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Combined third-party ownership and aggregation business model for the adoption of rooftop solar PV–battery systems: Implications from the case of Miyakojima Island, Japan

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A B S T R A C T

Solar photovoltaics with behind-the-meter energy storage systems are gaining recognition as net energy billing replaces feed-in tariffs because they can unlock demand-side flexibility, keep grid stability, and enhance the resilience of end users. However, incumbent grid companies tend to prioritize grid stability and reliability and disregard resilience, which decreases end users' perceived benefits, intention, and adoption of the systems. The combined third-party ownership–aggregation business model could drive adoption because it can enhance grid stability and reliability, and resilience at the same time. This study explores how the model works to increase the intention and adoption, and what policies and regulations are required to enable the model to mitigate the conflict of interest taking Miyakojima Island in Japan as a case study. The study finds that the model can increase adoption by reducing perceived risks. Policy and regulations, and resistance and inert of incumbent grid companies block the model from effectively working to change the benefit-sharing. Science-based regulations on the use of energy storage systems during power outages, stringent policy implementations of updated renewable energy targets and the 2050 carbon neutrality, and detailed time-of-use pricing can change the benefit-sharing in favor of end users and increase adoption.

1. Introduction

Behind-the-meter (BTM) energy storage systems (ESSs) in residential and commercial buildings can unlock demand-side flexibility. Such systems provide voltage and frequency support for system operators, helping them integrate higher shares of renewable energy-based electricity (RES-E) into the grid. In addition, these systems help replace diesel generators with RES-E-based mini-grids (IRENA, 2019). A dramatic decrease in the upfront cost of solar photovoltaic (PV) and battery storage and credits and upfront subsidies have made PV-BTM ESSs accessible to individual or household end users and utilities (Baek et al., 2020). Demand response (DR), peak shift, and ancillary services can reduce asset aging (Specht and Madlener, 2019) and increase the reliability of the grid system (Jin et al., 2022), thus increasing the economic benefits of BTM ESSs and justifying high upfront costs.

PV-BTM ESSs can also help end users save on electricity bills through demand-side management, as they enable end users to store energy during low-price periods for use during high-price hours. Time of use (TOU), or real-time pricing, demand charges on consumption increase bill-saving benefits (McLaren et al., 2019). Replacing net energy metering with a net energy billing scheme can shift investments from grid-connected solar PV toward PV-BTM ESSs because the sale rate for the grid is set at a lower cost than the retail electricity tariff (Rezaeimozafar et al., 2022). Retail rates with high maximum demand charges and low volumetric TOU prices have the same effect (Boampong and Brown, 2020). They can also minimize cost-shifting to consumers who do not install PV-BTM-ESSs and reduce the grid costs associated with the large-scale integration of distributed RES-E (Fridgen et al., 2018). ESSs adoption can be concentrated in high-income households, even when funding targets low-income households (Brown, 2022).

The systems also supply backup power and improve end users' resilience (Hanser et al., 2017). They can offer useful solutions, particularly for remote microgrids that suffer from severely unreliable power supplies (Trevizan et al., 2022) and in regions where natural disasters pose a high risk of power outages (IRENA, 2019).

However, the current benefit-sharing scheme may not sufficiently motivate end users to invest in PV-BTM ESSs. Grid companies do not recognize resilience benefits as a value that should be compensated to end users. They provide compensation to distributed ESSs participants under DR programs in exchange for their contributions to grid stability and reliability (Kang et al., 2018). Thus, resilience benefits do not justify the high upfront costs of PV-BTM ESSs for buildings without peak demand, such as hospitals, because these buildings generate negligible bill savings (Mahani et al., 2020).

A combined TPO-aggregation business model can reconcile grid

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Abbreviations

AIC	Akaike information criterion
BTM	Behind-the-meter
BIC	Bayesian information criteria
CFI	Comparative Fit Index
DR	Demand response
ESS	energy storage system
FiT	feed-in tariff
IPP	independent power producer
MMEC	Miyako Mirai Energy Company
OEPC	Okinawa Electric Power Company
PBC	perceived behavioral control
PPSs	power producer and suppliers
PV	photovoltaic
REC	renewable energy certificate
RES-E:	renewable-energy-sourced electricity
RMSEA	Root Mean Square Error of Approximation
RPS	renewable portfolio standard;
SEM	Structural equation modeling
TOU	Time-of-use
TPB	Theory of Planned Behavior
TPO	Third-Party-Ownership

stability and reliability benefits for grid companies and bill savings and resilience benefits for end users. In the TPO model, TPO installers or power producers and suppliers (PPSs) either lease PV-BHM ESSs or only purchase electricity generated by the systems. The model reduces or eliminates the upfront capital costs, technology risks, and complexity of monitoring systems (Kircher and Zhang, 2021). It unlocks financial constraints for end users to gain bill savings through lower fees per kWh or specified tariffs. It can connect distributed BTM ESSs to grid systems to pool flexibility in a large group to supply balancing power to the market by installing smart meters and deploying smart grids at the same time. In the TPO-aggregation model, aggregators and energy service companies enable to offer incentive-based DR to distributed BTM ESSs in addition to time-based DR (IRENA, 2019). In other words, end users are given opportunities to gain benefits by reducing their demands at a requested time for grid reliability by Independent System Operator (Kang et al., 2018) even where TOU prices are not implemented. Thus, the combined business model appears to be a promising approach for reducing grid system costs and helping end users become prosumers without taking risks (Specht and Madlener, 2019).

Business models are embedded in policy and regulatory frameworks. Distributed PV and BTM storage business models are driven by policy and regulatory factors (Burger and Luke, 2017). There is a considerable awareness gap in countries where the TPO model is absent (Saleh and Upham, 2022). When the TPO model is translated to fit local market conditions (Ode and Wadin, 2019), it encounters specific local barriers, such as the unclear legal status of the model and prohibitions on the reverse flow of excess electricity to the distribution grid (Potisat et al., 2017). As a result, the TPO model has not been a driver for PV-BHM ESSs outside the United States, where it was established under the California Solar Initiative (Li, 2018). In Germany and Japan, building owners have been receptive to purchasing and financing PV systems (Strupeit and Palm, 2016), and business revenue streams have been directly generated from the sale of energy at feed-in tariff (FiT) rates (Burger and Luke, 2017). When the Japanese government committed to carbon neutrality by 2050, replacing a FiT with net energy billing, the TPO and third-party aggregator business gained attention (Ministry of Environment, 2021).

