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Exploring the Impact of Housing Characteristics on Residential Photovoltaic Adoption in Hong Kong: A Comparative Survey of Housing Types and Homeownerships

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Abstract: The global shift towards sustainable energy practices underscores the importance of residential photovoltaic (PV) adoption, a trend that has been gaining more attention in Hong Kong. Despite this, existing research in this area lacks quantitative analysis, with a particular deficiency in statistically robust surveys across diverse residential sectors in Hong Kong and in comparative studies between PV installers and non-PV installers. Addressing these gaps, this study employed a comprehensive questionnaire survey to collect data from a representative sample of both PV installers and non-PV installers regarding their housing types and homeownerships, followed by chi-square tests of independence to explore the demographic distinctions influencing residential PV adoption. The findings highlight significant variance in adoption rates between homeowners and tenants, with a noticeable inclination for PV installation among owners of independent houses. In contrast, co-tenants in residential flats demonstrated a lower propensity for PV adoption. These insights provide a crucial understanding of the factors that affect PV system uptake and could inform the formulation of targeted policies to boost renewable energy integration in urban residential settings.

Key words: Residential Photovoltaic Adoption; Housing Characteristics; Comparative Study; Questionnaire Survey; Chi-square Test of Independence

1. Introduction

The urgency of climate change mitigation has propelled renewable energy technologies to the forefront of global energy policy agendas. Among these, solar photovoltaic (PV) systems are particularly poised to play a transformative role due to their ability to generate clean electricity, reduce dependence on fossil fuels, and decrease greenhouse gas emissions [1]. While utility-scale solar farms are significant, the cumulative impact of residential PV adoption is also vital for achieving renewable energy targets. The decision of households to install solar panels is complex and influenced by a variety of factors, including economic incentives, environmental concerns, and socio-demographic characteristics [2]. This paper delves into two specific factors: housing type and homeownership, exploring their influence on the propensity of households to adopt PV systems.

1.1. Research background

1.1.1. Influence of housing type on PV adoption

The housing type has a profound impact on the adoption of residential PV systems. The architectural characteristics, including design, roof size, and orientation, are critical in determining not only the potential energy production but also the physical viability of installing solar panels. Detached single-family houses generally offer the most favourable conditions for PV adoption. These houses often come with larger roof areas, fewer shading issues, and the autonomy to make modifications, leading to higher rates of solar installation in such settings [3]. In contrast, residents of multi-family dwellings or townhouses face unique challenges. Shared roofs, limited space, and the need for collective decision-making processes among multiple stakeholders can significantly slow down or even prevent the adoption of PV technology in these housing types [4].

In addition to the physical aspects, the subjective perception of solar panels by households can also influence their decision to adopt PV systems. For many, the aesthetic impact of solar installations on their houses is a major consideration. Some households may perceive solar panels as incongruent with the design of their residences, particularly in neighbourhoods with strict architectural controls or in houses with historical significance. These households may be reluctant to adopt solar technology due to concerns about altering the visual appeal or character of their properties, which can be a considerable obstacle to residential solar proliferation [5].

1.1.2. Role of homeownership in PV adoption

Homeownership is a significant predictor of residential PV adoption. The economic benefits of solar energy, such as lower electricity bills and potential property value appreciation, are direct incentives for homeowners to invest in PV systems. Homeowners usually have the right to make modifications to their properties and are more likely to invest in long-term improvements compared to renters [6]. The decision to install PV systems is often viewed by homeowners as a value-adding investment that aligns with their commitment to sustainable living and energy independence.

Additionally, the length of residence is a factor closely tied to homeownership, influencing the decision to adopt renewable energy technologies. Homeowners with a long-term horizon for their occupancy are more inclined to consider the installation of PV systems as a worthwhile investment. They are not only looking at the immediate economic returns but also at the long-term environmental impact and the legacy they leave for future generations. This sense of permanence and stability fosters a conducive environment for the adoption of sustainable technologies [7].

In contrast, renters face several barriers when it comes to the adoption of PV systems. The transient nature of renting, along with the lack of authority to make substantial modifications to the property, often leaves renters with little motivation or capacity to pursue solar energy options. This disparity highlights the need for alternative models of solar adoption that can accommodate the unique circumstances of renters, ensuring equitable access to renewable energy across different homeownerships [8].

