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Factors Influencing Household Adoption of Rooftop Solar Power in the Philippines: An Empirical Analysis Using the Contingent Valuation Method

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Abstract: The Philippines possesses significant solar energy potential, yet the adoption of rooftop solar power (RTSP) among households remains limited despite its benefits in reducing electricity costs and contributing to the clean energy transition. This study investigates the determinants influencing households' willingness to adopt RTSP in Metro Manila and surrounding provinces, utilizing the contingent valuation method. Survey results indicate that economic factors, particularly the potential for electricity bill reduction, along with environmental considerations, are positively associated with adoption intentions. While a substantial portion of households (82%) expressed some level of intention to adopt RTSP, the figure drops to 20% when focusing exclusively on households with definitive adoption plans. This suggests that perceived returns on RTSP investments are insufficient to spur broader adoption without further intervention. Policy measures, including increased financial incentives such as enhanced net metering rates, the accreditation of RTSP providers to mitigate perceived risks, and the provision of low-cost financing options, are deemed necessary to enhance adoption rates. Additionally, other economic advantages, such as property value appreciation and enhanced roof durability, could be emphasized in future marketing and public awareness campaigns to strengthen the case for RTSP adoption. Greater government support is critical to unlocking the potential of RTSP in the Philippines and aligning household energy practices with national sustainability goals.

Keywords: Contingent valuation; Adoption determinants; Renewable energy; Rooftop solar power; Metro Manila; Philippines

1. Introduction

Electricity generation using fossil fuels results in large and concentrated amounts of carbon dioxide (CO_2), a major type of greenhouse gas that causes climate change. In 2021, global CO_2 emissions from energy combustion and industrial processes were estimated to be at a peak level of 36.3 gigatons (Gt), a 6% increase from 2020. This increase accompanied the rapid post-pandemic economic recovery in 2021, during which global domestic production expanded by 5.9% (IEA, 2022). CO_2 and other greenhouse gases can lead to the warming of the atmosphere and ocean, which in turn leads to rising sea levels. The World Meteorological Organization (WMO) reports that the years 2015-2021 were the seven warmest years on record, with global mean temperature in 2021 being 1.11 ± 0.13℃ above the pre-industrial (1850–1900) average. WMO also notes that global mean sea level reached a new record high in 2021, with an average increase of 4.5 mm/year during the years 2013-2021, compared to just 2.9 mm/year during 2003-2012 and 2.1 mm/year during 1993-2002 (WMO, 2022). Damages caused by climate change are enormous and manifold, including coastal erosion and flooding; saltwater intrusion in aquifer and freshwater bodies; increased frequency, intensity, and duration of droughts and typhoons; and altered ecosystems and habitats. Key economic sectors, such as agriculture, fisheries, construction, water and energy, and tourism, are highly vulnerable to climate change (IPCC, 2022). The social cost of CO_2 emissions, defined as the total loss in welfare resulting from an extra emitted ton of CO_2, is estimated to be about US$158-307, implying massive socioeconomic damages from climate change (Kikstra et al., 2021). The transition to clean renewable

energy (RE) for electricity generation is one major climate action area. But despite the highest ever annual growth in RE generation in 2021, post-pandemic electric power demand was met largely with the burning of coal (IEA, 2022), suggesting that efforts on the RE transition are wanting.

Solar energy is said to be the RE type that has the highest potential to replace fossil fuels in electricity generation. Much of the world's area has a theoretical solar energy potential of 4-8 kilowatt-hour (kWh) per m^2, which translates into an average daily practical photovoltaic (PV) potential of 3-5 kWh per kilowatt-peak (kWh/kWp) for 93% of the global population (ESMAP, 2020). Estimates from the International Renewable Energy Agency indicate that the cost of generating electricity from utility-level solar had dropped precipitously by 85% between 2010 and 2020 (Vetter, 2021). Further, estimates of global levelized electricity prices in 2020 reveal that utility-level solar has the least cost of $36 per MWh, compared to $40 for onshore wind, $112 for coal, and $164 for nuclear power in 2020 (Vetter, 2021). Beside utility-level solar power generation, solar panels can also be installed on building and house roofs. RTSP offers even more advantages, namely, (1) decentralized people-driven uptake and hence quick deployment, (2) reduced transmission loads due to decentralized electricity supply, (3) zero impact on land and ecosystems as the solar panels are installed on existing houses and buildings, and (4) broad participation of the people in the clean energy transition (Vetter, 2021). It is calculated that covering the entire 0.2 million km^2 surface area of all rooftops in the world with solar PV panels could theoretically generate 27 petawatt hours of electricity annually, which is even more than the combined electricity consumption of the world in 2018 (Joshi et al., 2021).

Located in the tropics, the Philippines is endowed with vast solar energy potential. Solar energy can be collected almost anywhere in the country, with peak sun-hours of about 4.5-5 hours on an average day (Ahmed, 2018). The United States National Renewable Energy Laboratory estimated an average daily solar potential of 5 kWh per m^2 for the Philippines (DOE, 2020). More recently, ESMAP (2020) put the country's theoretical and practical solar potential at 4.72 kWh per m^2 and 3.932 kWh/kWp, respectively. Further, the cost of solar power generation in the Philippines is becoming increasingly viable. Utility-scale solar power costs as low as PhP2.99 per kWh, while RTSP costs about PhP2.50 or 5.30 per kWh, depending on whether financing costs are excluded or included (Ahmed, 2018). These rates compare quite well with power generation costs from diesel-fired plants (PhP15-28 per kWh), coal-fired plants (PhP3.8-6.5), wind (PhP3.5), geothermal (PhP3.5-4.5), and run-of-river hydro (PhP3-6.2).

In the recently updated National Renewable Energy Program (NREP 2020-2040) of the Philippine government, the target share of RE in the power generation mix is set to 35% by 2030, and 50% by 2040. The 2040 target will require a total of 52,826 MW of new installed RE capacities, the bulk of which (27,162 MW, or 51%) are to be sourced from solar (DOE-REMB & NREB, 2022). Also included in the NREP 2020-2040 is the Expanded Rooftop Solar Program (ERSP), which aims to scale up solar energy production at the end-use level. Apart from helping meet the country's CO_2 emissions reduction commitment in the Paris Agreement, RTSP is seen as a solution to the high electricity prices that afflict Philippine households and businesses. Filipinos face the highest electricity prices among Southeast Asian countries due to an electricity pricing policy that transfers fuel price and foreign exchange risks to consumers. In 2020, average household electricity price in the Philippines was US$0.20 per kWh, the highest among Southeast Asian countries and way above Singapore's US$0.14, Thailand's US$0.12, Indonesia's US$0.10, Vietnam's US$0.08, and Malaysia's US$0.06 (UNESCAP, 2020). It is argued that the high electricity price, together with power shortages due to inadequate investments in power plants, would be the core driver of demand for RTSP in the Philippines (Ahmed, 2018). Yet, RTSP remains largely untapped in the country. In 2018, the Philippines Energy Regulatory Commission (ERC) reported about 1,400 customers with a total of 10 MWp net metering capacity (Ahmed, 2018). In 2023, net metering capacity nationwide had increased to 7,583 customers with 63 MWp rated capacity (Fuentebella, 2023). This latest net metering statistic, however, still represents a very minute portion of the Philippine electricity market, where the largest distribution utility, the Manila Electric Company (MERALCO), alone has 7.63 million customers (Statistica Research Department, 2023). Clearly, the uptake of RTSP in the Philippines needs to accelerate further.