Nonetheless, minimal research has explored how the TPO business model can address end users' intention and adoption and the inherent conflict of interest. Against this backdrop, this study explores how the combined TPO-aggregation business model works to increase the intention and adoption, and what policies and regulations are required to enable the business model to work effectively for mitigating the conflict of interest. We take Miyakojima Island in Japan as a case study. The island has remote microgrids, is vulnerable to natural disasters, and has an active TPO–aggregator devoted to rolling out PV-BTM ESSs.

This study makes two contributions. First, it provides novel empirical evidence regarding the effectiveness of the combined TPO–aggregation business model in mitigating end users' sociopsychological barriers to PV-BTM ESSs adoption. Second, it provides policy implications to make the combined TPO–aggregation business model work for changing the benefit-sharing in favor of end users.

The remainder of this paper proceeds as follows. The next section presents a literature review to identify plausible motivations for, and barriers to, adopting rooftop solar PV–battery systems in the TPO model. Section 3 conducts a context analysis to add them, presenting our hypothesis. Section 4 details our methodologies, models, and materials. Section 5 provides the results, and Section 6 interprets the results to discuss policy implications. Finally, Section 7 concludes the study and provides policy implications and limitations of the study.

2. Literature review

Previous empirical studies have revealed different motivations and barriers based on the type of business model. In the homeownership model, financial and economic benefits, such as bill savings from the utility (Claudy et al., 2013; Sommerfeld et al., 2017), extra income through a positive net energy life cycle (Raugei et al., 2012), rising energy prices, and generous government support (Braito et al., 2017) are major motivations. This especially holds for individual buildings, such as cases of building integrated or applied PVs that claim much higher upfront capital costs than conventional energy technologies (Karteris and Papadopoulos, 2012). Per capita income has shown mixed results, suggesting that accumulated capital affects end users' financial constraints and risk-bearing potential (Graziano and Gillingham, 2015).

Household conditions, such as ownership and unshared roof space, the credibility of the government (Briguglio and Formosa, 2017), and the provision of information, and social influences, such as communities of information, technical support, and social networks are also found to be significant motivations, particularly for the better educated (Jager, 2006). Preexisting and basic knowledge of energy and green energy is strongly associated with purchasing intention toward green products in general (Arkesteijn and Oerlemans, 2005).

Conversely, environmental benefits, such as decreasing local pollution, have not been identified as a motivation (Jacksohn et al., 2019), particularly for the middle class (Bondio et al., 2018), or are found to be marginal at best (Schelly, 2014; Braito et al., 2017). Homeowners' age shows mixed results, as some research shows that younger generations are more motivated (Briguglio and Formosa, 2017), whereas others demonstrate that post-family homeowners who can raise funds to cover upfront capital costs and economic life events, such as retirement, influence perceptions of affordability (Schelly, 2014; Bondio et al., 2018). The complexity of rules and administrative procedures are also identified as barriers (Karteris and Papadopoulos, 2012).

For adopters, empirical studies have produced varying results. Information provision and social influence emerge as important motivations and barriers. A steeply tiered tariff structure increases bill savings, which enhances motivation (Borenstein, 2017). Early adopters perceive heightened socioeconomic status that improves their standing in the community (Dharshing, 2017) through delivering information as early adopters (Karjalainen and Ahvenniemi, 2019), which increases motivation. Knowledge of energy systems also raises motivation (Parkins et al., 2018). Neighborhood peer effects (Schaffer and Brun, 2015), particularly active peer association through direct interpersonal contact with friends, colleagues, and relatives, are more likely to induce adoption (Palm, 2017). The spread of information can inspire imitation in neighboring regions (Rode and Weber, 2016). Homeowners' age becomes insignificant when the age of an owner's house is added as a predictor (De Groote et al., 2016).

As opposed to the homeownership model, environmental benefits (Zhang et al., 2011; Schaffer and Brun, 2015), settlement structure (Schaffer and Brun, 2015; Dharshing, 2017), and independence from electricity suppliers (Karakaya et al., 2015) also emerge as important motivations in the TPO model. Younger, less affluent, and less educated populations are more likely to adopt the TPO model (Drury et al., 2012). Neighborhood peer effects work as a motivation (Brudermann et al., 2013). Prosuming activities are increased if potential prosumers can easily access solar land maps and third-party PV installers and leasing firms (Inderberg et al., 2018), and grid companies and municipalities provide information-based facilitation (Inderberg et al., 2020).

The TPO model also has several barriers that are distinguished from the homeownership model. These include delays in grid-connection processes that damage the viability of solar PV projects (Karteris and Papadopoulos, 2013), concerns about the quality of PV systems, lack of adequate knowledge of the technical details, inadequate installation space, competing technologies, such as solar water heating systems (Karakaya and Sriwannawit, 2015), and high switching and maintenance costs (Jager, 2006; Zhang et al., 2012). In addition, weak and neglected after-sales services prevent adopters from improving access to information, knowledge, communication channels, technical assistance, and other infrastructure (Karakaya and Sriwannawit, 2015).

3. Contexts of the case

3.1. RES-E policy in Japan

Japanese electricity policy has oscillated between unbundling, liberalization, and RES-E on one hand and reinforcing the incumbent centralized, nuclear-based regime on the other (Mori, 2019). The 2008–2009 global financial crisis, increasing global pressure to reach the post-Kyoto climate target, and the Fukushima nuclear disaster pushed the government to implement more favorable RES-E policies. These policies included the replacement of a renewable energy portfolio with minimum obligations with a FiT for rooftop solar PV with net energy metering, the expansion of the scope of FiT to utility-scale solar PV, wind, geothermal, and biomass power, and the increase in the RES-E target in the Strategic Energy Plan. The Fukushima nuclear disaster also promoted unbundling of the vertically integrated electricity companies and market liberalization. The retail market was fully liberalized in 2016, allowing more new suppliers to enter, offer TOU prices, and supply net carbon-zero electricity.

These generous supporting policies directed investments toward utility-scale and rooftop solar PV installation. IPPs and PPSs have increased supplies, reaching around 20% of the total supply (METI, 2022). However, the surge in the availability of variable solar power with higher leverage cost of generation triggered repercussions from incumbent electric power companies, leading to the replacement of a FiT with a net energy billing scheme for rooftop solar (OEPC, n.a). The government did not ensure priority grid access to RES-E IPPs and PPSs, legitimizing solar curtailment without compensation by the incumbent electricity utilities and imposing additional grid and transmission fees upon IPPs and PPSs to maintain grid capacity for nuclear power for future recommission (Haukkala et al., 2021). It also imposed capacity charges and imbalance prices when power production imbalances were generated within their balancing groups. Meanwhile, the government provided funding to develop grid capacity only at the threshold of interconnections between the main transmission networks to avoid fierce competition among regionally monopolized incumbent electricity companies (Hatta, 2012).

