

## Article

# Factors Influencing the Willingness of Dairy Farmers to Adopt Biogas Plants: A Case Study in Hokkaido, Japan

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**Abstract:** Intensification of the livestock industry has become environmentally problematic due to the uncontrolled treatment of large amounts of watery manure. One solution is the adoption of biogas plants (BGPs). Hokkaido, Japan, has significant potential for BGP adoption, however, the large financial investments and lack of grid space for selling electricity are barriers. We investigated the relationship between the willingness of farmers to adopt BGPs and their current farming situations. Using a questionnaire survey and multivariate analyses, the results showed that large-scale farmers, particularly those with more than 100 mature cows, were clearly willing to adopt BGPs and expand their businesses in the future, while farmers who planned to downsize their businesses did not exhibit strong willingness to adopt BGPs. In addition, farmers willing to adopt BGPs thought the plants would help solve problems with manure treatment. BGPs might be more accepted by dairy farmers if there were greater incentives for installation given the role BGPs can play in providing stable energy and revitalizing local economies.

**Keywords:** biogas plants (BGPs); dairy farmers; Hokkaido; willingness; manure treatment; future farming plan; sustainable farming

## 1. Introduction

Intensification of the livestock industry has led to serious environmental problems. Chief among these problems is untreated manure resulting from the increased number of livestock per household and changes in farming style. The amount of industrial waste generated in Hokkaido, Japan, in 2015 was recorded to be about 40 million tons, of which the proportion of livestock manure accounted for about 50% [1]. Problems caused by improper manure treatment include nitrate from undecomposed compost polluting the soil and water, poor feed (grass) produced without compost, the presence of weed seeds, the occurrence of pathogenic bacteria, and odor emissions resulting from insufficient aerobic fermentation, which reduces the quality of life in neighboring communities and impacts human health (e.g., headaches and eye and nose irritation) [2–8].

Therefore, the treatment of livestock manure is a critical issue, and appropriate treatment measures for concentrated dairy and livestock farming are urgently needed. One way to reduce these impacts is through the adoption of anaerobic digestion (AD). AD is normally carried out in biogas plants (BGPs), and it has several benefits. For example, it reduces biomass, alleviates adverse effects by

microorganisms, and reduces undesirable odors [3,5,9,10]. In addition, it produces digestate that can be used as organic fertilizer and reduce the need for chemical fertilizers [11]. Finally, it produces methane ( $\text{CH}_4$ ), providing a source of renewable energy that can be used for heating and electricity, and in place of diesel or gasoline to operate equipment [12].

In addition to environmental benefits, BGPs can also improve overall business operations by reducing chemical fertilizer expenses, which can be replaced by digestate; increasing revenue from agricultural products by organic farm branding; and reducing the need for labor. This can allow for an increase in the number of cows, which enhances milk production. There is also a benefit of securing employment for BGP management in local areas [1,6,13,14]. Most of the dairy farmers have dealt with manure by making composts. However, Babalola (2020) pointed out that BGPs are preferably introduced to treat organic wastes in Japan because of the higher benefits, efficiency and safety, compared to composting, incineration, and landfill [15]. In addition, the utilization of biomass energy has become a global trend as a measure to mitigate climate change and relevant issues, and AD in BGPs has further been enhanced over composting from the viewpoint of energy production, which would be an additional source of income for dairy farmers [15–17]. Therefore, the dairy farmers might be motivated to adopt BGPs.

The adoption of BGPs over the past two decades has led to more appropriate treatment of manure as well as diminished greenhouse gas (GHG) emissions. The Fukushima Daiichi Nuclear power plant accident in 2011 led to renewed public interest in renewable energy. The Japanese government offered a feed-in tariff (FIT) that donates 39 JPY/kWh (tax exclusive) for the purchase price of biogas-generated electricity over the next 20 years [18]. The system incentivizes various actors to establish new biogas power plants. As of 2020, there were 117 BGPs in Hokkaido with a total power capacity of 18.7 MW. Seventy-one percent of these plants primarily use cattle manure as a substrate for biogas generation [19].

However, there are problems to be solved for promoting adoption of BGPs. For instance, there are voices of opposition from residents over the construction of BGPs. This is considered to result primarily from concerns that the BGPs would disturb the view of the landscape and would enhance traffic transporting dairy manure in surrounding areas every day (“not in my back yard” (NIMBY) syndrome) [20,21]. The second possible reason is that, while the construction of BGPs requires a large financial investment, the profitability of electricity generated by BGPs is nowadays uncertain due to the lack of grid availability to transfer and sell the electricity, and the difficulty of using the other energy sources generated by BGPs, such as gas and heat [22,23]. These concerns are critical obstacles for dairy farmers’ willingness to adopt BGPs, resulting in the reluctance of farmers. In addition, Rupf et al. (2015) reported that the lack of experience to operate BGPs and insufficient follow-up services of BGPs were the chief obstacles [24].