This study examined the factors that influence household decisions to adopt RTSP. Understanding Filipino households' awareness and preferences for RTSP, and how these translate into adoption, could inform policy formulation, and program design and implementation strategies for the government's Expanded Rooftop Solar Program (ERSP). The household sector tops both the industrial and commercial sectors in terms of electricity consumption in the Philippines. For on-grid electricity sales, the residential sector's 41% share was trailed by the industrial sector's 31% and commercial sector's 25% shares. For off-grid electricity sales, the residential sector with a share of 61% was followed by the commercial sector with a share of 21% (DOE, 2020). Thus, the household sector has a key role in the ERSP. Through widespread RTSP adoption, Filipino households can simultaneously and effectively increase clean electricity supply capacity and lower electricity prices.

Literature on RTSP adoption highlights either the economic (see, for instance, Abdullah et al., 2017; Colasante et al., 2021; Mundaca & Samahita, 2020; Sardianou & Genoudi, 2013; Wee, 2016) or non-economic motivational factors (Ameli & Brandt, 2015; Arkesteijna & Oerlemans, 2005; Ecker et al., 2017; Wolske et al., 2018; Zhai & Williams, 2012). More recent studies, apart from identifying factors that influence RTSP adoption, also present

estimates of willingness to pay for household-level renewable energy technology (Hwang et al., 2023; Lan et al., 2021). However, up until the present, quantitative evidence on the predictors of and willingness to pay for RTSP adoption is still scarce, particularly in the context of developing southeast Asian countries.

This study employed the contingent valuation (CV) framework, a non-market valuation technique used in environmental economics, to investigate RTSP adoption in the Philippines, particularly in the country's main metropolis, the National Capital Region (also referred to as Metro Manila), and its neighboring urbanized provinces. These areas comprise the service area of MERALCO, the largest electric distribution utility company in the Philippines, accounting for 55% of the country's total electricity output/distribution (MERALCO, 2024). Specifically, the study aimed to accomplish the following tasks:

(1) Assess awareness and attitudes about climate change, RE, and RTSP;

(2) Estimate willingness to pay for RTSP;

(3) Perform binary logit regression to determine the factors – demographic, socio-economic, and awareness and attitudes – that influence RTSP adoption.

To the author's knowledge, this is the first study on household-level solar power adoption in the country. The survey or stated preference approach was earlier utilized by Palanca-Tan et al. (2023) in estimating Philippine households' willingness to pay for an increase in the share in the electricity generation mix of RE technologies, but not in the specific case of individual RTSP systems for households. Findings from this study can provide relevant inputs in the formulation of policies and programs to incentivize, and hence accelerate household RTSP adoption in the Philippines.

2. Literature Review

Earlier studies on RTSP adoption and demand highlight non-economic motivational factors. Arkesteijna & Oerlemans (2005) found that in addition to financial variables, basic knowledge and past environmental behavior are robust predictors of the probability of early adoption of clean solar electricity among Dutch residential users. Zhai & Williams (2012) likewise found that, apart from cost, maintenance requirements and environmental concerns influenced the solar power adoption and purchase decisions of homeowners in Arizona, USA. Using the Organization for Economic Cooperation and Development (OECD) household environmental behavior and attitudes survey data, Ameli & Brandt (2015) have likewise shown that positive environmental attitudes and beliefs (proxied by energy conservation practices and membership in environmental organizations), in addition to higher income and home ownership (as opposed to renting), increase the probability of the household investing in clean energy technologies. Furthermore, the study of Wolske et al. (2018) revealed that non-economic factors, namely, pro-environmental stance, consumption innovativeness, and perception of social support, are the primary drivers of RTSP adoption and that different ways of reframing the financial benefits of RTSP did not significantly affect the likelihood to respond positively to mock solar electricity advertisements. In a study by Ecker et al. (2017), the prospect of autonomy in providing for one's energy needs, that is, the ability to self-determine, control, and secure one's energy provisions, was shown to lead to decisions to adopt and purchase innovative energy systems, such as the RTSP.

There are also quite a number of studies that underline the importance of economic factors and incentives in RTSP adoption decisions. The findings by Wee (2016) reveal that in the case of Hawaii, the state with the highest number of per capita installations in the USA, RTSP was considered a home improvement that increases the value of the house by 5.4%. The survey results of Colasante et al. (2021) reveal that green energy self-consumption (electricity from one's own RTSP system), as opposed to energy purchase from fossil fuel-dependent generation and distribution utility companies, is a key factor in reducing electricity bills. They found that economic incentives are largely driving energy consumption choices and accordingly recommended the introduction of rewards (specifically, a bonus of 4 cents per kWh and a green premium of 10 cents per kWh) for self-consumed energy to enhance the development of solar power systems. Likewise, Mundaca & Samahita (2020) have shown that subsidies as well as environmental awareness significantly induce adoption in Sweden. On the other hand, the empirical results by Sardianou & Genoudi (2013) for Greece suggest that a tax deduction, relative to a subsidy, is a more effective financial policy measure to promote residential renewable energy technologies. They also found that income and education are positively related to adoption. In the case of Pakistan, Abdullah et al. (2017) found that despite substantial interest in the solar home system (81% of respondents), obstacles such as the high cost of solar panels and the lack of information and trust in suppliers and installers deter actual adoption, suggesting the need for government intervention in the provision of solar panels and information dissemination.

More recent studies do not only identify the determinants of adoption, but also present estimates of willingness to pay for end-use solar power. Lan et al. (2021) found that 33% of 300 households surveyed in the Daklak Province of Vietnam expressed intention to install RTSP, and were willing to pay US$1,240-2,220 for a RTSP system that suits their current electricity consumption. Awareness of the RTSP and government incentives were the major factors that raised the likelihood to install RTSPS, while environmental concerns and innovativeness

were less influential. Hwang et al. (2023) conducted a contingent valuation survey in South Korea to estimate the willingness to pay for a community solar business, a mechanism whereby community members or subscribers bear the cost of the solar power system and share the profit through off-sets in their electricity bills. They arrived at an average monthly willingness to pay of 25,572 won (USD 21.90), and found that willingness to pay was significantly higher for a respondent who is male, with PV business experience, and with higher income. In the case of Norway, where residential use of solar power systems has lagged behind other Scandinavian countries, Cherry & Sæle (2020) estimated that, on average, households are willing to pay 9,280 NOK for a solar power installation. Their also argued that household awareness, continuing technological advances, clarity of the grid tariff system, and effective regulatory and support programs can induce adoption and substantially raise residential solar power capacity.