Solar curtailment and net energy billing redirected PPSs and prosumers toward peak cut and self-consumption. In response, the government created the DR market in the electricity wholesale market to host bidding for ancillary services, authorized energy resource aggregator licenses to offer incentive-based DR, and replaced the balancing group model of the wholesale market with the pool model that ISO operates across regions (METI, 2022). The non-fossil value trading market for RES-E started operation in 2017. With the government's carbon neutrality pledge and subsequent Strategic Energy Plan posited RES-E as one of the core sources of energy supply, distributed ESSs and energy resource aggregators have emerged as drivers for taking imbalance risks and boosting RES-E under net energy billing (METI, 2021).

As a result, lithium-ion battery storage in on-grid BTM soared, adding 800, 900, and 1000 MWh in 2019, 2020, and 2021, respectively, and cumulatively reached 4.4 GWh in 2021 (Gorka, 2022). Nonetheless, the balancing and ancillary service market will not become operational until 2024. While reserve power has been procured through auction, few ancillary services have been supplied from RES-E (Agency for Natural Resources and Energy, 2021).

3.2. Case description

Miyakojima Island is one of the archipelagos of Okinawa prefecture, located 300 km from the main Okinawa Island. The island comprises six islands: Miyakojima Main Island, Ikema, Irabu, Shimoji, Kurima, and Ogami. Miyakojima Island refers to these six islands. It has a 204 km^2 land area with a population of about 55,000. Most people live on Miyakojima Main Island, which has the largest land area and a diesel power plant (Fig. 1) (Miyakojima City, 2012). It is a typhoon-prone area and thus has suffered from typhoon-induced power outages three times a year on average for many years (Fujimoto, 2019b).

Okinawa Electric Power Company (OEPC), one of the vertically integrated incumbent electric companies, is responsible for supplying electricity to the Okinawa mainland and 37 of the archipelago's islands, including Miyakojima Island. Because it does not have transmission lines connecting the archipelago, it imports diesel to generate and supply electricity to each group of islands. However, high fuel shipping costs, no scale economy, recovery work from typhoon-induced power outages, and price regulation force the company into a deficit (OEPC, 2017). The absence of interconnected transmission lines and low energy self-sufficiency prolong power outages when the region is hit by natural disasters. Frequent and long-period power outages raise the willingness of residents to secure a self-supplying system, motivating some to independently purchase diesel electricity generators. Nonetheless, the highly leveraged cost of electricity, no space for utility-scale generation, and price regulation discourage OEPC from deploying PV-BTM ESSs in the archipelago.

Recognizing that solar PV can mitigate power outages, the Miyakojima municipality released a sustainable development strategy in 2008. When the Japanese government implemented the FiT, it began leasing rooftop solar PV using the TPO model. Funded by the Ministry of Economy, it implemented a demonstration project of a large-scale front-of-the-meter battery storage system to test its function and system flexibility. However, the ratio of RES-E had only risen to 3% in total consumption by 2016 (Fujimoto, 2019b). In response, the municipality set renewable energy targets of 22% by 2030 and 49% by 2050 (Miyakojima City, 2020), inviting Miyako Mirai Energy Company (MMEC), a local start-up TPO installation and leasing company, and NEXTEMS, an aggregator succeeding with the TPO model (Fig. 2). The TPO–aggregator prepared four options for installing rooftop solar systems, including PV–only, PV–battery systems, PV–water heating systems, and PV–battery–water heating systems. In exchange for exempting upfront capital costs, the company requires a 10-year leasing contract with a cancelation fee at a bill of US$0.18 for the PV–only option, with

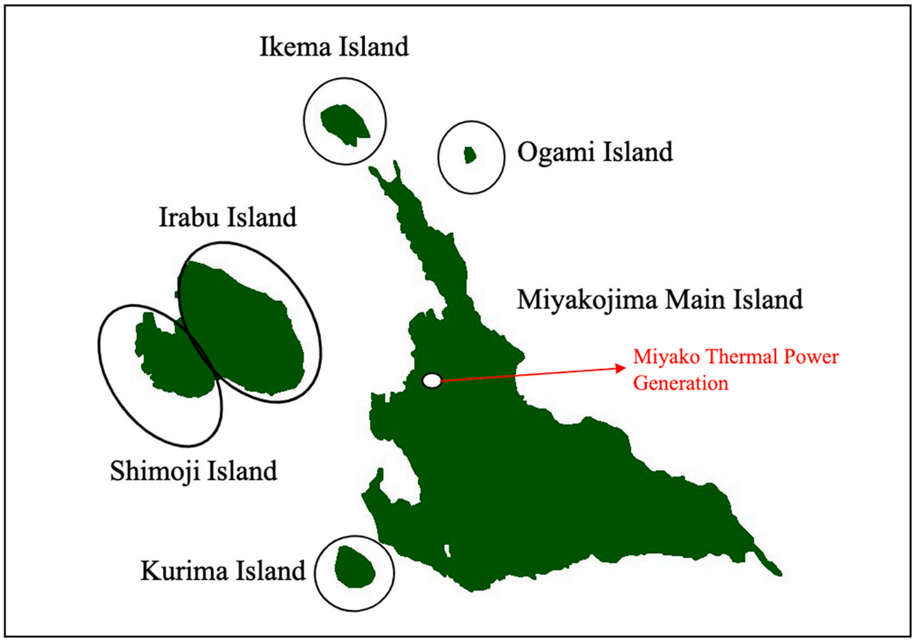

Fig. 1. Location of Miyakojima Islands.
Source: Compiled by the author based on Raimlight

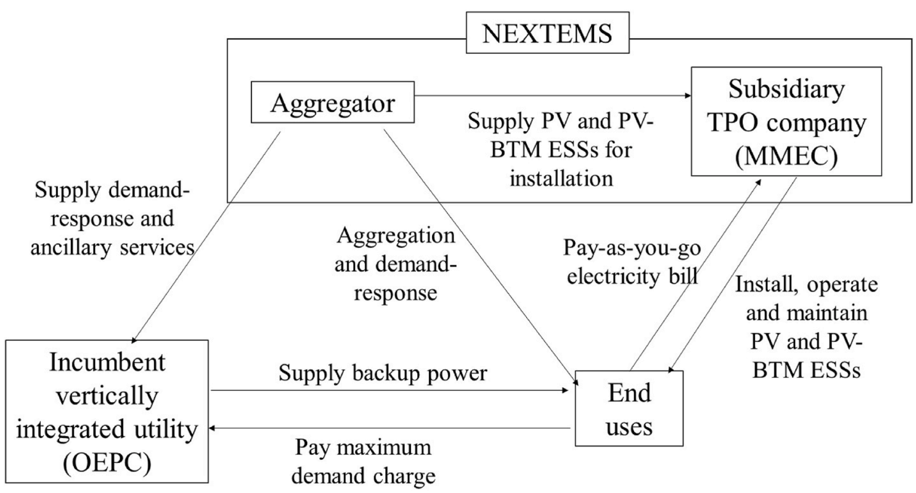

Fig. 2. The combined TPO–aggregation business model.
Source: author

additional charges of US$0.07 for the battery system and US$0.45/100l for water heating (Fujimoto, 2019b). The bill structure is designed to bring marginal bill saving to end users (MMEC, 2021), instead highlighting the function of battery systems as backup power for stronger resilience to typhoon disasters.[1]

