調査報告書 23－03

Japan Residential Electricity Consumption in Response to Climate Change

令和 **6**（**2024**）年 **3** 月

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Japan Residential Electricity Consumption in Response to Climate Change

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Abstract

This study examines the impact of extreme temperatures on residential electricity consumption in Japan. Using a panel fixed effect model, we find a U–shaped relationship between temperatures and electricity usage, with colder climates showing greater sensitivity to cold temperatures and warmer climates exhibiting increased consumption during hot spells. Our findings highlight the importance of considering regional heterogeneity in energy policy formulation under climate change. Transitioning to renewable energy sources may mitigate the environmental impact, but upfront costs pose a barrier. Addressing energy poverty and promoting energy efficiency are crucial strategies, requiring concerted efforts from policymakers and stakeholders.

1. Introduction

Temperature fluctuations exert varying impacts on residential electricity usage, notably during hot and cold periods. During hot spells, households increase electricity consumption to cool their living spaces, while colder periods witness higher usage for heating purposes. Increasing energy demand, dwindling reserves of fossil fuels, and climate change have spurred a rise in studies examining the impact of weather conditions on electricity consumption. A special report issued by the IPCC in 2018 highlighted the prospect of a 1.5°C rise in global surface temperatures between 2030 and 2052 if current trends continue.[1] According to the Agency for Natural Resources and Energy, Japan is gradually exceeding its maximum electricity demand in anticipation of a severe heat wave or cold snap.[2] This dynamic interplay between extreme temperatures and electricity consumption underscores the urgency of this research endeavor. Ihara et al. (2008) and

[1] See IPCC Special Report: Global Warming of 1.5 ºC (IPCC, 2018) for detailed information.
[2] See Energy White Book 2023 (Agency for Natural Resources and Energy, 2023) for detailed information.

Hashimoto et al. (2019) estimated the sensitivity of electricity consumption to temperature using Tokyo and Osaka, Japan, as case studies, respectively. This study enhances the representativeness of the findings by including cities with prefectural capitals and government–designated cities, thus better capturing the average impact across Japan.[3]

This paper confirms the nonlinear (U–shaped) impact of extreme temperatures on the residential electricity consumption. The results indicate that the preferred temperature for the household to live in is approximately 9–21°C. That is in line with the threshold temperatures found in the existing literature, which range from about 50 to 77°F (10–25°C).[4] These findings hold across various specifications.

Furthermore, this study underscores the importance of examining heterogeneity across various dimensions. Specifically, the findings reveal that northern Japan, encompassing the Hokkaido and Tohoku regions known for their colder climates, exhibit greater vulnerability to extreme cold temperatures, whereas regions beyond these areas primarily experience significant impacts from hot temperatures.

The remainder of this paper is organized as follows: Section 2 presents the literature review; Section 3 provides the empirical methodology and data; Section 4 discusses the estimation results; and Section 5 draws conclusions.

2. Literature Review

This section summarizes recent prominent papers used to measure residential electricity consumption due to extreme temperatures.[5] In the realm of research investigating the influence of temperature on electricity consumption, three principal methodological approaches have emerged as prevalent: 1. Cross–sectional studies: These investigations, characterized by data collection at a specific moment in time, typically concentrate on elucidating interregional disparities in the impact of climate variables on energy usage. While cross–sectional studies offer expedient and cost–effective analyses, they are susceptible to the oversight of temporal dynamics within individual units, thus potentially introducing omitted variable bias; 2. Panel studies: Employing data longitudinally to

[3] Government–designated cities other than prefectural capitals are Kawasaki, Sagamihara, Hamamatsu, Sakai, and Kitakyushu.

[4] See Ko (2023): Economic Effects of Temperatures on Household Electricity Consumption: A review of the empirical literature for a detailed review of previous research findings.

[5] See Ko (2023) for a detailed review of recent previous studies focusing on household electricity consumption. For more detailed information on the impact of climate on energy consumption, see Auffhammer and Mansur (2014) and Dell et al. (2014).

observe entities over time, panel studies afford researchers the opportunity to account for individual–specific and time–invariant unobserved heterogeneity. Nevertheless, the annual fluctuations inherent in longitudinal data restrict our capacity to delve into the prolonged effects of climate change, thereby primarily enabling exploration of short–term weather impacts; 3. Time–series studies: Time–series studies focus on the temporal evolution of variables, allowing researchers to identify patterns, trends, and dynamics over time that might not be apparent in cross–sectional assessments. However, akin to panel studies, time–series analyses may fall short in capturing the protracted adaptations to climatic shifts and are susceptible to the confounding influence of unobserved variables evolving over time.