1.2. Research gap

There is a notable research gap in the study of PV adoption within the residential sector in Hong Kong due to the absence of comprehensive questionnaire surveys. Existing studies have predominantly employed qualitative interviews as their primary methodology, providing rich descriptive data but lacking the breadth and statistical robustness that quantitative methods can offer [9]. The reliance on interviews limits the generalizability of the findings as they are typically based on a smaller sample size and are subject to the interpretations of the researchers conducting the study. As a result, there is a gap in the current literature regarding large-scale, statistically driven insights into the factors influencing Hong Kong residents' decisions about PV adoption. Another significant research gap is the lack of comparative studies between households that have installed PV systems and those that have not. Current literature tends to amalgamate data from both groups without distinction, which obscures the unique characteristics and motivations of each subgroup [10]. Understanding the differences between PV installers and non-PV installers is critical for identifying the barriers and drivers of solar PV adoption. Without this differentiation, it is challenging to design effective interventions that address the specific concerns of households who are reluctant to invest in solar technology.

1.3. Research aims and objectives

The primary aim of this research is to enhance the understanding of the factors, housing characteristics in particular, influencing residential PV adoption in Hong Kong. Specifically, the study aims to: (i) evaluate the demographic differences between households that have adopted PV systems and those that have not, using the chi-square test of independence; and (ii) identify and analyze the critical factors that affect household decisions regarding PV adoption to inform strategies for future solar energy penetration. To achieve the aims above, the following objectives will be pursued: (i) Conduct a comprehensive questionnaire survey on residential PV adoption; (ii) perform statistical analysis (i.e., chi-square test of independence) to determine potential statistically significant differences in residential PV adoption among various demographic groups of PV installers and non-PV installers; (iii) interpret the statistical analysis results to identify the housing characteristics that exhibit the strongest association with the decision to adopt PV systems; and (iv) provide recommendations for facilitating future PV penetration.

By addressing these objectives, the study will fill existing research gaps and contribute to a more finely tuned approach to increasing residential PV adoption in Hong Kong. The insights gained could be instrumental in shaping future renewable energy policies and initiatives, ensuring they are well-informed and effective in encouraging sustainable energy practices among households.

2. Methodology

The data collection involving a questionnaire survey is administered between PV installers and non-PV installers regarding their housing types and homeownership. Then, data validation and verification are performed to ensure the expected frequency is within the requirement for non-parametric statistical test (i.e., Chi-square test of independence). Next, the primary statistical tests and the post-hoc tests are conducted to testify if the null hypothesis (i.e., H_0) should be rejected or not. Finally, the interpretation of the statistical results is presented, which is expected to fulfil the research objectives and contribution in various aspects. A detailed introduction to the research methodology will be presented in the following sections.

2.1. Data collection and verification

The questionnaire survey is distributed via online channel, and the valid responses of 776 participants are collected, including 371 PV installers and 405 non-PV installers. Both PV installers and non-PV installers were further categorized according to their housing types, including (i) independent houses (i.e., villas, bungalows, or village houses); and (ii) residential flats, as well as their homeownership status, including (i) owner; (ii) sole tenant; and (iii) co-tenant. The Chi-square test of independence is used for categorical data, and it is necessary to verify that the expected frequencies meet specific criteria to ensure the validity of the results. More specifically, each cell should have an expected frequency of 5 or above in at least 80% of the cells, and no cell should have an expected frequency below 1 [11]. This requirement is crucial as chi-square test results are sensitive to the distribution of expected frequencies, and violating this assumption could lead to misleading inferences. In this study, the expected frequencies are checked and ensured with no violation.

2.2. Primary statistical test and post-hoc test

After data validation and verification to ensure that the assumptions for each statistical test are satisfied, the statistical analysis is performed, using Matlab_R2022b. The Chi-square test of independence is utilized to examine the relationship between two categorical variables [12]. This non-parametric test is appropriate for determining whether there is a significant association between the categories of the variables. In this study, the null hypothesis (H_0) and the alternative hypothesis (H_1) for Chi-square test of independence are stated below:

H_0: There is no association between the housing characteristics and the installation of PV systems.
H_1: There is an association between the housing characteristics and the installation of PV systems.