Quantitative analyses of factors driving the adoption or non-adoption of RTSP, particularly in the developing countries of southeast Asia, are still scarce. And with findings varying across study areas, there is a need to investigate what factors matter for particular countries and contexts. This study employed the contingent valuation (CV) method to identify the determinants of RTSP adoption in the Philippines and estimate the willingness to pay for RTSP. CV has been applied increasingly in both developed and developing countries in estimating preferences for clean energy. Earlier CV studies on green electricity were mostly focused on developed and industrialized countries (Oerlemans et al., 2016). In recent years, however, CV research on RE in developing countries has remarkably increased. Kowalska-Pyzalska (2019) calculated Polish households' willingness to pay for renewable electricity to be about US$3.5 per month. Muhammad-Jawad & Abdul-Rahim (2020) found that urban households in Pakistan were willing to pay slightly more (US$0.33 per KWh) for green electricity than rural households (US$0.24 per KWh). Ayodelea et al. (2021) estimated that respondents in Nigeria were, on average, willing to pay an additional 5–10% of their current electricity bill for green electricity. Azlina et al. (2022) found that residential electricity users in the East Coast of Peninsular Malaysia were willing to contribute US$ 1.18 per month to a Renewable Energy Fund, while Han et al. (2020) estimated that Myanmar households were willing to contribute US$1 per month for research and development of Myanmar's solar energy. In the case of the Philippines, Palanca-Tan et al. (2023) found that Metro Manila households were willing to pay an additional 7.4–10.6% of their monthly electricity bill (equivalent to US$4.00–5.74 per month) for an additional 20% share of RE in the electricity generation mix. For the specific case of rooftop solar electricity supply, a household-based energy system, this paper is the first research on determinants of adoption and estimation of willingness to pay using the CV method.

3. Methodology

To determine household preferences for rooftop solar power, a CV survey was undertaken. CV is a stated preference technique in non-market valuation. In CV, people's willingness to pay for a non-marketed good or a good that has substantial externalities is elicited through a survey. The rooftop solar power system does not only benefit those who install and pay for the system in terms of reduced electricity bills and uninterrupted power supply (in case of power outage from the utility provider), it also yields positive environmental outcomes (e.g., cleaner air and climate change mitigation) and economic benefits (e.g., low dependence on imported fuels for energy generation leading to energy security and more stable exchange rates) for the wider public.

3.1 The CV Survey

A series of key informant interviews, focus group discussions, and pretests were undertaken to come up with the survey instrument used for this study. Internet advertisements and vlogs of RTSP suppliers and installers were used, together with findings from interviews with households with existing rooftop solar panels, to formulate awareness and opinion questions about households' perspectives on RTSP, indicators and reasons for purchase decisions, and issues and problems with the installation, operation, and maintenance of the solar panels.

Focus group discussions with households were conducted to test and validate the questionnaire for reliability. A series of pre-tests were undertaken to determine the appropriate minimum and maximum price (bids) of the RTSP. Based on the results of the pre-tests, the minimum bid was set at PhP50 and the maximum bid at PhP150 per kWp.

The final survey instrument consisted of four parts. Part 1 included questions on the latest monthly electricity bill, satisfaction with MERALCO service, and factors that have a bearing on electricity consumption (e.g., household size, house area, electric appliances, home business operations). Part 2 dealt with knowledge and opinion questions about climate change, RE, and RTSP. Part 3 contained the willingness to pay question, while Part 4 asked demographic and socio-economic questions about the respondent (age, sex, education, work status, and household income).

Part 2 contained five sets of questions to assess respondents' awareness and attitudes. Set A assessed knowledge (revealed) about climate change, RE, and electricity pricing, while Set B dealt with attitudes and opinions. Set C probed households' prior use of electricity-saving devices. Sets D and E focused on RTSP, with Set D dealing

with perceived benefits and costs of RTSP and Set E probing actual exposure and steps taken toward RTSP adoption.

For the valuation task in Part 3, the willingness to pay question format specified a price per kilowatt-peak (kWp) of a RTSP system. To facilitate quick and easy understanding of respondents and avoid respondents' aversion or confusion with highly technical engineering jargon, 1 kWp was simply described as the amount that can result in monthly electricity savings of PhP1,000. Further, instead of the common dichotomous "yes or no" answer format, respondents were presented with four answers to choose from – "definitely no", "probably no", "probably yes", and "definitely yes". This four-answer format substitutes for the certainty question after the willingness to pay question. Before answering the willingness to pay question, the respondent was reminded of the benefits that the RTSP system could offer, namely, savings in monthly electricity payments, environmental benefits (climate change mitigation, air pollution control), and avoidance of power outages.

The survey was conducted during the months of October-December 2023 by experienced CV survey enumerators. Only the household head or the spouse of the household head was asked to participate in the survey. The survey was conducted in the national capital region of the Philippines, Metro Manila, and its nearby provinces, which are within the service areas of MERALCO, the largest electric distribution utility company in the Philippines. Although its franchise area of 9,685 km^2 is only about 3% of the country's total land area, MERALCO accounts for 55% of total electricity output and distribution (MERALCO, 2024).

3.2 Data Analysis

Survey results were analyzed using the framework developed by Hanemann (1984) based on the random utility model. Indirect utility (U) was specified as a function of the respondent's answer to the CV question (which was equated to *1* for yes respondents, or *0* for no respondents), household income (Y), a vector of characteristics of the respondent and his/her household (M), and a component of preferences known only to the respondent and not to the researcher (ε). Assuming a utility function that is additively separable in deterministic (V) and stochastic preferences (ε): $U(B, Y, M, \varepsilon) = V(B, Y, M) + \varepsilon$, the probability ($Pr$) that a respondent would answer yes to the CV question at a specified price, B, could be written as:

$$\begin{aligned} Pr\,(Yes) &= Pr\,[\,V(1, Y-B, M) + \varepsilon_1 \geq V(0, Y, M) + \varepsilon_0\,] \\ &= Pr\,[\,V(1, Y-B, M) - V(0, Y, M) \geq \varepsilon_0 - \varepsilon_1\,] \\ &= F\varepsilon\,(\Delta V) \end{aligned} \tag{1}$$

$F\varepsilon\,(\Delta V)$, the probability that the random variable ε will be less than ΔV, represents the cumulative density function of the respondent's maximum willingness to pay. Assuming a linear indirect utility function and stochastic terms ε that are independently and identically distributed following a normal distribution with a mean of *0* and standard deviation of σ, Eq. (1) could be evaluated using the binary logit regression procedure.