In evaluating the impact of temperature on electricity consumption, researchers commonly utilize two primary approaches to measure temperature: 1. Temperature bin: This method involves categorizing temperature ranges to assess their influence on electricity usage. Researchers such as Deschênes and Greenstone (2011), Davis and Gertler (2015), and Zhang et al. (2022) have employed temperature bins by grouping temperatures into predefined ranges (e.g., 60–65°F, 65–70°F, 70–75°F, etc.); 2. Cooling degree days (CDD) and heating degree days (HDD): CDD and HDD are metrics used to quantify the discrepancy between outdoor temperatures and a reference temperature (typically 65°F) accumulated over time. Ayyash et al. (1985), Li (2018), Du et al. (2020), Silva et al. (2020), Zhang et al. (2020), Zheng et al. (2020), and Zhang et al. (2021) have investigated the impact of CDD on electricity consumption during warm weather (i.e., cooling needs), while also examining the influence of HDD on electricity usage during cold weather (i.e., heating needs).

Here are key findings from recent studies: 1. Non–linear response functions: Recent research reveals non–linear (often U–shaped) response functions, indicating higher residential electricity consumption during very cold and hot days; 2. Threshold temperatures: Studies identify threshold temperatures typically falling within the range of approximately 50–77°F (10–25°C), marking pivotal points where electricity consumption notably varies; 3. Focus on China: A significant proportion of recent studies investigating the temperature's effect on residential electricity consumption have concentrated on case studies in China.[6] However, it's noteworthy that there are also case studies utilizing data from Japan. For instance, Ihara et al. (2008) and Hashimoto et al. (2019) estimated the sensitivity of electricity consumption to temperature using Tokyo

[6] These studies have been published in journals such as Energy Economics, Energy, Energy and Buildings, Energy Policy, Utility Policy, China Economic Review, PNAS, and Applied Energy.

and Osaka, Japan, as case studies, respectively. Nonetheless, it is essential to recognize that these studies concentrated solely on individual cities, thereby leaving the average impact across Japan uncertain; 3. Preference for panel analysis: Panel analysis emerges as the preferred methodology in recent studies due to its ability to account for individual–specific and time–invariant factors; 4. Wide usage of measurement methods: Both temperature bins and degree days (CDD/HDD) methods are widely utilized across recent research, reflecting their utility in analyzing temperature–electricity consumption relationships.

3. Methodology and Data

3.1 Methodology

To estimate the impact of extreme temperatures on the residential electricity consumption, our baseline specification uses temperature bins as a measure of heat. We employ the following empirical panel fixed effect model:

(1) $$\mathrm{Y}_{it} = \alpha_0 + \sum_{n=1}^{N} \alpha_n\, Temp_{nit} + \mathbf{Z}_{it}\gamma + \mathrm{C}_i + \lambda_t + \varepsilon_{it},$$

where Y_{it} is the residential electricity consumption in the city i in year t, $Temp_{nit}$ denotes the number of days where the daily mean temperature is in the n^{th} of the N bins (<0, 0–3, 3–6, 6–9, 9–12, 12–15, 15–18, 18–21, 21–24, 24–27, >27°C). A vector $\mathbf{Z}_{it}$ includes the sum of daily precipitation, along with their quadratic terms. Additionally, it incorporates various household characteristic variables, such as the number of individuals per household, the number of individuals aged above 65 years old per household, electricity price, and income. The inclusion of income is particularly pertinent as energy consumption is known to be influenced by household income levels. C_i is the city fixed effect, λ_t is the year fixed effect, and ε_{it} indicates the error term.

