. 6) is dominant in mecca of the Japanese tea farming, Shizuoka prefecture, but some tea farmers converted it to more profitable, high value-added tea cultivar like *Okumidori* (*Chanorin* no. 32) upon electing agrivoltaics as we see in Ryutsu Service Co., Ltd. case.[25]

Matcha is the one of the highest quality Japanese green tea, which is made by griding *tencha* into powder. *Okumidori* is a suitable cultivar to produce *tencha*. Ballpark figure of wholesale price of *matcha* made of *Okumidori* is ten times more than that of ordinally *Yabukita* tea. Producing *tencha*, however, requires special cares of tea tree, where agrivoltaics can play a significant role.[26] Only fresh young shoots are picked and used for *tencha*. To produce tender, mild, sweet taste, tea plants must be grown under the darkness at 90% shading rate from the 1 to 1.5 leaf stage for about 20 to 30 days during the growing period to suppress catechin formation, which causes bitter taste. The cheapest way to achieve this is to cover the tea plant manually with the dark shading net, i.e., direct netting, but the net readily damages young shoots because it directly contacts with tea plant and it also create a hot and humid environment, which is an ideal condition for plant disease propagation. A netting frame can be constructed to overcome these drawbacks, but it costs you 15 to 20 million Japanese yen ha^{-1}. Introducing agrivoltaics can solve all these problems. Mounting frame of agrivoltaics can substitute the netting frame. Photovoltaic panels also provide a milder growing conditions to the tea plant grown underneath, mitigating harsh direct sunlight during the hottest season and preventing frost formation during the coldest season, which negate the cost of frost protection fan normally used in the conventional tea farming.

It is said that 97% of tea tree in Shizuoka prefecture is *Yabukita* and they are around 50 years old, which should be replanted to maintain its quality and productivity. However, many farmers are reluctant to do so because of its cost and aging farming population. You need to wait 4 to 5 years after planting tea tree to see the first harvest and income for which income from electricity sale of agrivoltaics can compensate.

Agrivoltaic tea farming also had a positive impact on marketing. Matcha itself is already high value-added product but agrivoltaics enhanced the value further. It started attracting environmentally conscious international buyers from overseas. Organic, renewable energy, healthiness, all sounds very attractive to the buyers. Ryutsu Service Co., Ltd.[26] now has constant sales to buyers in New York, London, and other international destinations.

In sum, agrivoltaic tea farming has a potential to revitalize aging tea farming industry in Shizuoka prefecture, which may enlighten other farming systems elsewhere.

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