Hokkaido is a northern island of Japan with an area of 83,424 km<sup>2</sup>, accounting for 22% of the total land area of Japan and containing the most intensive dairy farms in the industry [25]. As of 2019, Hokkaido had around 801,000 dairy cattle, representing 60% of the total dairy cattle in Japan. Revenue from the dairy industry in Hokkaido was 652.9 billion JPY, accounting for 40% of total agricultural revenue in Hokkaido in 2018 [26,27]. BGPs are expected to be adopted in local regions where dairy farming is vigorous, and the local people in Hokkaido are expected to accept the new technology to improve the situation of the industry which is familiar in their daily lives [20]. Additionally, BGPs are expected to function as distributed power plants by generating and providing energy locally. In Hokkaido, which experienced a blackout caused by the 2018 Hokkaido Eastern Iburi Earthquake, it is considered essential to assess the possibility of distributed power systems in terms of energy security [14]. Yabe (2013) reported that Hokkaido has the potential to install 330 BGPs that can produce upwards of 730 GWh per year [28]. Finally, effective utilization of the digestate produced in BGPs needs fields that are wide enough for spreading [29]. From the above points, Hokkaido is regarded as the most suitable area to install BGPs in Japan.

Considering social backgrounds, this study aimed to clarify farmers’ willingness to adopt BGPs in Hokkaido and the relationship with their current farming situations. The study included three

steps. First, we conducted a questionnaire survey to understand farmers' willingness and their current situations (the number of cows, the existence of successors, and the existence of issues surrounding manure treatment). Second, we analyzed this relationship and identified factors contributing to willingness to adopt BGPs using multivariate analyses. Third, we discussed the expected effects of, and possibilities for enhancing, BGP installation as a means to achieve sustainable agriculture in Hokkaido.

## 2. Conceptual Framework of Adoption of BGPs

Technology adoption in the agricultural field has been a central topic of agricultural research and has been widely considered by scientists and economists for decades [30]. Various previous studies have explained and expected key factors of adoption and diffusion of technologies by evolving essential sets of conceptual frameworks [31]. Among them, the diffusion of innovation model has been extensively recognized. This model suggests the compatibility and complexity of the new technology, the prospective end user's characteristics, the person's perception and knowledge regarding the technology, and the communication channels to determine the diffusion and the adoption of innovative new technologies [31,32].

Operation of BGPs needs local acceptance and cooperation with farmers, which indicates that it is important to understand farmers' perceptions and characteristics. According to Penshin et al. (2019), much of the research on the diffusion of innovation has analyzed socio-personal and socioeconomic variables [33]. The socioeconomic variables include education, gender, age, social status, income, labor, and so on. Tranter et al. (2011) reported that the survey questioned farm size (the number of cattle and the area of field), labor, age, and income, and that expected adopters of BGPs tended to have a large farm size [22]. Knowler et al. (2007) also showed that farm size positively influences the decision of adopting BGPs, indicating that owners of larger facilities are more willing to accept new technologies [34]. Lansink et al. (2003) found that the existence of successors is a key factor for determining the expansion of a farm and improvement of the quality of the production process. The results were based on data analyses including the age, existence of successors, and farming plans [35]. Additionally, in most countries, creation of local employment and the subsequent vitalization of the local economy are probably the two most important issues regarding the use of local biomass for energy production [36].

Based on the previous criteria, we selected several questions, i.e., willingness to adopt BGPs, number of dairy cows, existence of successors, and existence of issues on manure treatment (Table 1). We hypothesized that in the case of Hokkaido there was also a possibility to distinguish the farmers who were willing to adopt BGPs from those who were not, through the factors of the number of dairy cows (as farm size), the existence of successors (as labor force), and the existence of issues on manure treatment (as farming quality). In addition, the future plan of the business (change of the number of dairy cows in the future) would be a certain criterion as an indicator of investment and income gain. Finally, we added the existence of BGPs as a possible factor which could be a communication channel for farmers to get knowledge about BGPs.

**Table 1.** Questionnaire summary.

Element	Expression	Purpose
Willingness to adopt BGP	"Yes" or "No"	Willingness to adopt BGP is questioned.
Number of dairy cows	Current and future numbers (in the next 10 years) of milking cows, dry cows, heifers, and calves, respectively	Number of dairy cows needed to decide the scale of BGP. The extent of the change indicated the farmer's future plans, i.e., to increase, decrease, maintain, or abandon farming.
Existence of successors	"Already determined", "Not decided but have a candidate", "No candidate", or "No successors required"	Existence of a post-retirement successor would influence the decision whether to adopt BGPs.