The TPO–aggregator entered contracts with 240 households and 10 care houses for the elderly by 2020. Among them, PV–battery systems with and without an EV charger system dominate, accounting for 70%. PV–battery–water heating systems with and without an EV charger account for the second largest adoption (21%), followed by PV–water heating systems (8%) and PV–EV charger systems (1%).[2]

[1] Based on an interview with the CEO of MMEC on September 25, 2020.
[2] Based on an interview with the CEO of MMEC on September 25, 2020.

4. Methodology and materials

4.1. Theory of planned behavior

We begin with the theory of planned behavior (TPB) as our prediction model. The TPB provides a framework for understanding and predicting human behavior in circumstances in which people have incomplete volitional control (Ajzen, 2001). It is one of the most widely used behavior prediction models in psychological research, with applications for environmental behavior, such as energy conservation, purchases of green products, and adoption of renewable technologies (Chen and Knight, 2014; Chen et al., 2016; Setyawan et al., 2018).

The TPB posits that behavior is preceded by behavioral intention, which is determined by individuals' attitudes, subjective norms, and perceived behavioral control (PBC), meaning the perceived ease or difficulty of performing a behavior (Ajzen, 2002). Perceived ease or difficulty is assumed to be related to skills or abilities, time, money, opportunities, and other resources. PBC only generates indirect influence when predictors cover the full range of possible scores; thus, many researchers have posited economic life events and settlement structure as PBC (Schelly, 2014; Schaffer and Brun, 2015), treating it as a control variable (Ajzen, 2002).

We deviate from the standard model on several points. First, we assume that PBC affects behavior only directly (Fig. 3). Second, we disaggregate settlement structures into traditional-style (PBC1), old-aged buildings (PBC2), more than four floors (PBC3), and inadequate installation space (PBC4) (Korcaj et al., 2015), and assume that all these parameters directly affect adoption.[3] Third, we add two economic life events as PBC of future renovation (PBC5) and house movement within 10 years (PBC6).

Attitude is the result of a general appraisal of behavior, which depends on individuals' perceptions regarding possible outcomes and their evaluations of those consequences. Subjective norms are defined as perceived social pressure from significant others that influences a user to perform a particular behavior (Chen and Knight, 2014).

We categorize economic and social climate change mitigation benefits as attitudes. We identify bill saving (PB1) as individual economic benefits (IB). Considering the local context, we also add adaptation (AB1) and energy independence (AB2) as components of the IB. We disaggregate social benefits (SB) into personal socioeconomic status (SSB), local economy (SB1) (Korcaj et al., 2015), and the social network of the island (SB2) (Chen et al., 2016). We also disaggregate environmental benefits into climate change benefits mitigation (EB1) (Jager, 2006; Chen et al., 2013) and mitigation of future bill hikes (EB2).

Subjective norms are composed of descriptive and injunctive norms. A descriptive norm is the perception of what most other people do and is thus identical to the neighboring peer effects (Cialdini et al., 1990). An injunctive norm is the perception of potential approval or disapproval from others. We assume that both norms come from family and friends, denoting descriptive norms from family as DN1, and those from friends as DN2, while injunctive norms from family and friends are IN1 and IN2, respectively.

We disaggregate perceived technological and managerial risks into five categories, including rules and administrative procedures (POC1), appearance (POC2), quality of the PV systems (Safety1), lack of adequate knowledge (Unfam), and uncertainty (Uncert), adding the context-specific perceived risk of typhoon-induced power outages (Safety2) to this category.

Finally, we identify subjective and factual knowledge as components of knowledge, choosing energy systems (RE) as subjective knowledge and the state of energy on the island (ES) as factual knowledge (Parkins et al., 2018).

4.2. The model and the data

We employed structural equation modeling (SEM) to estimate the correlations between intention and the socio-psychological predictors of attitude, subjective norms, risk, and knowledge. We measured the overall model fit by applying the comparative fit index (CFI), root mean square error of approximation (RMSEA), chi-squared (X^2), and confidence interval tests.

We also used logistic regression to estimate the correlation between actual behavior and the sociopsychological predictors of intention identified as statistically significant in the SEM and the PBC. We employed the stepwise method to improve model fit regarding *p*-value, Akaike information criterion (AIC), and Bayesian information criteria (BIC). We used JMP software for the analysis.

We conducted two types of questionnaire surveys. One was used for SEM and logistic regression analysis measuring actual and potential adopters' perceptions on the 5-point scale (Appendix A). The other was used for understanding respondent attributes (Appendix B). We distributed the questionnaire in two ways, including a paper-based questionnaire to 350 randomly selected residents of Miyakojima Main Island during November 15–18, 2020, and an online questionnaire distributed to 1000 employees of the Miyakojima municipality.

To understand the underlying factors behind our quantitative analyses more comprehensively, we conducted one-on-one, semi-structured interviews with the selected MMEC customers on November 16–17, 2020. When preparing three questions beforehand, we deviated from the question frame by presenting additional questions or removing questions from the list depending on the course of the interview. We conducted six interviews, with one person per household or building. We designated interviewees as the person responsible for adopting a PV or PV–BTM battery system. Each interview lasted about 40 min with three categories of questions, namely, the reasons for adoption, concerns and perceived risks, and the challenges of the prevailing electricity systems to adopting PV–BTM ESSs.

We recorded the interviews with the interviewees' permission, transcribing the interview data and analyzing it through coding to identify the keywords regarding system adoption.

In addition, we conducted one-on-one, open-ended interviews with the municipality on November 16–17, 2020, to obtain their understanding of the business model, policy measures, and their perspectives on residents. We also conducted interviews with the TPO–aggregator on September 25, 2020, to acknowledge the business model and state of progress, then on September 26, 2022, for feedback on the results.