All tests are two-tailed, and a p-value of less than 0.05 is considered indicative of statistical significance. Following the primary inferential analyses, post-hoc tests are implemented to further investigate the data and validate the model assumptions.

For the Chi-square test of independence, standardized residuals are examined to identify specific cells in the contingency table that contributed disproportionately to the overall Chi-square statistic. Standardized residuals, which are the differences between observed and expected frequencies standardized by the standard deviation, provide insights into the nature and strength of the association between categorical variables. An absolute value of standardized residual greater than 2 indicates a cell that has a higher or lower frequency than expected, and can be considered significant [13].

3. Result and discussion

The data presented in Fig. 1 illustrates the distribution of respondents from PV installers and non-PV installers a range of residential groups delineated by housing types and homeownerships. PV installers represent a larger subset of the population in most categories when compared to non-PV installers for independent houses (i.e., Villas, bungalows, or village houses). In particular, the ownership of residential flats stands out as the category with the most substantial representation in both groups, with non-PV installers accounting for 194 owners as opposed to PV installers' 144. This is indicative of a predominant preference or capacity for residential flat ownership within the population sampled.

Besides, a similar trend can be observed among sole tenants in residential flats, where non-PV installers comprise 129 individuals, in contrast to 70 in PV installers. The discrepancy between the groups in this category may reflect varying levels of commitment or financial ability to engage in sole tenancy agreements, which could be influenced by socio-economic factors or individual preferences. Moreover, the categories of sole and co-tenants within independent houses show a limited representation in the sample, with PV installers including 16 sole tenants and 5 co-tenants, while non-PV installers consists of 4 sole tenants and only 2 co-tenants. This could suggest that independent housing is a less preferred or feasible option for tenants, possibly due to higher rental costs or limited availability. Finally, the co-tenancy in residential flats, a living arrangement that often implies shared financial responsibility, includes 68 individuals from non-PV installers and 36 from PV installers. The presence of co-tenants in both groups might be reflective of economic strategies employed by individuals to manage the cost of urban living, with non-PV installers showing a greater inclination towards such arrangements.