3.2 Data

3.2.1 Electricity Consumption and Household Characteristic Data

The annual residential electricity consumption data and household characteristic data (the number of individuals per household, the number of individuals aged above 65 years old per household, and income) used in this study are obtained from Family Income and Expenditure Survey from Statistics Bureau, Ministry of Internal Affairs and Communications.[7] The annual average results of electricity price data is from Retail Price Survey (Trend Survey) from Statistics Bureau, Ministry of Internal Affairs and Communications.[8]

3.2.2 Weather Data

The weather data utilized in this study is sourced from Agro–Meteorological Grid Square Data, NARO.[9] They provide 14 types of daily meteorological weather data by 1km square (third–order grid unit) covering the entirety of Japan. Consistent with prior research, our analysis concentrates on two primary variables: daily mean temperature and daily precipitation. To harmonize the grid–level data with city–level data, we leverage a list of mesh codes by city provided by the Statistics Bureau of Japan. This facilitates the seamless integration of these datasets, ensuring robust analysis at the city level.

This study examines data spanning from 2015 to 2021. Table 1 provides an overview of the main variables under consideration. Across the study cities during this period, the average annual residential electricity consumption per household stands at 105,923 yen.[10,11] The distribution of daily mean temperature over the year (365 days) is delineated, with 17 days experiencing temperatures below 0°C, approximately 97 days falling within the range of 0 to 9°C, and roughly 196 days characterized by moderate temperatures ranging from 9 to 24°C. Additionally, there are 33 days with temperatures ranging between 24 and 27°C, while temperatures exceeding 27°C occur for approximately 22 days.[12] Figure 1 illustrates this temperature distribution across eleven temperature bins (<0, 0–3, 3–6, 6–9, 9–12, 12–15, 15–18, 18–21, 21–24, 24–27, >27°C). On average, the sum of daily precipitation throughout the year totals 1,865 mm. Other household characteristics include an average of 2 persons per household, with 0.7 persons

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[7] See Statistics Bureau, Ministry of Internal Affairs and Communications for more detailed information of the survey: https://www.stat.go.jp/data/kakei/.

[8] See Statistics Bureau, Ministry of Internal Affairs and Communications for more detailed information of the survey: https://www.stat.go.jp/english/data/kouri/doukou/index.html.

[9] See Agro–Meteorological Grid Square Data, NARO for more detailed information: https://amu.rd.naro.go.jp/wiki_open/doku.php?id=start.

[10] At the time of this writing, 100 USD is approximately 15,040 JPY.

[11] Electricity consumption is normally distributed (see Appendix Figure A1). As a test of robustness, taking the logarithm of electricity consumption confirms that consistent results are obtained (see Appendix Figure A2).

[12] To apply the temperature bin method, it is necessary to ensure that all years have the same date, thus the weather on 2/29 are excluded from the study.

above 65 years old per household. The average electricity price per 441kWh per month is 12,511 yen,[13,14] while the average monthly household income amounts to 491,489 yen.[15,16]