Mean willingness to pay, $E(B)$, can be estimated using non-parametric and parametric procedures. Non-parametrically, $E_{NP}(B)$ can be calculated using the Turnbull formula (Haab & McConnell, 2002):

$$E_{NP}(B) = \sum_{j=0}^{n} B_j \left(F_j + 1 - F_j\right) \tag{2}$$

where, n is the number of specified prices, B_j is the specified price of the RTSP in the CV question, F_j is the proportion of "no" responses to bid price B_j, $F_0 = 0$, and $F_{n+1} = 1$. Using the parameter estimates derived from the binary logit model, parametric mean willingness to pay. $E_P(B)$, can be estimated as:

$$E_P(B) = -\beta X / \beta_B \tag{3}$$

where, β is a vector of estimated coefficients of all explanatory variables except the specified price (vector X) and β_B is the estimate for the bid or price coefficient.

4. Results and Discussion

4.1 Respondents' Profile

A total of 403 respondents were generated for the study, 227 (56%) of whom are from Metro Manila and the rest from the neighboring provinces of Metro Manila that are within the service areas of MERALCO. Table 1 presents the summary profile of respondents. The average age of the respondents is 50 years, and 32% are male. The majority (63%) of respondents are college graduates, and a substantial proportion (27%) have graduate

degree(s). In terms of work status, the majority (59%) are permanent employees, 14% have their own business, and 10% are freelance professionals. Only 3% are contractual employees. The 14% who are retired or unemployed are mostly retired with pensions and financial investments. Since only households residing in structures, preferably single detached, that have roofs on which solar panels can be installed were invited to participate in the survey, the survey effectively was confined to the middle- and high-income groups. Low-income households in informal settlement areas (squatters) and middle- and high-income households residing in condominium buildings were excluded from the sampling frame. Consequently, the average income of the respondents amounts to PHP90 thousand. The middle- and high-income status of the respondents is also reflected in the educational attainment and work status data, as well as house ownership. A substantial 68% of the respondents own the house where they live, 14% live in a house owned by relatives, and the remaining 18% are renting. On average, each household has five members.

The second panel of Table 1 contains the variables related to the household's electricity consumption. The average electricity bill of respondents' households is PhP6,366 with a standard deviation of PhP6,651, reflecting wide variability as in the case of income. On average, each respondent's house has two floors with a total floor area of 149 m^2, two television sets, four electric fans, two air conditioning units, and one refrigerator/freezer. Only 13% of the households are operating a business at home. In the largely urbanized service area of MERALCO, power outages are somewhat controlled, with almost three-fourths of respondents experiencing only 1–5 times power outages in a year and 14% experiencing no power outage at all. Only 8% indicated 6-8 power outages in the past year, and a meager 3% indicated more than 10. On average, the respondent households are somewhat satisfied with the services of the distribution company, MERALCO, with an average satisfaction rating of 3.57.

Table 1. Respondents' demographic and socio-economic profile, n=403

Variable	Description	Mean (Std Deviation)
	Socio-economic profile of respondents	
Age	Number of years	49.99 (12.23)
Sex	Proportion of respondents who are male	0.3201
Educational attainment	Proportion of respondents with	
	No diploma	0.0025
	Elementary graduate	0.0025
	High School graduate	0.0620
	Vocational	0.0323
	College graduate	0.6303
	Graduate (Masters/Doctoral)	0.2705
Work status	Proportion of respondents who are	
	Permanent employee	0.5856
	Contractual employee	0.0298
	Freelance professional	0.1017
	Own business	0.1439
	Retired/unemployed	0.1390
Monthly household income	PhP	90,323 (70,904)
Household size	No of household members	4.97 (2.36)
Residence	Proportion of respondents residing in Metro Manila	0.5633
House ownership	Proportion of respondents	
	Own	0.6774
	Renting	0.1861
	Owned by a relative	0.1365
	Electricity consumption-related variables	
Monthly electricity bill	PhP	6,366 (6,651)
House floor	Number of floors	1.89 (0.77)
House area	m^2	149.13 (126.54)
Television sets	Number of units	1.73 (1.03)
Electric fans	Number of units	3.67 (2.25)
Air-conditioning units	Number of units	1.77 (1.56)
Refrigerators/freezers	Number of units	1.12 (0.63)
Business at home	Proportion of respondents	0.1266
Power outage	Number of power outages during the last 12 months (proportion of respondents)	
0 time		0.1365
1-5 times		0.7444
6-10 times		0.0844
More than 10 times		0.0347
Satisfaction with MERALCO services	Scale of 1-5, where 1 is not satisfied at all and 5 is completely satisfied	3.57 (0.94)

4.2 Awareness and Opinions

Respondents' knowledge about global warming, RE, and electricity pricing was probed by asking respondents to agree, disagree or indicate "not sure" to eight statements, two of which (statements A4 and A5) are false. This was done to come up with an indicator of revealed knowledge, rather than stated or self-assessed knowledge. The "agree or disagree" answer format was used instead of the "true or false" format so as not to make the question sequence appear like an exam which can be offensive or intimidating to respondents. The proportions of correct answers as well as "not sure" answers for each statement are given in Table 2. The largest proportion of correct answers was obtained for statement A2. Almost all (91%) of respondents are aware of the negative impact of global warming in terms of stronger and more frequent typhoons. The cause of global warming, however, appears to be a little less known to the people – with a slightly lower proportion (85%) of respondents correctly agreeing with the statement that CO_2 emissions cause global warming. Even less is the proportion of respondents (81%) who are aware that CO_2 emissions result in air pollution. Remarkably, respondents are more knowledgeable on the economic aspects of electricity supply and pricing, and the implication of RE therein. The large majority are aware that the devaluation of the Philippine peso raises electricity price (88% of respondents), and that RE can reduce the country's dependence on imports for electricity generation (87%). Much less known to the respondents are specific technical details about RE technologies. Less than the majority (48%) are aware that coal currently accounts for the largest share in electricity generation in the country. Only slightly more than a third (37%) correctly disagreed with the statement that coal power plants generate less CO_2 than geothermal plants. Respondents also appear to be not sufficiently aware of the difference between large-scale and small-scale hydropower in terms of environmental impacts as a measly 10% of respondents correctly identified statement A4 as incorrect. The relatively big proportions of "not sure" answers for statements A3-A5 further reflect limited knowledge on technical details about RE. Over-all, the average number of correct answers of respondents is four out of eight statements, indicating that awareness on all aspects of the global warming-RE-electricity nexus is rather inadequate and needs to be improved.