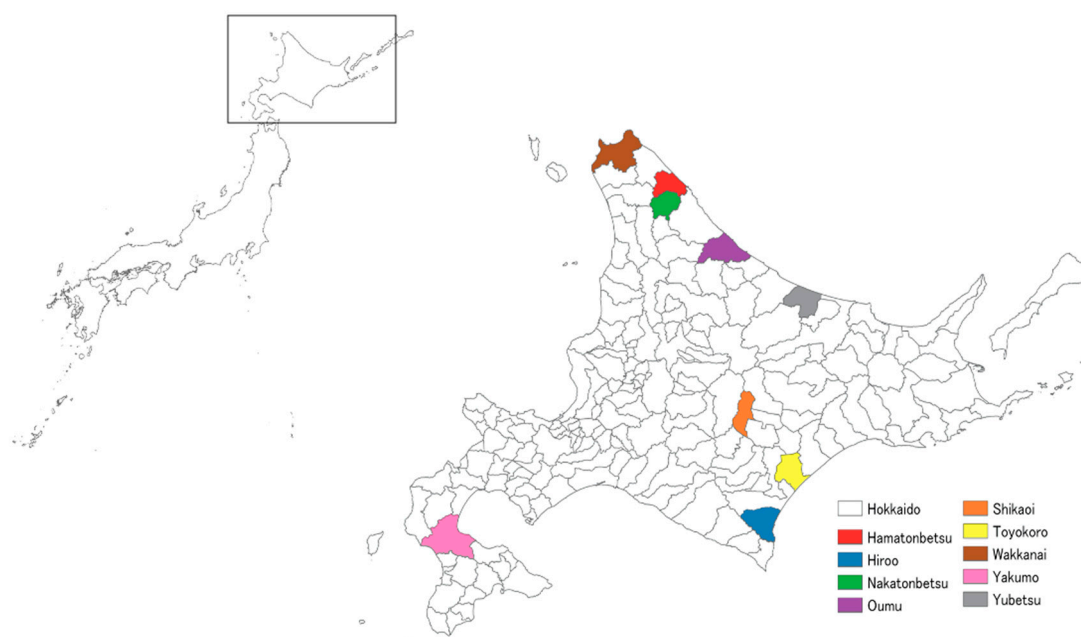
Table 1. Cont.

Element	Expression	Purpose
Existence of issues on manure treatment	"Yes", "No", or "No, but it may occur in the future"	Optional answers for specific issues on manure treatment: "Bad odor of manure is generated", "Not enough space to make compost pile", "Weeds increase in the field due to weed seeds mixed in the compost", "Compost does not work as fertilizer", "Not enough time to spread the compost", "Field requiring compost is too far from farm", "Field area is not large enough to spread compost", "It takes a long time to treat manure."

### 3. Materials and Methods

#### 3.1. Data Collection from Dairy Farmers

The questionnaire survey was carried out from 2017 to 2018. The research targets were 601 dairy farmers across nine municipalities of Hokkaido (Oumu, Yubetsu, Hamatonbetsu, Nakatonbetsu, Toyokoro, Hiroo, Wakkanai, Shikaoi, and Yakumo) that did not operate BGPs (see Figure 1). The research sites were one city and eight towns whose main industries are agriculture and related businesses. In some of the municipalities, private sectors already owned BGPs. The survey was conducted in cooperation with the local administration and the Japan Agricultural Cooperatives (JA) within each community. The questionnaire contained closed- and open-ended questions about willingness to adopt biogas projects, the number of dairy cows, the existence of successors, and issues with manure treatment (see Table 1). Answer sheets from 422 participants were collected, from which 286 (47.6%) were chosen for data analyses. Answer sheets that were completely filled out and whose respondents owned dairy cows were used for the analyses. The answer sheets from respondents with beef cattle were not used because the number of respondents was not statistically sufficient.



**Figure 1.** Map of Hokkaido island, Japan, and the nine municipality research sites (Oumu, Yubetsu, Hamatonbetsu, Nakatonbetsu, Toyokoro, Hiroo, Wakkanai, Shikaoi, and Yakumo).

### 3.2. Sociodemographic Characteristics of Surveyed Farmers and Mature Cows

From the questionnaire results, we assessed farmers' willingness to adopt BGPs, and their current and estimated future numbers of mature cows (MCs) [37,38]. MCs include both milking and dry cows, and the number is an indicator of farm size for milk production [39]. In addition, we estimated the ratio of change as future farming planning and assessed the difference in farmers' willingness to adopt BGPs [35].

### 3.3. Analyses of Current Situations

The results of the questionnaires were classified into "existence of successors" and "existence of issues surrounding manure treatment" based on willingness to adopt BGPs. In addition, we divided the number of MCs into five categories, as shown in Table 2, following Miyake's (2018) approach that described farmers with 100 MCs or more as large-scale [39]. In addition, future business planning was divided into four categories: retirement, decrease, maintain, and increase. Zero future MCs were categorized as retirement. Decrease, maintain, and increase were based on future projected changes in the number of MCs. We added "existence of BGPs" as a factor because it is easier for farmers to obtain information and feedback on BGPs if there are already some in the area. We automatically categorized answers into either "yes" or "no" based on the list of power generation equipment allowed to sell generated electricity with FIT prices by the Japanese Ministry of Economy, Trade and Industry (METI). The choice of "yes" was selected for Yubetsu, Hiroo, Wakkanai, Shikaoi, and Yakumo, and "no" was selected for Oumu, Toyokoro, Hamatonbetsu, and Nakatonbetsu. There was one BGP in Oumu at the time, but it was excluded because it was not in operation when the survey was conducted [19].