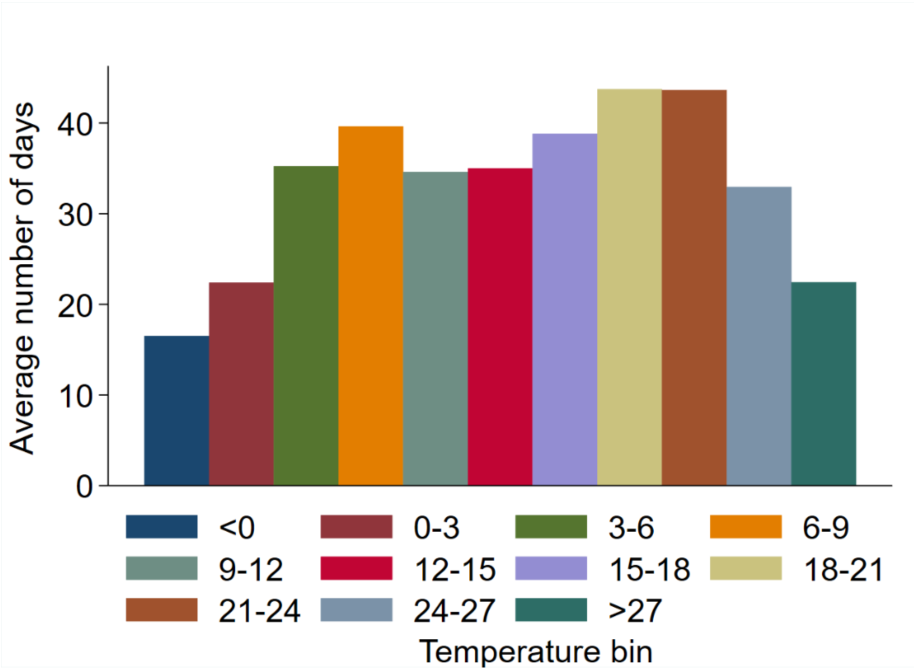

Figure 1: Distribution of daily mean temperature over 2015–2021

Notes: The figure represents the average number of days per year in each temperature bin (<0, 0–3, 3–6, 6–9, 9–12, 12–15, 15–18, 18–21, 21–24, 24–27, >27°C).

[13] Electricity price is either meter rate, ampere–based (50 ampere), or minimum charges system. Charges calculated by converting the original price to the charge for 441kWh per month.

[14] Electricity consumption and electricity prices are converted to real prices using national electricity CPI data. The calculation formula goes as follows: nominal price ÷ electricity CPI × 100. The base year is 2020. For more information, see https://www.stat.go.jp/data/cpi/index.html.

[15] Due to data availability, the income data are for workers' households out of all households. "Workers' households" are defined as households in which the head of the household works for a company, government office, school, factory, store, etc. However, households in which the head of household is a president, director, officer, or other executive of a corporate organization are defined as "Households other than working or unemployed".

[16] Income is converted to real income using national CPI data. The calculation formula goes as follows: nominal price ÷ CPI × 100. The base year is 2020. For more information, see https://www.stat.go.jp/data/cpi/index.html.

Table 1—Summary statistics

	Obs.	Mean	SD	Min	Max
Annual residential electricity consumption per household (yen)	364	105,922.70	15,511.63	66,307.05	149,813.30
<0 ℃ (days)	364	16.52	28.17	0	129
0–3 ℃ (days)	364	22.39	17.41	0	70
3–6 ℃ (days)	364	35.24	13.01	0	65
6–9 ℃ (days)	364	39.64	12.68	0	73
9–12 ℃ (days)	364	34.62	9.84	0	59
12–15 ℃ (days)	364	35.01	8.44	1	64
15–18 ℃ (days)	364	38.82	9.38	16	69
18–21 ℃ (days)	364	43.74	10.09	14	84
21–24 ℃ (days)	364	43.64	12.80	10	85
24–27 ℃ (days)	364	32.96	14.31	0	84
>27 ℃ (days)	364	22.44	21.31	0	140
Total precipitation (mm)	364	1,864.86	544.69	891.88	3,772.34
Persons per household (persons)	364	2.20	0.19	1.73	2.66
Persons above 65 years old per household (persons)	364	0.69	0.11	0.36	1.02
Average electricity price per 441kWh per month (yen)	364	12,511.45	619.12	10,823.47	15,354.65
Income per household per month (yen)	364	491,489.40	59,141.57	320,147.10	682,567.00

4. Empirical Results

4.1 Residential Electricity Consumption–Temperature Response Function

The estimation results are presented in Table 2.[17] Columns 2 includes additional control variables, as detailed in the data section. The temperature range of 18–21°C is excluded to maintain consistency with the World Health Organization (WHO) findings.[18] All specifications yield consistent temperature results regardless of whether other control variables are included. However, there are notable discrepancies in magnitudes, potentially indicating omitted variable bias in Column 1. In contrast to the reference temperature bin, our analysis reveals a positive correlation between residential electricity consumption and temperatures both below and above this reference. Our preferred empirical model, as presented in Column 2, demonstrates that exposure to an additional day below 0°C increases residential electricity consumption by 427 yen, while an extra day above 27°C results in a 242–yen increase. Figure 2 shows the residential electricity consumption–temperature response function from Column 2, along with 95 percent confidence intervals. These results suggest that the comfortable temperature range for households falls approximately between 9–21°C, aligning with threshold temperatures identified in existing literature ranging from about 50 to 77°F (10–25°C).[19,20]

In our analysis of other household characteristic variables, we observe that households with a greater number of elderly individuals tend to exhibit higher electricity consumption. This finding may be attributed to the vulnerability of the elderly population to the health impacts of extreme temperatures.[21] To safeguard the health of the elderly during periods of extreme weather, households may increase their electricity usage as a protective measure.[22] We observe a significant positive correlation between income and

[17] The significance of our Hausman specification test indicates a preference for the fixed effect model over the random effects model. For detailed results, please refer to Appendix Table A1.