Table 2. Revealed knowledge about global warming, renewable energy, and electricity pricing

Statement	Proportion (%) of	
	Correct Answers	"Not Sure" Answers
A1. Carbon dioxide emissions cause global warming	84.86	13.15
A2. Global warming can lead to stronger and more frequent typhoons	91.32	7.44
A3. Currently, the biggest source of electricity in the Philippines is coal power plants	48.14	39.70
A4. Large-scale hydropower plants are more environment-friendly than small-scale hydropower plants	10.17	46.15
A5. Coal power plants generate less carbon dioxide emissions than geothermal power plants	36.97	45.91
A6. Renewable energy can reduce the Philippines' dependence on imported oil to produce electricity	86.60	11.17
A7. Carbon dioxide emissions cause air pollution	81.39	14.39
A8. An increase in the peso-dollar exchange rate (for example, from PhP55 to PhP60) can lead to an increase in the price of electricity in the Philippines	88.34	8.68
Number of correct answers per respondents – Mean (std deviation)	4.17 (1.07)	

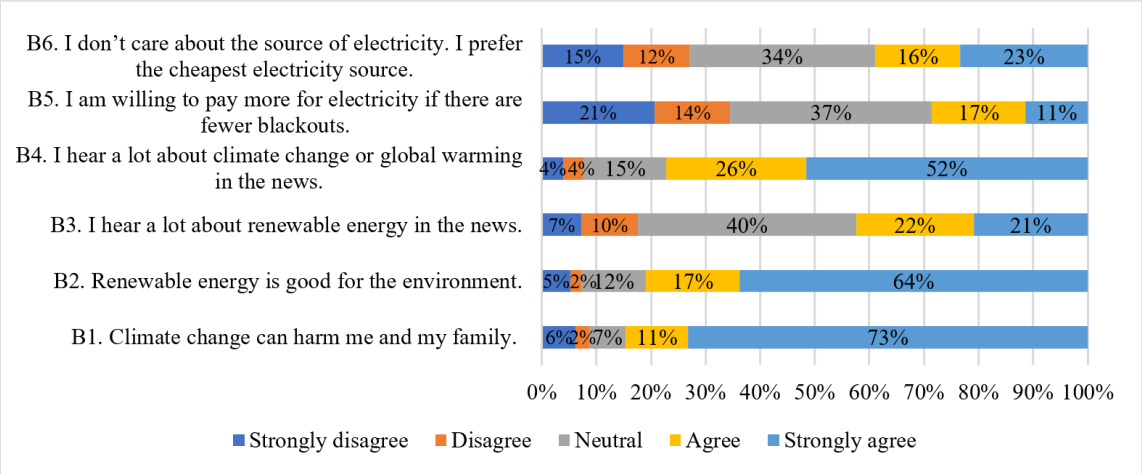

Figure 1. Attitudes and opinions about climate change, renewable energy, and electricity pricing

On the other hand, respondents' attitudes and opinions pertaining to climate change, RE, and electricity pricing were probed by asking them to agree or disagree with statements using a five-point scale (Figure 1). Most respondents think that climate change can harm his/her family (85% - combined proportions of "agree" and "strongly agree" answers), and that RE is good for the environment (81%). While more than three-fourths (77%) of respondents believe that they hear a lot about climate change in the news, less than a majority (42%) hear a lot about RE. Only a very small proportion of respondents are amenable to an increase in the price of electricity, even if this would reduce power outages (29%), and if the price hike is aimed at inducing power saving behavior (16%). As seen in Table 1, power outage is not a major issue in much of the survey area. And the already very high electricity price in the Philippines makes people generally averse to power price increases.

Three sets of questions focusing on potential markers for RTSP adoption were presented to the respondents. First, respondents were asked about their use of electricity-saving devices and appliances at home. Figure 2 reveals that 65% of the surveyed households have inverter refrigerators, 57% use inverter air conditioning, less than a third (31%) have solar lights, and very few (2%) have used energy-saving paint.

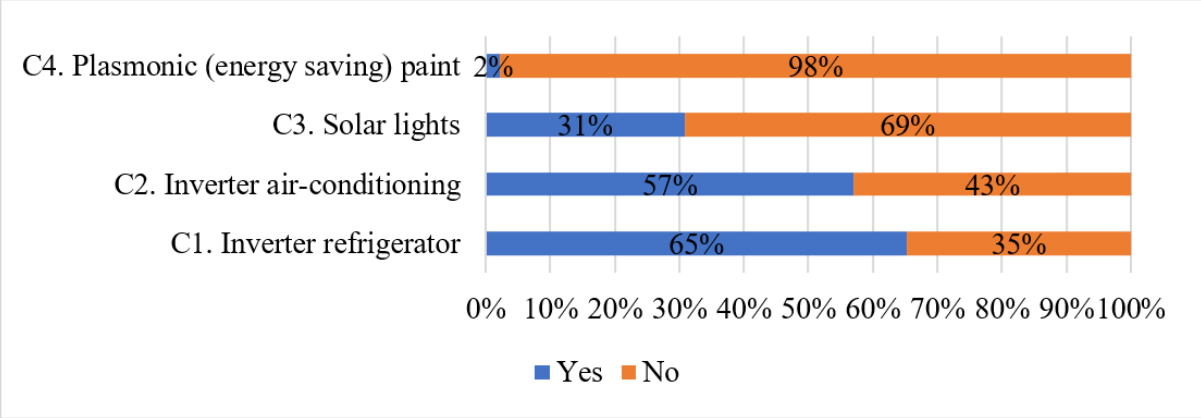

Figure 2. Use of energy-saving devices

Second, respondents were presented with statements about the potential impact and cost of RTSP with which they were asked to agree or disagree using a five-point scale. Survey results presented in Figure 3 reveal that the most recognized benefit from RTSP is the reduction in monthly household electricity bill (with 80% of respondents agreeing with statement D1). The other private benefits that may accrue to owners of RTSP are less known – only 67% think that RTSP can raise the house value, and an even lower proportion (46%) believe that RTSP can serve as protection for the roof. Nonetheless, 75% of the respondents believe that RTSP is a viable long-run investment, even when a substantial majority (67%) think RTSP is very expensive. RTSP suppliers and installers' advertisements highlighting attractive return on investments (ROI) of 3-5 years and the long lifespan (25 years) of the solar panels could have led to this impression among Filipino households. The positive externalities of RTSP are equally recognized, with at least three-fourths of respondents agreeing that RTSP can help solve global warming (75%), protect the environment (77%), and enable households to contribute to the preservation of nature and humanity (78%). Further, it is remarkable that the majority (62%) of respondents are optimistic that solar will be the main energy source in the future, even when government support for this energy source is perceived as inadequate (only 10% of the respondents disagreed with the statement that the Philippine government is not promoting the use of RTSP).