5. Results

5.1. Characteristics of respondents and interviewees

We obtain valid responses from 220 residents, of which 116 are males, 96 are females, and others are no reply. Table 1 summarizes the descriptive statistics of each predictor. Table 2 shows that their ages range from 10s to over 70s, with the highest concentration in the 40s. 80% of respondents live on Miyakojima Main Island, 5% on Irabu Island, 2% on Korima Island, and 1% on Shimoji Island (Table 3). This is consistent with the population census. Of the respondents, 43 use the TPO model, and six do the homeownership model (Table 4).

All six face-to-face interviewees are male, ranging in age from the 40s–70s (Table 5). Four live on Kurima Island and two on Miyakojima Main Island. Adopters A and F run the kindergarten and welfare business and adopt the rooftop solar PV–battery system for their buildings (Table 5).

As for the predictors, we observe a high correlation between SB1 and SB2 (Table 6), excluding SB2 from the analysis. We also note insistences from many interviewees and some respondents that most people would not interfere in others' decisions once they are made; thus, we exclude injunctive norms (IN1 and IN2) from the analysis.

5.2. Sociopsychological predictors of intention

The path analysis shows a moderate model fit with CFI = 0.940, RMSEA = 0.0588, and df = 112. In our estimation, attitude, and risk perception account for a large portion of the variance of intention (Fig. 4). Among the attitudes, IB proves to be a strong predictor. Independence from the power generation system is the most influential predictor (AB2; $B = 0.431$, $p < 0.001$), followed by bill saving (FB1; $B = 0.295$, $p < 0.001$), and climate change adaptation through backup power (AB1; $B = 0.263$, $p < 0.001$). SB also proves to be a strong predictor. Both social status benefits (SSB; $B = 0.488$, $p < 0.001$) and economic impacts (SB1; $B = 0.463$, $p < 0.001$) are statistically significant with a high correlation. In contrast, climate change mitigation benefits are statistically nonsignificant.

Risk perception and all the six sub-predictors prove to be statistically significant and negatively affect adoption. Uncertainty (Uncert; $B =$

[3] Based on an interview with the CEO of MMEC on September 25, 2020.

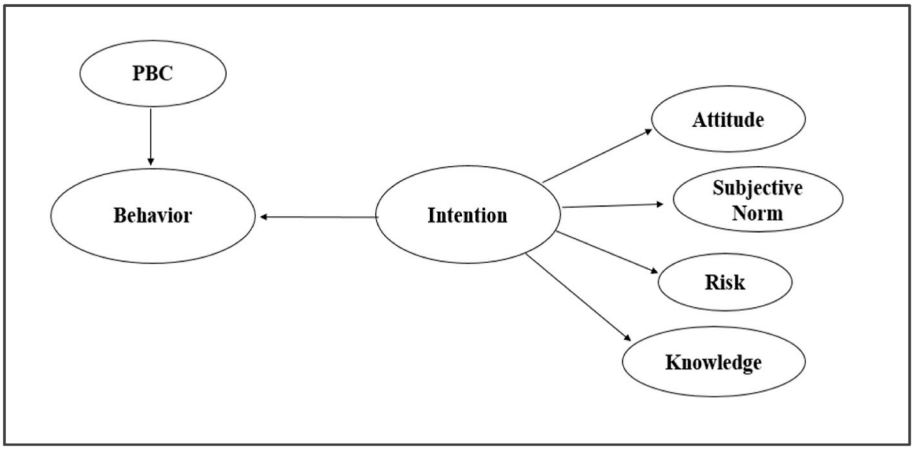

Fig. 3. Analytical framework of the study.
Source: author

Table 1
Descriptive statistics of predictors (N = 220).

Variables		Mean	SD
Attitude			
PB1	The PV-storage system will save utility bills	4.06	0.85
AB1	The PV-storage system will be a countermeasure against typhoon blackout	4.06	0.91
AB2	I feel a sense of security for having the independent power generation	3.78	0.94
EB1	The PV-storage system will prevent climate change	3.64	0.94
EB2	The PV-storage system can prevent future increases in electricity bills	3.36	0.93
SSB	The reputation of my house will increase in the community	3.90	0.93
SB1	The PV-storage system will have a good effect on Miyako Island's economy	3.76	0.95
SB2	The reputation of Miyakojima Island will rise by utilizing RE for city planning	2.88	1.13
Risk			
POC1	The installation procedure is troublesome	3.42	1.04
POC2	The appearance of the house will be spoiled	2.52	1.14
Safety1	I am concerned about the safety of the usage	3.28	1.19
Safety2	I am worried that the equipment will be blown away by the typhoon and cause damage to someone	4.00	1.03
Unfam	There is a sense of resistance because it is an unfamiliar technology	2.69	1.14
Uncert	I feel uneasy about the installation	2.90	1.09
Subjective Norm			
DN1	Is your family interested in the PV-storage system?	2.98	1.07
DN2	Is your friend interested in the PV-storage system?	2.91	0.88
IN1	I think my family would approve of me when I install the system	3.66	0.85
IN2	I think my friend would approve of me when I install the system	3.54	0.74
PBC			
PBC1	My house has a red-tile roof	1.21	0.74
PBC2	The aging of the building is conspicuous	2.5	1.26
PBC3	The building has more than 4 floors	1.42	1.15
PBC4	There is a garden which is more than 1 m^2	3.21	1.85
PBC5	We expected to renovate the house in the near future	1.79	1.07
PBC6	I will move to another place within 10 years	2.52	1.40
Knowledge (1: do not know at all, 5: know very well)			
RE	The merits and demerits of renewable energy	2.65	1.02
ES	Energy situation on the island	2.49	0.98

Table 2
Demographic characteristics of the respondents.

		N = 220
Gender	Male	116
	Female	96
	Other	1
	N/A	7
Age	10s	1
	20s	23
	30s	40
	40s	57
	50s	42
	60s	29
	Over 70s	21
	N/A	7

Table 3
Geographical characteristics of the respondents.

	N = 220
Miyakojima main island	182
Irabu island	10
Kurima island	4
Shimoji island	2
N/A	22

Table 4
Installation of rooftop solar PV-BTS ESS among respondents.

	N = 220
None	171
Solar PV only	22
PV-water heating systems	16
PV-battery storage-water heating systems	4
EV-charger	1
Others	6

0.803, $p < 0.001$) and system quality (Safety1; $B = 0.792$, $p < 0.001$) are the highest perceived risks. Subsequently, lack of adequate knowledge (Unfam; $B = 0.669$ with $p < 0.001$) and concerns regarding the damage to other people (Safety2; $B = 0.657$, $p < 0.001$) are perceived as higher risks. Damage to the house appearance (POC2; $B = 0.544$, $p < 0.001$) and administrative procedure (POC1; $B = 0.471$, $p < 0.001$) prove to be low. In contrast, knowledge proves to be a weak predictor at best.