**Table 2.** Categories of farmers according to number of **mature cows** (MCs).

Category	Current Number of MCs	Number of Farmers
1	0–50 heads	99
2	50–100 heads	125
3	100–150 heads	27
4	150–200 heads	15
5	>200 heads	20

### 3.4. Assessment of Critical Factors Influencing Willingness to Adopt BGPs

We used multivariate analyses to measure the strong factors influencing willingness to adopt BGPs. We used Hayashi's quantification theory type II, which is a statistical method for predicting or discriminating qualitative criteria ("yes" or "no") in qualitative data [40,41]. We evaluated the factors contributing to willingness to adopt BGPs and the total weight of each factor, such as current farming status, future plans, and existence of BGPs in the surrounding area, using Equation (1) (see Table 3) [42,43]:

$$y = \sum_{j=1}^Q \sum_{k=1}^{C_j} a_{jk} x_{jk} + \varepsilon \quad (1)$$

where  $y$  is the sample score as an objective variable,  $Q$  is the item number of explanatory variables,  $C_j$  is the category number of the  $j$ -th explanatory variable,  $x_{jk}$  is a dummy variable that takes a value of 1 or 0 depending on whether the objective variable responded to the  $k$ -th category of the explanatory variable  $j$ ,  $a_{jk}$  is the coefficient of the model formula and is known as the "category score", and  $\varepsilon$  is the error. We used Maruchi–Tahenryo (multivariate analysis) software developed by the Institute of Statistical Analyses Inc. (Tokyo, Japan) to solve Equation (1) [44]. Difference values between the maximum and minimum value of category scores of each explanatory variable were defined as the "range". Explanatory variables with a larger range have greater contributions to the objective variable,

which is a stronger category affecting the perspective of farmers [43]. Positive  $y$  values denote that farmers are willing to adopt BGPs, while negative  $y$  values denote they are not.

**Table 3.** Summary of items and categories used in quantification theory type II.  $a_{jk}$  denotes the category score related to Equation (1) in the text.

Item	Category	$a_{jk}$
Existence of successors	Already determined	$a_{11}$
	Not determined, but have a candidate	$a_{12}$
	No candidate	$a_{13}$
	No successors required	$a_{14}$
Existence of issues on manure treatment	Yes	$a_{21}$
	No, but it may occur in the future	$a_{22}$
	No	$a_{23}$
Current number of MCs	0–50 heads	$a_{31}$
	50–100 heads	$a_{32}$
	100–150 heads	$a_{33}$
	150–200 heads	$a_{34}$
	>200 heads	$a_{35}$
Future plan of business (change of number of MCs)	Retirement	$a_{41}$
	Decrease	$a_{42}$
	Maintain	$a_{43}$
	Increase	$a_{44}$
Existence of BGPs	Yes	$a_{51}$
	No	$a_{52}$

## 4. Results

### 4.1. Sociodemographic Characteristics of Surveyed Farmers and MCs

The current and expected future numbers of MCs, and the corresponding average of MCs per household, are illustrated in Table 4. At the time of the survey, there were 26,415 MCs with an average of 92 MCs per farmer. The number of MCs per household differed among municipalities, with a maximum of 182 in Toyokoro and a minimum of 41 in Yakumo. In the future, most farmers anticipate expanding their businesses, with the total number of MCs expected to increase by 21.4%, from 92 to 112. Farmers in Shikaoi, Toyokoro, and Yubetsu expect to increase their number of MCs by 33.4%, 33.0%, and 33.0%, respectively. It is predicted that the number of MCs in Yakumo and Nakatonbetsu will decrease by 18.9% and 3.4%, respectively.

**Table 4.** Current and future numbers of MCs among municipalities, and the ratio of expected change from the present to the future. “#” denotes the number.

Municipality	# of Farmers	Current # of MCs		Future # of MCs		Ratio of Change (%)
		# of MCs	# of MCs/Farmer	# of MCs	# of MCs/Farmer	
Toyokoro	31	5634	182	7495	242	33.0
Nakatonbetsu	22	1220	56	1178	54	−3.4
Yakumo	13	528	41	428	33	−18.9
Shikaoi	24	2904	121	3873	161	33.4
Yubetsu	46	3691	80	4910	107	33.0
Oumu	35	3339	95	3750	107	12.3
Hiroo	20	1808	90	2116	106	17.0
Wakkanai	53	3096	58	4005	76	29.4
Hamatonbetsu	42	4195	100	4305	103	2.6
Total	286	26,415	92	32,060	112	21.4



Tables 5 and 6 show the number of dairy farmers who were and were not willing to adopt BGPs along with the number of MCs they own. We defined farmers willing to adopt BGPs as “Group 1” and farmers who were not as “Group 2.” Group 1 was estimated to include 119 households (41.6% of the 286 surveyed) with 15,116 MCs (57.2% of the 26,415 total), averaging 127 MCs per household. Group 2 consisted of 167 households (58.4% of the total) with 11,299 MCs (42.8% of the total), averaging 68 MCs per household, nearly half that of Group 1. The expected future number of MCs per household in Group 1 was estimated to be 174, an increase of 36.9%. There was a robust desire to increase operation size in most municipalities in Group 1, with farmers in Oumu expecting the highest increase of 66.6%. On the other hand, there were virtually no anticipated increases in MCs in Group 2, with farmers in Shikaoi and Wakkanai expecting to increase the scale of their operations and those in Yakumo and Hamatonbetsu expecting to decrease theirs.

**Table 5.** Number of farmers in Group 1, their current and estimated future numbers of MCs, and the ratio of expected change from the present to the future. “#” denotes the number.