Third, a set of "yes-no" questions on exposure and concrete steps undertaken toward RTSP adoption was presented to the respondents. Figure 4 reveals some considerable interests in and exposure to RTSP, as a slight majority of respondents claim to have some background and/or interest in electronics, solar power, and RE (63%), have watched vlogs on solar power systems (57%), have friends and/or relatives with RTSP and have discussed about it with them (57%), and have checked the details of RTSP advertisements (51%). Some word-of-mouth marketing appears to be happening, with 44% of respondents claiming that friends, relatives, and/or house contractors have encouraged them to install RTSP. About 28% of the respondents have gone to the extent of asking for price quotations from RTSP supplier(s) and installer(s). Nonetheless, awareness of the two government incentive programs is found to be very limited. Only about 36% of the respondents are aware about the net metering program, and a very small proportion (5%) of respondents know that low-interest loans from the government's Home Development Mutual Fund, popularly known as the PAG-IBIG Fund, can be availed of for RTSP installation.

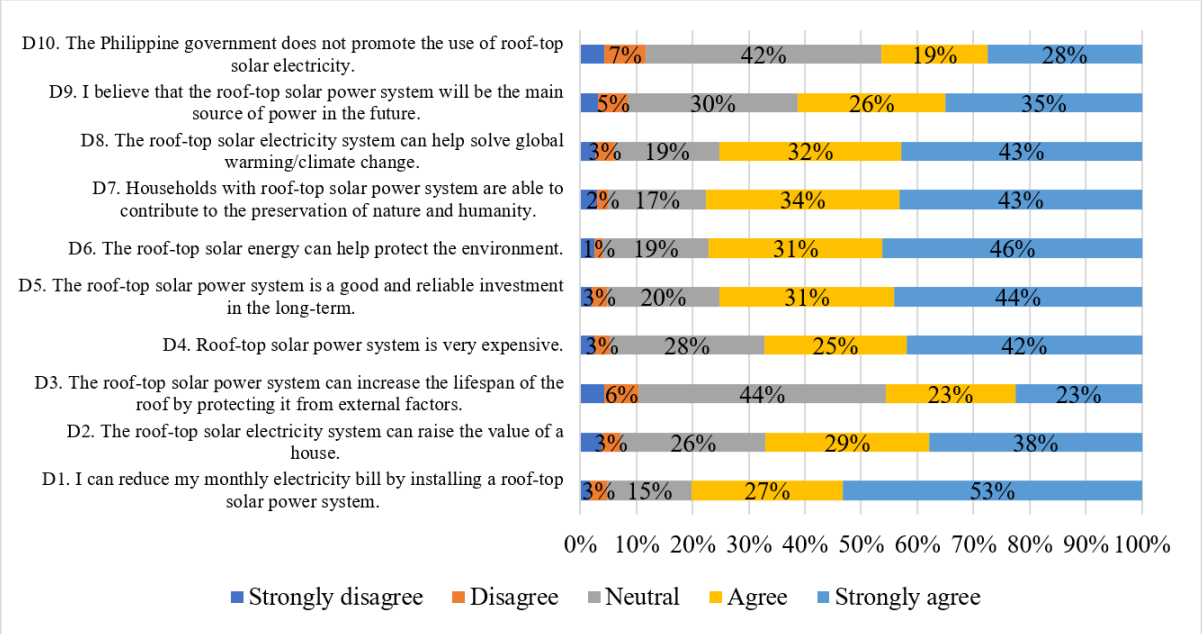

Figure 3. Awareness and opinions about roof-top solar power system

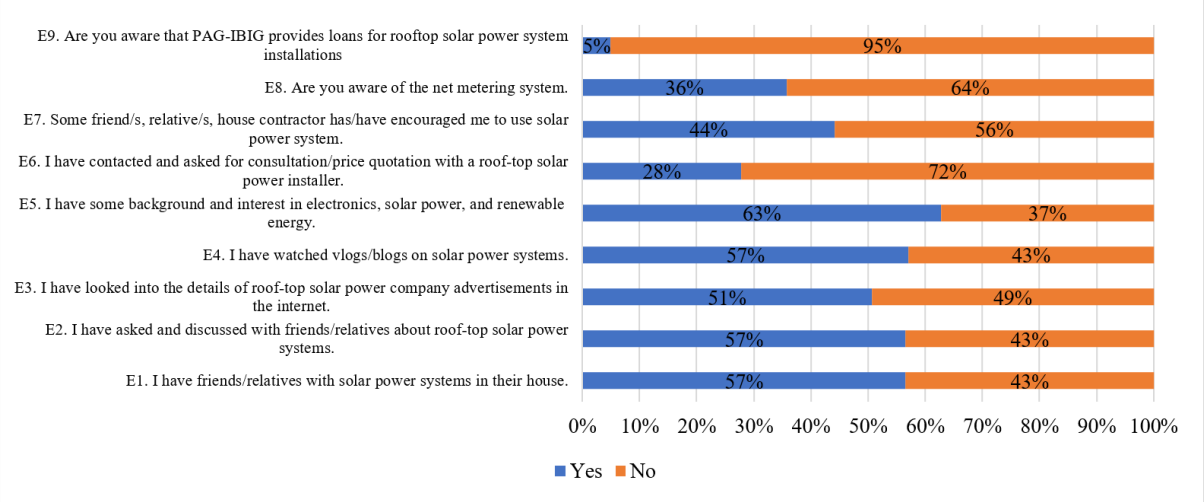

Figure 4. Exposure to and concrete steps toward RTSPS adoption

4.3 Willingness to Adopt and Pay for RTSP

Table 3 shows the proportion of "yes" answers by bid (price) level. The proportion of combined "probably yes" and "definitely yes" answers ranges from 90% for the lowest specified RTSP unit price of PhP50 per kWp to 79% for the highest price of PhP150,000. If only "definitely yes" answers are considered, the proportion substantially drops to just 27% for the lowest price, and 21% for the highest price. Three observations can be made. One, the high proportion of combined yes answers is largely accounted for by yes responses that are not 100% sure. Two, the proportion of yes answers does not substantially change with different price levels. And three, the proportion of yes answers does not monotonically decrease with the price.

Results of the binary logit regressions presented in Table 4 corroborate the last two observations. Price does not systematically influence the willingness to adopt and pay for the RTSP. This suggests that price is not the lone economic factor for the decision, and quality features such as brands and specifications of materials, maintenance service provisions, guarantees, and reputation of installers may be as relevant as, if not more relevant than, price. This may be particularly true for RTSP, a consumer-based electricity-generation system that is still at an early stage of development and commercialization in the Philippines.