[18] The World Health Organization (WHO) in 1987 found that for healthy adults with proper clothing, humidity, and other factors, a comfortable indoor temperature of 18–24°C is not associated with health risks.

[19] This could be due to milder temperatures leading to less need for heating or cooling, thereby reducing electricity consumption.

[20] See footnote 4.

[21] Rupa Basu (2009) reviewed the evidence on mortality associated with extreme temperatures, focusing on studies from January 2001 to December 2008. The review identified vulnerable subgroups associated with the relationship between extreme temperatures and mortality, with particular emphasis on those aged 65 years and older, who are more susceptible to adverse health effects during periods of extreme temperatures.

[22] Deschênes and Greenstone (2011) has shown that the weak relationship between mortality and

electricity consumption. Income plays a pivotal role in shaping electricity consumption patterns, primarily by influencing the affordability and adoption of energy–intensive appliances. This implies that households with lower income may face higher health risks during extreme temperatures, as they may lack the financial means to increase electricity usage for protective measures, such as air conditioning or heating, potentially exacerbating their vulnerability to temperature–related health issues.

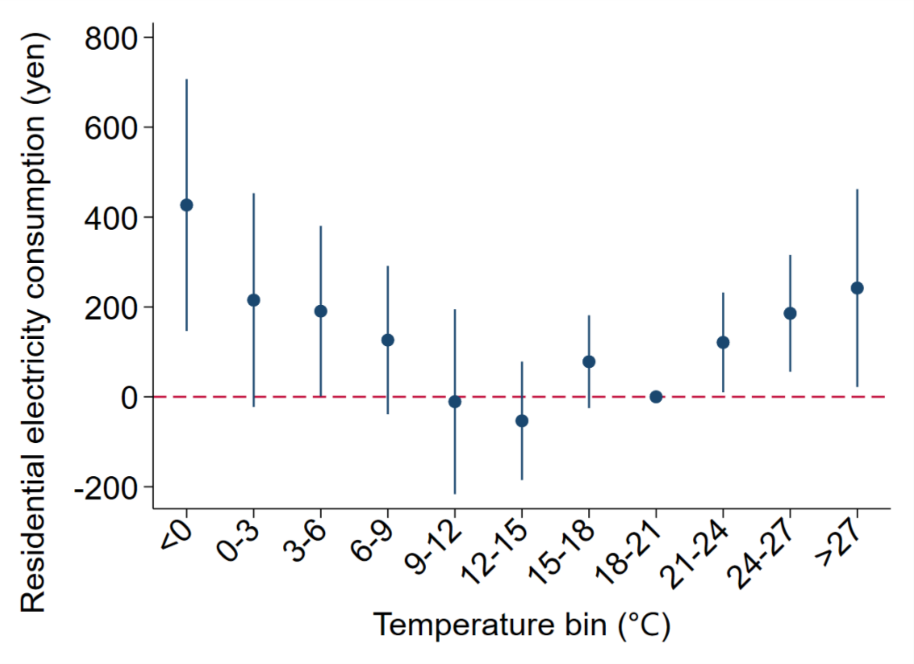

Figure 2: Relationship between temperature and electricity consumption

Notes: Estimates display the change in residential electricity consumption under an extra day of exposure to a given °C temperature bin relative to a day spent at base temperature bin. The lines are 95 percent confidence intervals.

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temperature is due, at least in part, to self–protection from increased energy consumption by cooling.