Municipality	# of Farmers	Current # of MCs		Future # of MCs		Ratio of Change (%)
		# of MCs	# of MCs/Farmer	# of MCs	# of MCs/Farmer	
Toyokoro	18	4383	244	6102	339	39.2
Nakatonbetsu	5	336	67	351	70	4.5
Yakumo	5	225	45	231	46	2.7
Shikaoi	17	2124	125	2891	170	36.1
Yubetsu	16	1789	112	2844	178	59.0
Oumu	8	1088	136	1813	227	66.6
Hiroo	14	1123	80	1413	101	25.8
Wakkanai	17	1074	63	1592	94	48.2
Hamatonbetsu	19	2974	157	3457	182	16.2
Total	119	15,116	127	20,694	174	36.9

**Table 6.** Number of farmers in Group 2, their current and estimated future numbers of MCs, and the ratio of expected change from the present to the future. “#” denotes the number.

Municipality	# of Farmers	Current # of MCs		Future # of MCs		Ratio of Change (%)
		# of MCs	# of MCs/Farmer	# of MCs	# of MCs/Farmer	
Toyokoro	13	1251	96	1393	107	11.4
Nakatonbetsu	17	884	52	827	49	−6.4
Yakumo	8	303	38	197	25	−35.0
Shikaoi	7	780	111	982	140	25.9
Yubetsu	30	1902	63	2066	69	8.6
Oumu	27	2251	83	1937	72	−13.9
Hiroo	6	685	114	703	117	2.6
Wakkanai	36	2022	56	2413	67	19.3
Hamatonbetsu	23	1221	53	848	37	−30.5
Total	167	11,299	68	11,366	68	0.6

#### 4.2. Analyses of Farmers’ Current Situations

Differences in the responses from Groups 1 and 2 are compared in Table 7. Statistical analyses using the chi-square test indicated significant differences in the responses to questions about the existence of successors, issues with manure treatment, current number of MCs, and future plans.

Of those in Group 1, 37.8% indicated they had chosen successors, compared to 24.0% of farmers not willing to adopt BGPs (those in Group 2). In addition, farmers who had not chosen successors but had candidates comprised 28.6% of Group 1 and 23.4% of Group 2. The existence of a successor may influence a farmer’s perspective on BGPs. The analyses showed that 58.8% of Group 1 experienced problems with manure treatment, while 32.8% did not currently but might in the future. In Group 2, 22.8% had issues with manure treatment and 25.1% did not currently but might in the future. These

results indicate that 91.6% of respondents in Group 1 were worried about issues with manure treatment while 52.1% of those in Group 2 were not.

**Table 7.** Category distribution according to willingness to adopt biogas plants (BGPs).

Categories		Number of Farmers (ratio)		<i>p</i> -Value
		Group 1	Group 2	
Existence of successors	Already determined	45 (37.8%)	40 (24.0%)	0.0044 *
	Not determined, but have a candidate	34 (28.6%)	39 (23.4%)	
	No candidate	36 (30.3%)	69 (41.3%)	
	No successors required	4 (3.4%)	19 (11.4%)	
Existence of issues on manure treatment	Yes	70 (58.8%)	38 (22.8%)	0.0000 *
	No but it may occur in the future	39 (32.8%)	42 (25.1%)	
	No	10 (8.4%)	87 (52.1%)	
Current number of MCs	0–50 heads	30 (25.2%)	69 (41.3%)	0.0004 *
	50–100 heads	48 (40.3%)	77 (46.1%)	
	100–150 heads	15 (12.6%)	12 (7.2%)	
	150–200 heads	9 (7.6%)	6 (3.6%)	
	>200 heads	17 (14.3%)	3 (1.8%)	
Future plan of business (change of number of MCs)	Retirement	4 (3.4%)	30 (18.0%)	0.0003 *
	Decrease	3 (2.5%)	13 (7.8%)	
	Maintain	45 (37.8%)	67 (40.1%)	
	Increase	67 (56.3%)	57 (34.1%)	
Existence of BGPs	Yes	70 (58.8%)	87 (52.1%)	0.3142
	No	49 (41.2%)	80 (47.9%)	

Note: The *p*-values with “\*” denote those that are statistically significant ( $p < 0.01$ ).

Most respondents in both groups had less than 100 MCs. Of those in Group 2, 41.3% were small-scale with 0–50 livestock, while 14.3% of Group 1 were large-scale farmers with 200 MCs or more. This implies that farm size affects willingness to adopt BGPs. Concerning the future plans, 56.3% of those in Group 1 planned to expand the size of their farms and were willing to increase BGPs, while 40.1% of Group 2 planned to maintain the same farm size and 18.0% planned to abandon their businesses. This indicates that business planning affects motivation to adopt BGPs. Finally, there was no significant relationship between willingness to adopt BGPs and the existence of BGPs in the area ( $p = 0.3142 > 0.01$ ), inferring that the condition affecting farmers’ willingness to adopt BGPs could not be verified.