Table 3. Willingness to adopt and pay, by bid (price) level

Bid (Price per 1kWp)	Proportion (%) of		
	Probably Yes	Definitely Yes	Probably & Definitely Yes
50,000	62.50	27.50	90.00
75,000	67.90	11.11	79.01
100,000	60.49	20.99	81.48
125,000	62.96	18.52	81.48
150,000	57.50	21.25	78.75

Table 4. Binary logistic regression results, combined "probably yes" and "definitely yes" answers

Explanatory Variables	Regression 1		Regression 2	
	Odds Ratio	z-value	Odds Ratio	z-value
Price	0.9940	-1.60	0.9942	-1.47
Monthly electricity bill	1.001	1.73*	1.001	2.49**
Age			0.9869	-1.08
Sex			0.9147	-0.30
Education			0.9964	-0.01
Revealed knowledge			1.0469	0.52
Metro Manila residence			0.4715	-2.51**
Own house			1.3216	1.36
Home business			0.4942	-1.82*
Power outage			1.0470	0.77
Log likelihood	-186.08		-178.99	
LR chi2(2)	6.14		20.32	
P > chi2	0.0465		0.0264	

*10% level of significance, **5% level of significance

As the price variable does not have a statistically significant coefficient, only the non-parametric mean willingness to pay (WTP) can be derived using the Turnball formula. If both "probably yes" and "definitely yes" answers are considered as yes answers, the mean WTP is PHP 124,395. If only the "definitely yes" answers are considered, the mean WTP estimate is considerably lower at PhP 18,239. This may suggest that for households to seriously consider adoption of RTSP, the effective price may have to be reduced substantially for the households. Thus, the Philippines may have to wait for further drops in the global price of solar panels and other materials, and/or the Philippine government may have to embark on an extensive program of incentives that will result in a substantial drop in the effective price of RTSP to the households.

Demographic and socio-economic variables are included in the binary logit regression to identify respondent household characteristics that influence the decision to adopt RTSP. Only the regression runs with the combined "probably yes" and "definitely yes" answers yield statistically significant odd ratios (Table 4). Monthly electricity bills have a significant positive influence on RTSP adoption. There are two explanations for the positive relationship between electricity consumption and the likelihood to consider RTSP adoption. One, savings in monthly electricity bills is viewed as the primary private benefit from RTSP, and hence, higher electricity consumption induces adoption. Two, the electricity bill is a proxy for household income or capacity to pay, which according to economic theory is positively related to demand. Remarkably, Metro Manila residents are less likely to adopt RTSP. The more severe congestion in Metro Manila compared to its neighboring urban areas could be discouraging RTSP adoption due to concerns of interference. Those with businesses at home are also less likely to install RTSP. Plausibly, returns to RTSP investments are not seen to be as attractive as returns to business investments, so they would rather use limited financial resources for their business needs. Respondents' characteristics, namely, age, sex, education, and revealed knowledge on global warming, RE, and electricity pricing (measured in terms of the number of correct answers), are not significant determinants of RTSP adoption. A power outage is likewise not a statistically significant factor. Because Metro Manila and its neighboring cities are the major economic districts in the country, they have been the priority areas for power supply distribution, and hence frequent power interruption has not been a big issue in recent years, as revealed earlier in Table 1.

4.4 Markers and Indicators of RTSP Adoption

Separate binary logit regressions were run with the awareness and opinion variables generated from the survey to identify statistically significant indicators of adoption and pre-adoption behavior, as well as check for consistency of the adoption response.

Results shown in Table 5 suggest that use of energy-saving devices is not a significant predictor of RTSP adoption. This may imply that these energy-saving devices are viewed neither as substitutes nor complements for RTSP. Though use of these devices results in a lower electricity bill, the same benefit that RTSP offers, this is just

a minor reason compared to the main purpose of the purchase, which is the use of the device.

Table 5. Separate binary logistic regressions, use of household energy-saving devices

Energy Saving Device	Odds Ratio	
	Combined "Probably Yes" and "Definitely Yes"	"Definitely Yes"
C1. Inverter refrigerator	1.07	0.98
C2. Inverter air-conditioning	0.94	1.24
C3. Solar lights	0.80	1.03
C4. Plasmonic (energy saving) paint	1.76	1.16

Among statements that pertain to opinions regarding climate change, RE, and electricity pricing, statements B2 and B4 have statistically significant odd ratios (Table 6). Respondents who believe that RE is good for the environment and who hear a lot about climate change in the news are more likely to adopt and be willing to pay for RTSP.

Table 6. Separate binary logit regressions: Opinions on climate change, renewable energy, and electricity pricing

Explanatory Variable	Odds Ratio	
	Combined "Probably Yes" and "Definitely Yes"	"Definitely Yes"
B1. Climate change can harm me and my family	1.17	1.01
B2. Renewable energy is good for the environment	1.45***	1.62***
B3. I hear a lot about renewable energy in the news	1.19	1.19
B4. I hear a lot about climate change or global warming in the news	1.31**	1.31**
B5. I am willing to pay more for electricity if there are fewer blackouts	1.10	1.13
B6. I don't care about the source of electricity. I prefer the cheapest electricity source	1.03	0.90
B7. The price of electricity should be increased to encourage electricity-saving practices	1.06	1.04

**5% level of significance, ***1% level of significance

Table 7. Separate binary logit regressions: Awareness and opinions about RTSP as adoption pointers

Explanatory Variable	Odds Ratio	
	Combined "Probably Yes" and "Definitely Yes"	"Definitely Yes"
D1. I can reduce my monthly electricity bill by installing a roof-top solar power system	1.27*	1.82***
D2. The roof-top solar electricity system can raise the value of a house	1.20	1.54***
D3. The roof-top solar power system can increase the lifespan of the roof by protecting it from external factors	1.13	1.25**
D4. Roof-top solar power system is very expensive	0.89	1.00
D5. The roof-top solar power system is a good and reliable investment in the long-term	1.55***	2.27***
D6. The roof-top solar energy can help protect the environment	1.20	1.59***
D7. Households with roof-top solar power system are able to contribute to the preservation of nature and humanity	1.08	1.57***
D8. The roof-top solar electricity system can help solve global warming/climate change	1.31**	1.84***
D9. I believe that the roof-top solar power system will be the main source of power in the future	1.30**	1.70***
D10. The Philippine government does not promote the use of roof-top solar electricity	0.92	1.21*

*10% level of significance, **5% level of significance, ***1% level of significance

Conceivably, knowledge and opinions, particularly about RTSP, are much better indicators of RTSP adoption behavior (Table 7). Respondents' recognition of the benefits—both private (D1-3, D5) and social (D6-8)—significantly raises the likelihood of sure adoption. The pointer that has the greatest impact on the probability of sure adoption is Statement D5 (RTSP is a good and reliable investment in the long term), followed by D8 (RTSP can solve global warming) and D1 (RTSP will reduce monthly electricity bill). Recognition of all private and

social benefits leads to definite RTSP adoption. On the other hand, only the belief that the RTSP is a good and reliable investment in the long run, will be the main source of power in the future, can reduce electricity bills, and can contribute to climate change mitigation can increase the likelihood of combined "probably yes" and "definitely yes" answers by 1.55, 1.30, 1.27, and 1.31, respectively. The secondary private benefits (home value increase and roof protection) do not substantially raise the likelihood of combined yes answers. Whether the respondent thinks that RTSP is very expensive does not significantly influence RTSP adoption, which is consistent with the earlier result that price does not significantly affect WTP.