5.3. Sociopsychological predictors of adoption

Table 7 summarizes the results of the logistic regressions. Model 1 includes all the predictors in PBC, attitude, and risk because attitude and risk perceptions are significant in the SEM. The model shows that Safety1 (perceived risk of system quality), PBC2 (house age), and PBC6 (future movement) are statistically significant and negatively affect

Table 5
Description of the interviewees.

Interviewee	Installation Location	Age	Gender	Living Area
A	Kindergarten with House	60s	Male	Miyakojima main Island
B	House	60s	Male	Kurima Island
C	House	40s	Male	Kurima Island
D	House	70s	Male	Kurima Island
E	House	50s	Male	Kurima Island
F	Welfare Building	50s	Male	Miyakojima main Island

implies that homeowners of old-aged houses are less likely to adopt because the settlement structure is not well-suited.

6. Discussion

The results provide insights into the combined TPO–aggregation business model and policy to make the model work to advance the adoption of PV–BTM battery systems. First, the TPO–aggregator model works to increase adoption by reducing risk perception. It increases intention to adopt PV–BTM battery systems by increasing end users' perceived personal benefits, such as bill savings, backup power, and independent power generation systems, as well as SB, such as employment and social status in the region. The business model persuades those who have intentions to adopt by reducing perceived risks derived from the system's uncertain effects, damage to others, lack of adequate knowledge, and rules and administrative procedures. These results are confirmed in the interview with the TPO–aggregator, confirming that most of those expressing intentions have adopted the systems thus far.[4] The reduction accrues partly to the customer-centered culture and personnel with customer orientation and interdisciplinary know-how of the TPO–aggregator (Helms, 2016), which reaches beyond a change in

Table 6
Correlation among predictors.

	PBC1	PBC2	PBC3	PBC4	PBC5	PBC6	PB1	AB1	AB2	EB
PBC1		0.0048	−0.0144	0.0447	−0.0281	0.0253	−0.0411	−0.0478	0.0096	0.0641
PBC2	0.0048		0.0348	0.1029	0.4365	0.2630	0.0601	−0.0954	−0.0194	−0.0392
PBC3	−0.0144	0.0348		−0.3187	−0.0295	0.1999	0.0548	0.1072	0.1440	0.0844
PBC4	0.0447	0.1029	−0.3187		0.1555	−0.3411	−0.0582	−0.0094	−0.0412	0.0330
PBC5	−0.0281	0.4365	−0.0295	0.1555		0.1092	0.1072	0.0235	0.0871	−0.0211
PBC6	0.0253	0.2630	0.1999	−0.3411	0.1092		0.1167	−0.0554	0.1000	−0.0972
PB1	−0.0411	0.0601	0.0548	−0.0582	0.1072	0.1167		0.3678	0.5788	0.3816
AB1	−0.0478	−0.0954	0.1072	−0.0094	0.0235	−0.0554	0.3678		0.5035	0.3309
AB2	0.0096	−0.0194	0.1440	−0.0412	0.0871	0.1000	0.5788	0.5035		0.4726
EB1	0.0641	−0.0392	0.0844	0.0330	−0.0211	−0.0972	0.3816	0.3309	0.4726	
EB2	0.0663	0.0174	0.1123	−0.0895	−0.0009	0.0592	0.5166	0.3544	0.6417	0.5956
SSB	0.1468	−0.0872	0.00570	−0.1590	0.0470	0.1186	0.3664	0.2840	0.5138	0.3754
SB1	0.1634	−0.0983	0.0395	0.0196	0.0439	0.0192	0.3670	0.3217	0.5134	0.4941
SB2	0.0708	−0.1657	0.0295	0.0299	0.0509	−0.0377	0.4095	0.3617	0.5130	0.5318
POC1	0.1379	0.1203	−0.0503	−0.0328	0.1668	0.0498	−0.0603	−0.1679	−0.0798	−0.0770
POC2	0.1606	−0.0184	0.0571	−0.0427	−0.0187	0.0479	−0.0703	−0.1721	−0.0936	0.0317
Safety1	0.1851	0.0666	0.0648	0.0606	0.0660	0.1341	−0.1423	−0.0919	−0.1257	−0.0738
Safety2	0.1256	0.1010	0.0492	−0.0113	0.1398	0.0963	−0.1000	−0.1569	−0.1712	−0.0820
Unfami	0.1390	0.0813	0.0101	0.1098	0.0355	−0.0162	−0.0850	−0.1758	−0.1228	0.0409
Uncert	0.1526	0.1045	0.0078	0.1031	0.0854	0.0413	−0.1739	−0.1590	−0.2262	−0.0351

	EB2	SSB	SB1	SB2	POC1	POC2	Safety1	Safety2	Unfami	Uncert
PBC1	0.0663	0.1468	0.1634	0.0708	0.1379	0.1606	0.1851	0.1256	0.1390	0.1526
PBC2	0.0174	−0.0872	−0.0983	−0.1657	0.1203	−0.0184	0.0666	0.1010	0.0813	0.1045
PBC3	0.1123	0.0570	0.0395	0.0295	−0.0503	0.0571	0.0648	0.0492	0.0101	0.0078
PBC4	−0.0895	−0.1590	0.0196	0.0299	−0.0328	−0.0427	0.0606	−0.0113	0.1098	0.1031
PBC5	−0.0009	0.0470	0.0439	0.0509	0.1668	−0.0187	0.0660	0.1398	0.0355	0.0854
PBC6	0.0592	0.1186	0.0192	−0.0377	0.0498	0.0479	0.1341	0.0963	−0.0162	0.0413
PB1	0.5166	0.3664	0.3670	0.4095	−0.0603	−0.0703	−0.1423	−0.1000	−0.0850	−0.1739
AB1	0.3544	0.2840	0.3217	0.3617	−0.1679	−0.1721	−0.0919	−0.1569	−0.1758	−0.1590
AB2	0.6417	0.5138	0.5134	0.5130	−0.0798	−0.0936	−0.1257	−0.1712	−0.1228	−0.2262
EB1	0.5956	0.3754	0.4941	0.5318	−0.0770	0.0317	−0.0738	−0.0820	0.0409	−0.0351
EB2		0.5106	0.6343	0.4872	−0.0266	−0.0582	−0.0840	−0.0679	0.0050	−0.1000
SSB	0.5106		0.6758	0.6267	−0.0806	−0.0612	−0.0112	−0.1920	−0.0290	0.1702
SB1	0.6343	0.6758		0.6909	−0.1307	−0.0571	−0.0583	−0.0534	−0.0090	−0.0719
SB2	0.4872	0.6267	0.6909		−0.2059	−0.0876	−0.1254	−0.2087	−0.1450	−0.1771
POC1	−0.0266	−0.0806	−0.1307	−0.2059		0.1767	0.4230	0.4878	0.3550	0.3701
POC2	−0.0582	−0.0612	−0.0571	−0.0876	0.1767		0.4018	0.2470	0.4592	0.4847
Safety1	−0.0582	−0.0112	−0.0583	−0.1254	0.4230	0.4018		0.5934	0.4566	0.6353
Safety2	−0.0840	−0.1920	−0.0534	−0.2087	0.04878	0.3470	0.5934		0.4140	0.5958
Unfami	0.0050	−0.0290	−0.0090	−0.1450	0.3550	0.4592	0.4566	0.4140		0.6041
Uncert	−0.1000	−0.1702	−0.0719	−0.1771	0.3701	0.4847	0.6353	0.5958	0.6041	