#### 4.3. Assessment of Critical Factors Influencing Willingness to Adopt BGPs

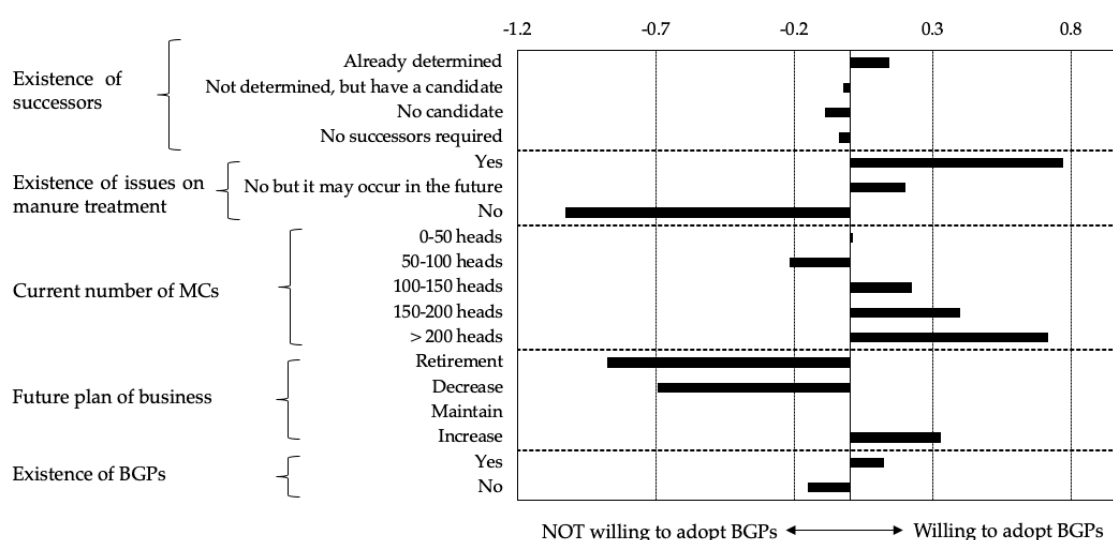
Table 8 shows the results of our analysis using the quantification theory type II. “Category scores” for each item are presented in Figure 2. This analysis is also a discriminant analysis, so if other farmers were asked the same questions, we could predict what they would think about BGPs. The analyses evaluated the rate of correct answers of predictions compared to actual answers (whether they were willing to adopt BGPs) and the predicted value by sample score  $y$ , as calculated in Equation (1). In total, 212 out of 286 farmers were correctly predicted, a rate of 74.1%. All comparison results are shown in detail in the Supplementary Materials. Among the items and categories, it was found that issues with manure treatment and future business plans have a significant, strong influence on the willingness to adopt BGPs. This is due to the category ranges, which are 1.796 (0.770 minus  $-1.026$ , based on the difference between maximum and minimum category scores for issues with manure treatment) and 1.204 (0.328 minus  $-0.876$  for future business plans) ( $p$ -values of 0.0000 [ $<0.01$ ] and 0.0011 [ $<0.01$ ], respectively). See Table 8.



**Table 8.** Summary of the results of quantification theory type II.

Items	Category	Number of Farmers	Category Score	Range	p-Value
Existence of successors	Already determined	85	0.142	0.232	0.7839
	Not determined, but have a candidate	73	−0.023		
	No candidate	105	−0.090		
	No successors required	23	−0.038		
Existence of issues on manure treatment	Yes	108	0.770	1.796	0.0000 *
	No but it may occur in the future	81	0.202		
	No	97	−1.026		
Current number of MCs	0–50 heads	99	0.010	0.935	0.0861
	50–100 heads	125	−0.218		
	100–150 heads	27	0.223		
	150–200 heads	15	0.399		
	> 200 heads	20	0.716		
Future plan of business (change of number of MCs)	Retirement	34	−0.876	1.204	0.0011 *
	Decrease	16	−0.695		
	Maintain	112	0.002		
	Increase	124	0.328		
Existence of BGPs	Yes	157	0.123	0.273	0.1320
	No	129	−0.150		

Note: The *p*-values with “\*” denote those that are statistically significant ( $p < 0.01$ ).



**Figure 2.** Category score analyses of different items. Bar chart shows the category score of each category for the items “existence of successors”, “existence of issues on manure treatment”, “current number of MCs”, “future plan of business”, and “existence of BGPs”.

In terms of influence on each category, the higher the positive value of the category score, the more the factor makes the farmers willing to adopt BGPs. For issues with manure treatment, the value was positive for farmers who had issues, and those who did not have any issues at present but may in the future were inclined to have a positive attitude towards adopting BGPs. Meanwhile, the value for farmers who did not have issues with manure treatment was strongly negative, thus they were not expected to adopt BGPs. Table 9 details the specific issues that were part of the optional answers. In Group 1, 286 answers (62.9% of the 455 total) were collected, compared to 169 (37.1%) in Group 2. Among the detailed problems seen individually, “not enough space to make compost pile” was selected by 100 farmers, representing the highest percentage (35.0%) of the 286 total farmers, followed by “it takes a long time to treat manure” by 96 farmers (33.6% of the total). Focusing on the 119 farmers in Group 1, 63 farmers (52.9%) selected “not enough space to make compost pile” and 53 farmers (44.5%) selected “it takes a long time to treat manure”. For future business plans, the value of increase

was positive, indicating that farmers who will expand their farms in the future were motivated to adopt BGPs. On the other hand, the category score of retirement and decrease was strongly negative, indicating that farmers planning to retire or shrink their businesses did not require BGPs or could not adopt them. This may be due to the significant investment needed to construct BGPs and the long-term planning required to operate them. There were no significant relationships in the items for existence of successors, current number of MCs, or existence of BGPs.