Expectedly, exposure and steps commonly undertaken prior to the purchase of a good or service (statements E1-7 in Table 8) significantly point to sure adoption ("definitely yes" answers). Best pointers are having checked the details of RTSP suppliers and installers' advertisements (odds ratio of 3.20), and encouragement of relatives/friends/house contractors (2.54). These results are consistent with Mundaca & Samahita (2020) which underline peer effects in RTSP adoption. Having asked for a price quotation has a lower odds ratio (1.76) than having checked the details of RTSP advertisement (3.2) presumably because the price quotation might have turned out to be restrictive for some. Of the two existing government support programs for RTSP, only net metering appears to affect RTSP adoption. Awareness of the net metering program increases the likelihood of adoption. Availability of PAG-IBIG loans for RTSP, and background and interest in electronics and solar power do not increase the likelihood of yes answers.

However, these exposure and steps do not systematically point to general yes answers (combined "probably yes" and "definitely yes"), which may suggest the extent of uncertainty of the general yes answers.

Table 8. Separate binary logit regressions: Pre-adoption exposure and actions as adoption pointers

Explanatory Variable	Odds Ratio	
	Combined "Probably Yes" and "Definitely Yes"	"Definitely Yes"
E1. I have friends/relatives with solar power systems in their house	1.13	1.66*
E2. I have asked and discussed with friends/relatives about roof-top solar power systems	0.92	1.66*
E3. I have looked into the details of roof-top solar power company advertisements in the internet	1.35	3.20***
E4. I have watched vlogs/blogs on solar power systems	1.52	1.62*
E5. I have some background and interest in electronics, solar power, and renewable energy	1.09	1.29
E6. I have contacted and asked for consultation/price quotation with a roof-top solar power installer	1.19	1.76**
E7. Some friend/s, relative/s, house contractor has/have encouraged me to use solar power system	1.50	2.54***
E8. Are you aware of the net metering system	0.98	2.25***
E9. Are you aware that *PAG-IBIG* provides loans for rooftop solar power system installations	1.25	1.37

*10% level of significance, **5% level of significance, ***1% level of significance

5. Conclusions

Through RTSP adoption, households become both producers and consumers of electricity, enhancing electricity supply to meet the needed increase in power generation capacity and effectively lowering electricity costs for themselves and for the whole economy. RTSP makes possible broad public participation in the transition to clean energy and a shift away from government and power company-centered electricity supply. This paper examined the factors—demographic, socio-economic, and awareness and attitudes—that contribute to the likelihood of RTSP adoption by households in Metro Manila and the surrounding provinces, which comprise the service area of MERALCO, the largest electricity distribution utility in the Philippines.

On awareness and opinions, the findings from the survey can be summarized as: (1) Over-all knowledge about the climate change-RE-electricity nexus is rather inadequate and needs to be improved; (2) Respondents are generally concerned about climate change and its detrimental effects; (3) Respondents are mostly averse to increases in the price of electricity as it is already currently very high; (4) Electricity bill savings is the most recognized private benefit from RTSP, other private benefits – house value appreciation and roof protection are much less known; (5) Nearly as recognized as the electricity saving benefit are the environmental benefits of RTSP – protection of nature and the environment, and climate change mitigation; and (6) There is low awareness of the two government support programs for RTSP – net metering and the low interest PAG-IBIG loan for RSTP.

On the determinants of RTSP adoption, the main findings are as follows: First, the price of the RTSP does not systematically influence the willingness to adopt and pay the specified bid or price of the RTSP, suggesting that other economic factors—quality features such as brands and specifications of materials, maintenance service

provisions, guarantees, and the reputation of installers—may be confounding the decision process. RTSP is still at an early stage of development and commercialization in the Philippines, and hence a lot of uncertainties obscure the adoption and purchase decision. Second, the monthly electricity bill has a significant positive influence on RTSP adoption. Higher electricity consumption increases the need to reduce electricity payments to MERALCO through RTSP, as well as indicates a higher capacity to pay for RTSP. Third, relative to knowledge about climate change and RE in general, awareness and opinions about RTSP are much better indicators of RTSP adoption behavior. Knowledge of both private and social benefits is significantly correlated with RTSP adoption.

Survey results point to considerable RTSP adoption potential if both "probably yes" and "definitely yes" answers are considered. But when only "definitely yes" answers are considered, adoption and mean willingness to pay drop substantially. While firm intention to adopt is significantly correlated with knowledge of roof protection and house value appreciation—the other two private benefits from RTSP—tentative adoption is not. This finding may suggest the need to highlight these two other private benefits in RTSP information dissemination and marketing campaigns. Furthermore, the very low mean willingness to pay if only "definitely yes" answers are considered suggests that for more households to seriously consider adoption (that is, for a widespread use of RTSP), the returns (private benefits less cost) to household RTSP investments may have to be raised substantially. This may necessitate greater government mediation in the household-level RTSP sector. For instance, the gap between the rate charged for electricity sourced from the grid (referred to as the import price in the MERALCO bill) and the rate for excess RTSP electricity sent to the grid (the export price) must be reduced. Based on a May 2023 MERALCO bill of a RTSP adopter, the export price of PhP7.67 per kWh is just about two-thirds of the import price of PhP12.75 per kWh. Raising the import price will increase the electricity bill savings from RTSP, most particularly for households that normally consume less electricity (as members are out of the house for work or school) during the daytime when electricity is generated by RTSP while consuming more electricity at night when solar electricity generation is zero. The government must also immediately undertake a program of accreditation and development of a database of RTSP providers to reduce risk-related costs of RTSP uptake. The government likewise needs to promote the development of competitive commercial financing schemes for RTSP, such as the leasing model, which a few RTSP providers are now offering to lower up-front costs for customers. As the low-interest PAG-IBIG loans are primarily earmarked for low-cost housing, there is also a need to inform the public that RTSP is categorized and prioritized in the home improvement provision of the Home Development Mutual Fund.

For future research, the attribute-based choice experiment (CE) method may be employed to further investigate RTSP adoption behavior. The use of the CV method in this paper constrained the analysis to a generic RTSP good without specifications of quality and materials, maintenance service provisions, guarantees, and RSTP installers' reputations, which could have caused the absence of a systematic price effect. The CE method can investigate trade-offs between money and the different levels of attributes of RTSP and hence allow the estimation of WTP for specific attributes of a RTSP system.

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Informed Consent Statement

Informed consent was obtained from survey respondents involved in the study.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare no conflict of interest.

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