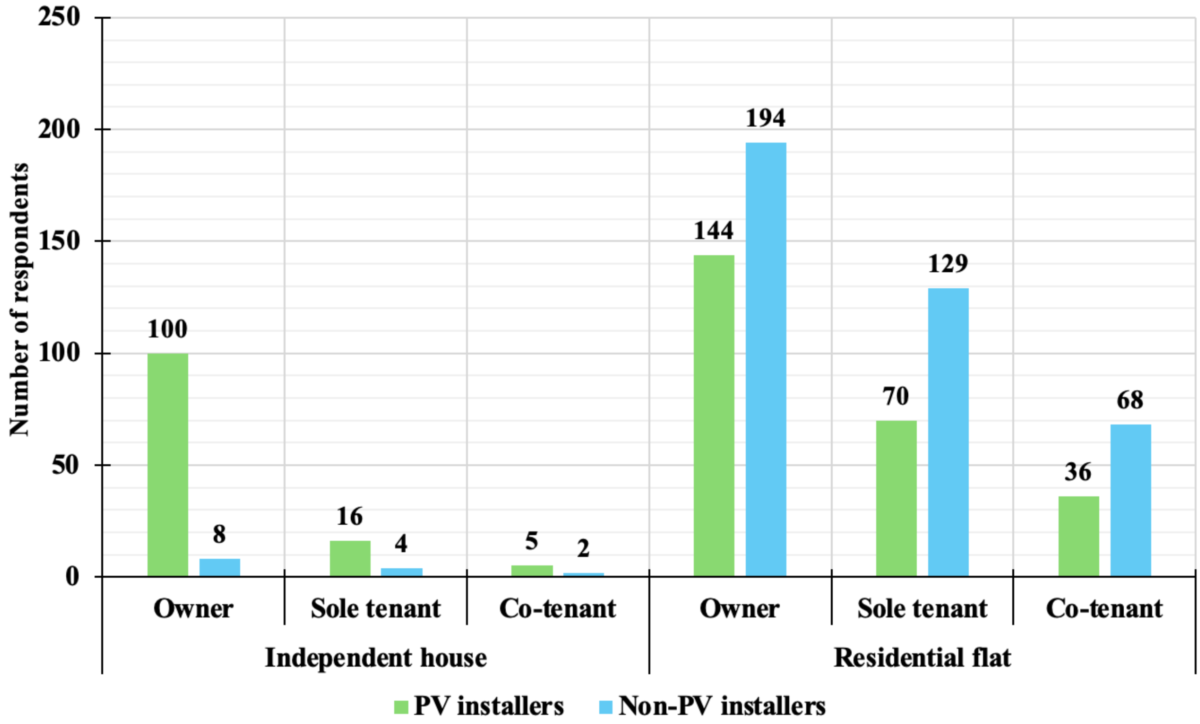

Figure 1. Descriptive result of questionnaire survey

Table 1. Statistical results of Chi-square test of independence

	Person Chi-square statistic	P-value	df
Housing type	115***	0.000	1
Homeownership	20***	0.000	2

The chi-square test results in Table 1 indicate significant associations between both housing types and homeownerships with the decision to adopt PV systems. For housing type, the chi-square statistic is 115 with a p-value of 0.000, and degrees of freedom (df) is 1. This result is highly significant, which suggests that there is a statistically significant association between the housing type and the variable of interest. The extremely low p-value indicates that the likelihood of this association being due to random chance is virtually zero. Similarly, for homeownership, the chi-square statistic is 20 with a p-value of 0.000, and df is 2. This result is also highly significant, pointing to a strong association between homeownership and the variable of interest. Again, the p-value being less than 0.001 confirms that the observed association is statistically significant and not due to random variation. The implication of these results is that these two factors should be considered carefully in any strategies or policies aimed at influencing the adoption of PV systems, as they are likely to have a significant impact on decision-making processes in the residential sector.

Table 2. Statistical results of post-hoc test

Categorical variable		PV installers	Non-PV installers
Housing type	Homeownership	Observed frequency (Expected frequency) Unstandardized residual (Standardized residual)	Observed frequency (Expected frequency) Standardized residual (Unstandardized residual)
Independent house (Villas, bungalows, or village houses)	Owner	100 (52) 48.37 (6.73) Δ	8 (56) -48.37 (-6.44) Δ
	Sole tenant	16 (10) 6.44 (2.08) Δ	4 (10) -6.44 (-1.99)
	Co-tenant	5 (3) 1.5 (0.90)	2 (4) -1.65 (-0.87)
Residential flats	Owner	144 (162) -17.60 (-1.38)	194 (176) 17.6 (1.32)
	Sole tenant	70 (95) -25.14 (-2.58) Δ	129 (104) 25.14 (2.47) Δ
	Co-tenant	36 (50) -13.72 (-1.95)	68 (54) 13.72 (1.86)

The chi-square analysis of housing type and homeownership between PV installers and non-PV installers reveals a significant discrepancy in the distribution of respondents that aligns with the theoretical expectations predicated on the null hypothesis of independence. In the category of independent houses (i.e., villas, bungalows, or village houses), the homeownership among PV installers reveals a pronounced positive deviation from the expected frequency with a standardized residual of 6.73. This marked deviation strongly indicates the considerable contribution of this group to the overall result. The prevalence of homeownership among PV installers exceeds what would be expected by chance alone, suggesting underlying preferences or economic capabilities within this residential group. Besides, the chi-square analysis yields a standardized residual of 2.08 regarding sole tenant who live in independent houses, although this value is slightly larger than 2 which represents a slightly higher deviation from the expected count in this group, it still it still indicates a notable tendency for sole tenants in independent houses to adopt PV systems compared to what was expected. Conversely, non-PV installers' representation in the same homeownership exhibits a stark negative deviation with a mere 8 occurrences against an expected 56, resulting in a commensurate negative unstandardized residual and a considerable standardized residual of -6.44. This leads to an intriguing finding that for owners who live in independent houses, the amount of non-PV installers is much less than expected. In addition, the chi-square analysis reveals that for other groups in independent house category, their influences and contributions to null hypothesis rejection are insignificant (i.e., standardized residual less than 2), which imply that the observed difference between the expected and observed frequencies could likely occur by chance alone. In other words, whether install PV systems may not strongly correlate with higher co-tenant rates when compared to the general population or other groups. Therefore, in terms of the underlying reasons beneath PV adoption in independent houses, it can be concluded that owners tend to demonstrate a strong commitment to sustainability and environmental-friendly behavior, driven by long-term financial incentives (e.g., Feed-in Tariff scheme) and the technical applicability of installing PV systems on their rooftops. While sole tenants who choose to install PV systems in independent houses intend to reveal a proactive attitude towards energy saving, motivated by electricity bill reduction purpose and strong intention to contribute to environmental protection.