Table 2—Results of the nonlinear temperature effects on residential electricity consumption

	(1) weather var. only	(2) add control var.
<0℃	211.90	426.68***
	(179.95)	(139.66)
0–3℃	34.41	215.20*
	(150.50)	(118.48)
3–6℃	52.71	190.62**
	(117.97)	(94.52)
6–9℃	-8.85	126.25
	(102.71)	(82.18)
9–12℃	-94.02	-10.84
	(133.20)	(102.47)
12–15℃	-44.88	-53.44
	(96.46)	(65.68)
15–18℃	38.16	78.12
	(70.90)	(51.42)
21–24℃	156.18**	121.00**
	(76.11)	(55.41)
24–27℃	189.65**	185.69***
	(83.40)	(64.78)
>27℃	372.30***	242.00**
	(120.10)	(109.69)
Precip	0.7910	3.8063
	(7.0502)	(4.3214)
Precip^2	0.0001	-0.0010
	(0.0017)	(0.0009)
Persons		24803.36***
		(4344.99)
Persons above 65		22303.39***
		(5036.20)
Electricity price		10.08***
		(1.94)
Income		0.03***
		(0.01)

Obs.	364	364
Control var.	No	Yes
F statistic	1.51	26.02
Prob > F	0.1510	0.0000
Adj. R^2	0.8142	0.8940

Notes: ***, **, and * denote 1 percent, 5 percent, and 10 percent significant level, respectively. All specifications are estimated with city and year fixed effects. Columns 2 includes additional control variables shown at the bottom; see main text for details. The excluded category is the daily mean temperature in the 18–21°C range. Standard errors clustered at the city level are reported in parentheses.

4.2 Heterogeneity of Temperature Impacts on Residential Electricity Consumption

Although a U–shaped relationship between temperature and residential electricity consumption is commonly observed, certain studies have highlighted significant effects only at high temperatures. For instance, Du et al. (2020) and Zhang et al. (2022) noted that in China, electricity consumption primarily responds to extremely warm days rather than cold ones. This phenomenon is attributed to the concentration of high Heating Degree Days (HDDs) in northern regions, where central (district) coal–fired heating is prevalent. Similarly, studies in the United States have revealed geographic heterogeneity in response to extreme temperatures (see, e.g., Deschênes and Greenstone 2011). Given the colder climate of northern Japan compared to other regions, residential electricity response to temperatures may vary.[23] To account for such heterogeneity, we categorize cities into two subgroups: the Hokkaido and Tohoku regions (relatively colder areas), and regions outside these areas. We then analyze temperature effects using separate sub datasets for each subgroup.

Figures 3 and 4 visually depict the impact of temperatures on residential electricity consumption across different climate regions. Our analysis reveals that in the Hokkaido and Tohoku areas, residential electricity consumption exhibits greater sensitivity to cold temperatures rather than hot temperatures. Conversely, in regions outside these areas, residential electricity consumption is primarily significantly affected by hot temperatures, with cold temperatures showing less significant influence.[24] In northern Japan, there are

[23] The temperatures in the Hokkaido and Tohoku regions are about 5°C lower compared to regions outside these areas. For visual reference, please see Appendix Figure A3.
[24] The table results of the analysis are presented in Appendix Table A2.

many days of cold temperatures, making electricity very susceptible to cold weather, while the opposite situation occurs in other regions. These results underscore the significance of examining heterogeneity across different geographical dimensions, such as north and south regions.

One interesting point here is that temperature control devices are quite different in northern Japan. In the Hokkaido area, kerosene serves as the primary heating source for households, with 82.3% of households relying on it, as reported by the Hokkaido Household Energy Consumption Survey 2022 conducted by the Hokkaido Consumers Association.[25] Despite this prevalence, electricity consumption in Hokkaido remains sensitive to cold temperatures, and several factors contribute to this phenomenon: 1. Multiple Uses of Electricity: Households in Hokkaido utilize electricity for various purposes beyond household heating, including lighting (due to limited bright time in winter), appliance operation, and potentially residential road heating systems. Even though kerosene is the dominant heating source, the cumulative electricity usage for these purposes significantly impacts overall electricity consumption; 2. Complementary Heating Systems: While kerosene serves as the primary heating source, some households in Hokkaido may employ electric heaters or heat pumps as supplementary heating systems. During cold periods, the utilization of these complementary systems leads to an increase in electricity consumption, further heightening sensitivity to cold temperatures.[26]

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[25] See Hokkaido Consumers Association for more detailed information of the survey: http://www.syouhisya.or.jp/research.html.

[26] According to Hokkaido Household Energy Consumption Survey 2022 by Hokkaido Consumers Association, 40.7% of households use electricity as their heating energy source. See Hokkaido Consumers Association for more detailed information of the survey: http://www.syouhisya.or.jp/research.html.