adoption.

Model 2 excludes insignificant variables based on the AIC standard in the stepwise method, adopting PBC2, PBC3, PBC6, and Safety1 as predictors. The model fit improves with smaller AIC and BIC. PBC2, PBC6, and Safety1 remain statistically significant.

Model 3 further excludes PBC3 because it is statistically insignificant in Model 2. While the model fit deteriorates with larger AIC and BIC, PBC2, PBC6, and Safety1 remain statistically significant. For this reason, we use Model 3 for further investigation.

In Model 3, Safety1 is the highest value among the predictors, implying that the perceived risk of system quality is the highest barrier. PBC6 has the second highest, statistically significant negative value, suggesting that those who foresee moving within the contract period are less likely to adopt. A statistically significant negative value of PBC2

[4] Based on an interview with the CEO of MMEC on September 26, 2022.

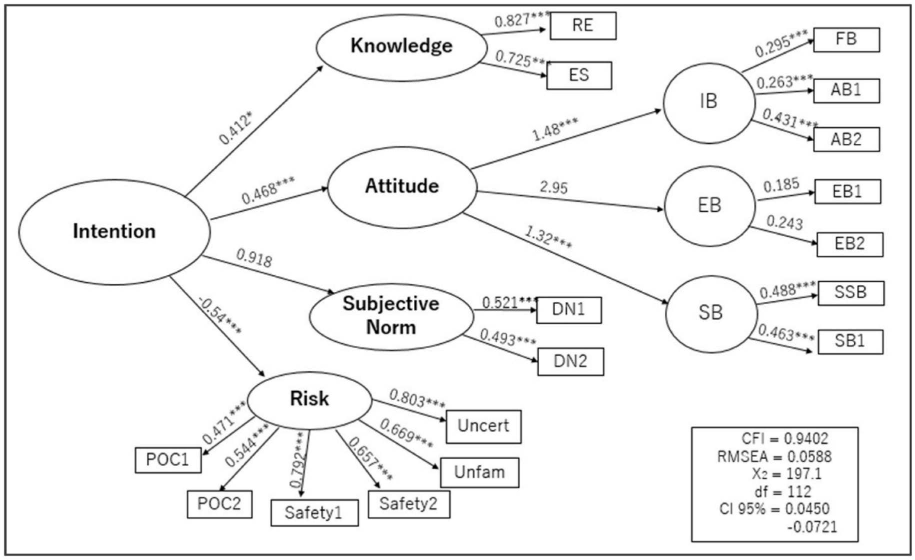

Fig. 4. Result of the SEM analysis.
Source: author

Table 7
Effects of PBC and statistically significant predictors of intention, as estimated by a logistic regression.

	1	2	3
PBC1	0.115 (0.284)		
PBC2	−0.549* (0.207)	−0.486** (0.172)	−0.464* (0.168)
PBC3	−1.1 (0.744)	−1.06 (0.653)	
PBC4	0.0177 (0.122)		
PBC5	0.216 (0.226)		
PBC6	−0.486* (0.186)	−0.372 (0.154)	−0.442** (0.151)
FB	0.114 (0.288)		
AB1	0.278 (0.266)		
AB2	0.163 (0.306)		
EB1	−0.376 (0.274)		
EB2	−0.0294 (0.34)		
SSB	0.148 (0.273)		
SB1	−0.0332 (0.342)		
SB2	−0.138 (0.329)		
POC1	0.0151 (0.236)		
POC2	0.176 (0.206)		
Safety1	−0.72* (0.263)	−0.526*** (0.157)	−0.493** (0.153)
Safety2	−0.00698 (0.263)		
Unfami	−0.146 (0.239)		
Uncert	0.237 (0.278)		
Intercept	2.78*** (1.75)	3.52*** (0.983)	2.31*** (0.637)
AIC	225.3	196.5	202.5
BIC	291.9	213.2	215.9

Note: The dependent valuable is the actual adoption.
*Significant at the 10% level, ** Significant at the 5% level, *** Significant at the 1% level.

financial structure from the homeownership model.

Second, the combined TPO–aggregation business model has limited influence on system adoption in old-aged or traditional-style houses and buildings where the PV–BTM battery system is known to trigger roof leaks. TPO companies have technological capabilities to fix such leaks; however, the additional expense discourages end users from adopting them.

Third, policy and regulations can significantly narrow the space that TPO–aggregators may use to improve the conflict of interest over the stability and reliability benefits for grid companies and resilience benefits for end users. The replacement of a FiT with a net energy billing angered adopters of solar PV without BTS battery systems (Table 8, adopter D), making it difficult for the TPO–aggregator to convince them to adopt BTM battery storage systems. The failure of a large-scale front-of-the-meter battery storage system demonstration project lost credibility for the municipality and any government-led RES-E projects thereafter with residents because the municipality propagated the benefits of backup power to convince residents to accept the project (Table 8, adopter B). The weak policy implementation of the updated RES-E target and the 2050 carbon neutrality leads to the low non-fossil value for non-hydro RES-E in the trading market. While the bidding price for renewable energy certificate (REC) has become higher from the outset, it is only less than 1.2 Eurocents per megawatt in April 2022 (J-Credit Scheme Secretariat, 2022). The price is less than one-tenth of the RES-E Guarantee of Origin certificate spot prices in the European market, which showed 19 Eurocent in 2013–2016 on average (Hulshof et al., 2019). The low REC price makes it difficult for the TPO–aggregator company to gain revenue and attract new customers from the new, differentiated business model, as represented in the statistically insignificant climate change mitigation benefits as the sociopsychological predictors of the intention of adopting PV-BTM battery systems (Fig. 4).