**Table 9.** Details of issues experienced with manure treatment selected by both Groups, i.e., the number of farmers and percentage of each group.

	# in Group 1 (119 farmers)			# in Group 2 (167 farmers)			Total
	Yes (%)	No, But It May Occur in the Future (%)	Total (%)	Yes (%)	No, But It May Occur in the Future (%)	Total (%)	
Bad odor of manure is generated	19 (16.0%)	11 (9.2%)	30 (25.2%)	6 (3.6%)	8 (4.8%)	14 (8.4%)	44
Not enough space to make compost pile	44 (37.0%)	19 (16.0%)	63 (52.9%)	18 (10.8%)	19 (11.4%)	37 (22.2%)	100
Weeds increase in the field due to weed seeds mixed in the compost	24 (20.2%)	7 (5.9%)	31 (26.1%)	9 (5.4%)	10 (6.0%)	19 (11.4%)	50
Compost does not work as fertilizer	8 (6.7%)	2 (1.7%)	10 (8.4%)	2 (1.2%)	1 (0.6%)	3 (1.8%)	13
Not enough time to spread the compost	25 (21.0%)	8 (6.7%)	33 (27.7%)	7 (4.2%)	9 (5.4%)	16 (9.6%)	49
Field requiring compost is too far from farm	27 (22.7%)	9 (7.6%)	36 (30.3%)	14 (8.4%)	14 (8.4%)	28 (16.8%)	64
Field area is not large enough to spread compost	20 (16.8%)	10 (8.4%)	30 (25.2%)	4 (2.4%)	5 (3.0%)	9 (5.4%)	39
It takes a long time to treat manure	36 (30.3%)	17 (14.3%)	53 (44.5%)	19 (11.4%)	24 (14.4%)	43 (25.7%)	96
Total	203	83	286	79	90	169	455

## 5. Discussion

Our survey showed that 41.6% of dairy farmers could be categorized as “willing to adopt BGPs”, with a corresponding number of 57.2% of the MCs. The expected number of MCs per household is an increase of 36.9%. Meanwhile, farmers who do not adopt BGPs will remain the farm size. This finding is in agreement with Tranter et al. (2011) and Aruba (2019), explaining that the larger the business, the more likely farmers are to introduce new equipment and technologies [22,45]. In this study, the size of a farm and future plans were significant factors contributing to the willingness of farmers to adopt BGPs. Large-scale farmers produced 36.1% of Hokkaido’s milk in 2010 [39]. In the 10 years from 2009 to 2019, the number of dairy farmers in Hokkaido decreased by 1720 (22.4%) [27,46]. As a result, farmers with large farms who are motivated to adopt BGPs account for an even greater proportion of the number of MCs, and they will play more important roles in the dairy industry in Hokkaido. This study revealed the importance of BGP installation by farmers who are most responsible for, and contribute the most to, the development of the local industry in the future.

This study also revealed that issues with manure treatment are a significant factor influencing BGP adoption. Of the farmers who were willing to adopt BGPs, 52.9% selected “not enough space to make compost pile” and 44.5% chose “it takes a long time to treat manure”. Since the enactment of the Act on Proper Management and Promotion of Use of Livestock Manure (hereafter, the “Livestock Manure Act”) in 2004, many farmers have built compost houses with a concrete floor for the composting space, but due to the increase in the number of MCs, the composting space has been insufficient and has taken more and more time to treat the manure. In addition, many farmers changed their feeding style to a stall barn, which does not require much bedding. However, it becomes difficult to make compost because the manure has a lot of water that can easily flow out of the compost house [1,47]. In addition,

30.3% of the farmers chose “field requiring compost is too far from farm” and 25.2% selected “field area is not large enough to spread compost”. This may be explained by the tendency of farmers to have large fields, and in order to increase the number of MCs, they add farmland abandoned by retired farmers. “Not enough time to spread the compost” was selected by 27.7% of respondents and relates to the excessive amounts of manure and compost that need to be spread across large fields. Selected by 26.1% of respondents, “weeds increase in the field due to weed seeds mixed in the compost” refers to compost and manure slurry that is contaminated by weed seeds that are not deactivated by the high aerobic composting temperature [48,49]. Referring to difficulties in making fully ripe compost because of the large amount of manure and its high water content, 25.2% mentioned “bad odor of manure is generated” and 8.4% indicated that “compost does not work as fertilizer” [47].

For these issues, BGPs can be expected to treat manure effectively. BGPs operate continuously, so treatment space for composting is not required. Because manure is collected regularly or is automatically carried into a BGP, the labor time required to treat manure is reduced. The liquid digestate can be used as an organic fertilizer, which adds nitrogen, phosphoric acid, and potassium, which are particularly important for agricultural products. In Hokkaido, it is common for operators of BGPs to spread digestate, which may reduce the labor time of farmers and enable the spreading of digestate to distant fields. BGPs could therefore solve the aforementioned issues, a view held by the dairy farmers in this study. Yet, the amount of digestate to be spread is controlled by the fertilization standard, which determines the upper limits of nitrogen, phosphoric acid, and potassium that can be spread [50]. The fertilization standard varies depending on the type of land. Thus, if the amount of digestate is too large and farmers cannot spread all of it on their own fields, they must cooperate with neighboring farmers to use all of it.