In the context of residential flats, a reversal of the aforementioned trend is observed. Owners within PV and non-PV installers are underrepresented with standardized residual of -1.38 and 1,32, respectively, albeit with a modest deviation (i.e., insignificant), this implies that the decision on PV adoption is not necessarily correlated with higher owner rate. On the other hand, chi-square analysis exhibits intriguing results on sole tenants who live in residential flats, with both significant standardized residual of -2.58 and 2.47 within PV and non-PV installers, respectively. This finding indicates that sole tenants within PV installers suggest a lower-than-expected frequency, while simultaneously, they are observed a higher-than-expected frequency within non-PV installers. Therefore, it can be concluded that sole tenants who live in residential flats tend not to install PV systems, possible explanations are that they may lack the authority to make significant alterations to the property, including installing PV systems. Besides, landlords or property management companies often retain control over structural changes to the building, such as mounting solar panels on rooftops. Without the ability to modify the property to accommodate PV installations, sole tenants may be deterred from pursuing renewable energy options. Furthermore, co-tenants who live in residential flats uncover uncorrelated relationship with PV adoption, exhibiting the same pattern as co-tenants who live in independent houses.

To summarize, owners and sole tenants who live in independent houses tend to install PV systems, likely owing to the autonomy they possess over property modifications and the availability of suitable rooftops for solar PV installation. Nonetheless, sole tenants who live in residential flats tend not to install PV systems, which is probably attributed to the limited authority they possess to make structural alterations to rented properties.

4. Conclusion

The research offers a comprehensive examination of the housing characteristics influencing residential PV adoption in Hong Kong with the emphasis on housing type and homeownership. Through statistical analysis, it has been demonstrated that housing type and homeownership play pivotal roles in determining the likelihood of households installing PV systems. The findings of this study indicate that owners of independent houses, such as villas, bungalows, and village houses, are significantly more inclined to embrace PV technology compared to other residential groups. This trend suggests that the characteristics associated with the homeownership of independent houses, including but not limited to, space availability, economic capacity, and perhaps a greater degree of autonomy in making modifications to the property, are conducive to the adoption of PV systems.

Conversely, tenants, particularly those sharing accommodations in residential flats, appear less likely to invest in PV installations. This could be attributed to a variety of factors, including restrictions imposed by rental agreements, transient housing situations, or limited financial incentives. The significant differences between homeowners and tenants underscore the necessity for policymakers to consider these demographic nuances when designing initiatives and incentives aimed at encouraging PV adoption across all residential categories.

The research underscores the critical need for tailored approaches in policy and program development to overcome the barriers faced by different demographic segments. For instance, strategies to encourage PV adoption among tenants could involve the development of community solar projects or the introduction of incentives for landlords that could trickle down to benefit tenants. Meanwhile, promoting PV adoption among independent house owners could be further enhanced through targeted information campaigns and subsidies that address their specific circumstances.

In conclusion, this study highlights the crucial role of demographic determinants in shaping a more sustainable and renewable energy future in Hong Kong's residential sector. By gaining a nuanced understanding of these determinants, policymakers and stakeholders can address the diverse needs and capabilities of homeowners and tenants. Consequently, Hong Kong can accelerate the adoption of PV systems more effectively, contributing to its broader environmental goals and reinforcing its commitment to a cleaner and greener future.

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