Finally, incumbent grid companies may block TPO–aggregators from gaining additional benefits from the new business model. They lobbied the central government to impose stringent regulations on grid stability, which de facto prohibits the TPO–aggregator from operating battery storage systems to supply incentive-based DR, not to mention to supply backup power to the incumbent vertically integrated utility, houses, and buildings suffering from outage during power outages in typhoon disasters[5] (Fig. 2). Incumbent grid companies may prevent TPO–aggregators from using customers' BTM battery systems to supply time-based DR by offering rough TOU prices, such as the one that differs only by peak (10–17 h), off-peak (23-7 h), and others at most (Okinawa Electric Power Company, 2019). The ORPC requires the TPO–aggregator to establish a joint venture to avoid the death spiral despite that the TPO–aggregator helps the OEPC to reduce the financial deficit that must be borne for assuming responsibility for securing universal service (Fujimoto, 2019a).

These policy responses and resistance from incumbent grid companies have blocked the TPO–aggregator from capturing the new values created through the combined TPO–aggregation business model and delivering them to end users to compensate for the low resilient benefits. The grid stability and reliability benefits are not discounted in the

[5] Based on an interview with the CEO of MMEC on September 26, 2022.

Table 8
Motivations and barriers in the semi-structured interviews by a coding analysis.

	Motivation	Barriers	Other Keywords
A	• Environmental awareness • Environmental education • Expectation for the island's future	None	• Importance of changing residents' mindset • Importance of energy interest and knowledge • Skeptical about the FiT
B	• Countermeasure against typhoon blackout	None	• Concerns about the past energy storage system project
C	• Interest in a storage battery • Countermeasure against typhoon blackout • Expectation for job creation and improvement of the island's economy	House damage	• Residential RET is still a 'luxury' for people • Skeptical about the FIT
D	• Expectation for life standard improvement • Countermeasure against blackout • Environmental awareness	None	• Concerns about the project of renewable energy with storage system, which has been pended now • Negative perception among residents toward renewable energy projects • Importance of changing residents' mindset
E	• Interest in PV system • Environmental awareness • Countermeasure against typhoon blackout	• Technological feasibility • Power generation in winter	• Past pending projects of renewable energy • Needs for accumulating know-how
F	• Reduction of social cost • Long-term business continuity • Reduction of utility cost and payback to facility users • Environmental awareness	None	• Concerns about the future social cost • Skeptical about the government because of the Fukushima nuclear accident

billing. The billing passes through the additional cost of battery storage in the form of higher upfront capital costs in the homeownership model and long-term contracts with a cancelation fee in the TPO model.

The above discussion brings three policy implications for the combined TPO-aggregation business model to work for mitigating the conflict of interest between grid stability and reliability, and the resilience of end users. First, the current ban on the use of ESS during power outages in typhoon disasters should be replaced with science-based grid regulations that reconcile the operation of ESS as backup power with grid stability. Once some methods are proven to operate ESS operations without triggering region-wide blackouts, the ban should be deregulated.

Second, more stringent climate and energy policies should be implemented that boost demand for the RES-E Guarantee of Origin certificate. The high REC prices enable TPO-aggregators to capture the non-fossil value and spend it on enhancing resilience.

Third, TOU prices should be detailed to offer opportunities for distributed BTM ESSs to supply time-based DR much more frequently. Given the power imbalance between incumbent grid companies and energy resource aggregators, and the high ratio of subsidiaries of the incumbent grid companies within the authorized energy resource aggregators,[6] the price for incentive-based DR can be lower even if it is determined by bidding. The low price squeezes the revenue sources of TPO–aggregators, disabling them from compensating for the value of resilience and addressing the remaining barriers to adoption. TOU prices can increase the revenue from time-based DR, compensate for the value of resilience, and mitigate the conflict of interest.

7. Conclusion and implications

PV-BTM ESSs are gaining recognition as net energy billing replaces FiT, and solar curtailment becomes prevalent. The combined TPO–aggregation business model could drive adoption because it reduces upfront capital costs, electricity bills, and technical risks and offers backup power to end users; however, the different types of benefits from PV–BTM ESSs and their distribution can raise a conflict of interest between grid companies and end users. Against this backdrop, this study explores how the TPO–aggregator model can address end users' intention and adoption as well as the conflict of interest and how policy and regulation influence the business model, taking Miyakojima Island in Japan as a case.

This study determines that the combined TPO-aggregation business model can effectively work for advancing adoption by reducing end users' risk perceptions if the combined TPO–aggregation business model entails business model innovation for servitization; however, the business model alone cannot address the underlying cause of the conflict of interest. Loss of credibility to government policy and regulations from local residents, the weak policy implementation of the updated RES-E target and the 2050 carbon neutrality, stringent regulations on the operation of backup power for grid stability during power outages, and restricted use of TOU prices block the business model from capturing non-fossil and resilience values, distributing them to end users, and accelerating adoption.

The empirical findings have three policy implications for the combined TPO-aggregation business model to work for changing the benefit-sharing in favor of end users. First, the current ban on the use of ESS during power outages in typhoon disasters should be replaced with science-based grid regulations that reconcile the operation of ESS as backup power with grid stability. Second, more stringent climate and energy policies should be implemented that boost demand for the RES-E Guarantee of Origin certificate. Third, TOU prices should be detailed to offer opportunities for distributed BTM ESSs to supply time-based DR much more frequently.

This study has two limitations. First, insignificant neighboring peer effects may accrue after the timing of the survey and interviews. We conducted them just before the PV–BTM battery storage systems started operation. No respondents had experienced damaged systems or the benefits of backup power during a power outage from natural disasters. In addition, Tesla's PowerWall, which is installed after our survey, increases the benefits of backup power.[7] The effects may prove to be significantly positive in future surveys.

Second, the effects of insignificant backup power on the adoption may be attributable to the residence location. Most of the respondents to the questionnaire survey were residents living on Miyakojima Main Island (Table 3), where power outages from typhoons are less severe than on remote islands. Conversely, respondents to the semi-structured interviews were residents living on a remote island who had already adopted solar PV without BTM ESSs under the homeownership model. These two groups may have different attitudes toward bill savings and

[6] One-third of the authorized wholesale energy resource aggregators are subsidiaries of incumbent grid companies (Agency for Natural Resources and Energy, 2022).

[7] Based on an interview with the CEO of MMEC on September 26, 2022.

backup power, which should be explored in the future.

CRediT authorship contribution statement

Ririka Yamashiro: Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Akihisa Mori:** Conceptualization, Supervision, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Akihisa Mori reports financial support was provided by the Japan Society for the Promotion of Science.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2022.113392.

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