As mentioned above, in this survey, it was confirmed that the existence of issues on manure treatment and the future plans of a business strongly influenced the willingness to adopt BGPs, which was consistent with our original hypothesis. On the other hand, the current number of MCs, the existence of successors, and the existence of BGPs did not show a clear relationship with the farmers’ willingness, which contradicts our original hypothesis.

The existence of successors is a major factor determining whether dairy farmers continue to farm. According to Araki (2017), the most frequent reason for farming abandonment is the absence of a successor (by 42%), following debts (by 24%), labor shortages (by 12%), and anxiety about the future (by 11%) [51]. As shown in Table 7, 66.4% of farmers motivated to adopt BGPs had identified successors or successor candidates, compared to only 47.4% of farmers who were not willing to adopt BGPs. This result infers that farmers may choose to install BGPs when they are likely to continue farming, which may align with the conclusions of Kurihara et al. (2019) that larger farms tend to have successors. However, through quantification theory type II, we did not find a significant correlation between willingness to adopt BGPs and the existence of successors. A possible reason is that our questionnaire did not ask about farmer age and thus could not identify differences by age structure. Kurihara et al. (2019) mentioned that farmers involved in large-scale farming who plan to expand the scale of their operations are relatively young [45]. Thus, it may be too early for the young farmers to consider successors, and they might have answered that they did not have a successor even if they were interested in BGPs. According to Araki (2017), successor shortages are due to a lack of consideration of working conditions (such as working hours) and sustainable farm management [51]. In recent years, the number of MCs per household has increased, and the expansion of farm sizes has led to an increase in the number of hours worked per person [45,52]. Miyake (2018) reported that owners tend to spend less time with their own MCs at farms that are poorly managed [39]. In other words, BGPs could reduce the time spent on manure treatment, increase the amount of time spent with MCs, increase production efficiency, stabilize business operations, improve working conditions, and allow more time to identify successors.

The biogas produced from BGPs is also important. ADs in BGPs use organic waste effectively to produce renewable energy that is distributed and can increase self-sufficiency and mitigate climate

change [14,15,28]. Distributed, self-sufficient energy is important in Japan given its history of large earthquakes (e.g., the 2011 Great East Japan Earthquake and the 2018 Hokkaido Eastern Iburi Earthquake) that have cut off the supply of large-scale, centralized power plants [53]. Electricity from the FIT policy generates the majority of BGP revenue, however, the constraint of grid interconnection remains a serious problem [6]. There are some discussions about revising the grid system, such as developing a Japanese “Connect and Manage” rule, but in Japan the energy is required to be used not only for electricity but also heating, gas, and hydrogen [54]. In Hokkaido, combined heat and power (CHP) systems in BGPs have been used to cultivate vegetables and fruits in greenhouses and aquaculture, however, heat can currently only be used in the surrounding area [23]. In Germany and Denmark, the gas grid is widespread across the country and the FIT system for gas supply is also institutionalized [55]. Because Hokkaido is a particularly cold region and energy demand per household is the highest in Japan, promoting biogas as a heat source makes sense [56].

Sufficient investment for construction is necessary to install more BGPs. There should also be subsidies for their operation, such as FIT schemes (despite the difficult situation they face for power grid use). The effects of BGPs on the environment and dairy farming have already been explained in previous studies, as mentioned above [1,3,5,6,9–15]. Therefore, it should be emphasized that BGPs are different from other power sources that require policy design, such as preferential grid use and support of continuous FIT schemes. FIT schemes for gas supply should be institutionalized in Japan. Zheng et al. (2020) showed the importance of subsidizing the production of BGPs [57]. It may be possible to consider support in the form of environmental, social, and governance (ESG) investments from the viewpoint of improving environmental problems and regional economies, for which the dairy farmers who are willing to adopt BGPs would be responsible.

## 6. Conclusions

To achieve sustainable farming with BGPs, this study investigated the relationship between farmers’ willingness to adopt BGPs and their current farming situations. We found that farmers who were willing to adopt BGPs were likely to have large farms and to expand the size of their farms in the future. As the number of dairy farmers has recently decreased, farmers motivated to adopt BGPs would play an important role in the dairy industry in Hokkaido. BGPs would support effective manure treatment to improve farming conditions and revitalize local economies.

In this study, we could not identify a clear relationship between the existence of successors and willingness to adopt BGPs, because we did not collect data on the age of the farmers. It seems that some of the farmers were relatively young and had not yet identified their successors. To identify successors is a major issue for sustainable dairy farming, and therefore, further research might be necessary to promote dairy farming, particularly in local scales.

There has been much discussion about barriers to the use of electricity produced by biogas (such as restriction of grid connection), but BGPs could be accepted as a means of agricultural promotion. Therefore, it is important to understand the effects of BGPs on farming. This study may be valuable for decision-making regarding efficient allocation of subsidies and efficient development of other energy systems that could reduce the cost of fossil fuels.

**Supplementary Materials:** The following are available online at <http://www.mdpi.com/2071-1050/12/18/7809/s1>, S1: Correct answer rate of the quantification theory type II.

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