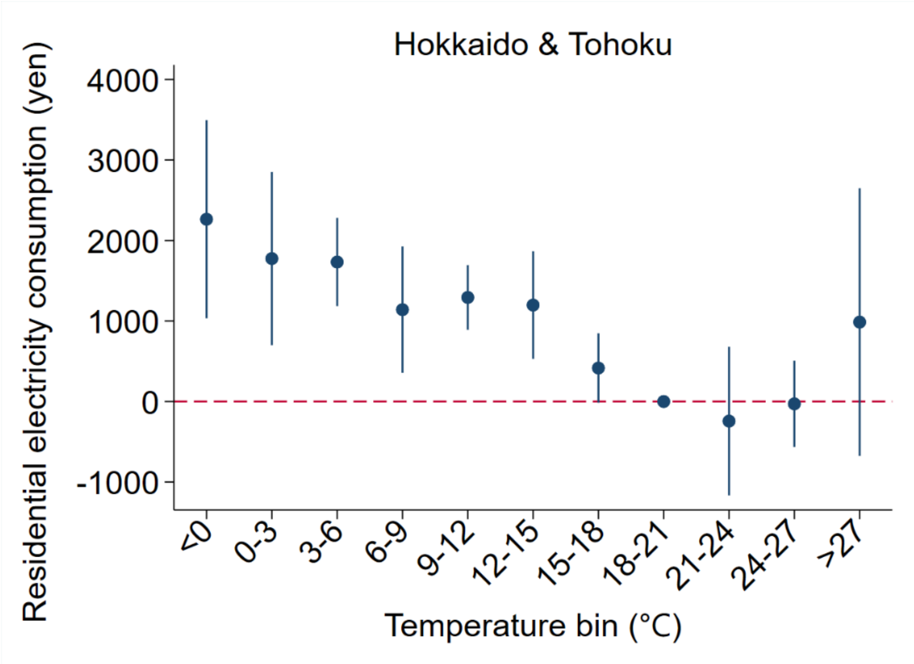

Figure 3: Relationship between temperature and electricity consumption in Hokkaido and Tohoku regions

Notes: See *Notes* in Figure 2.

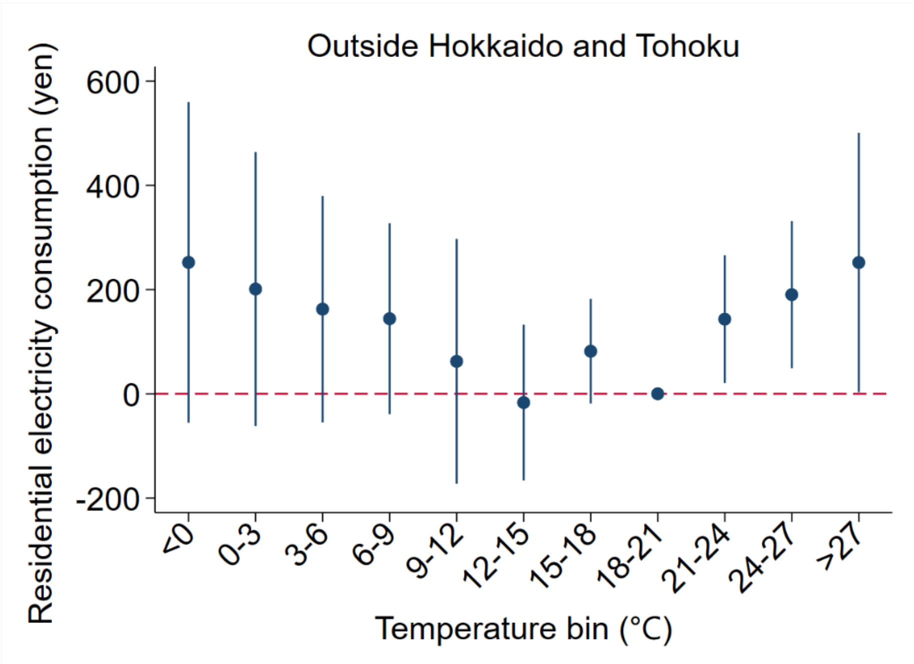

Figure 4: Relationship between temperature and electricity consumption in Outside Hokkaido and Tohoku regions

Notes: See *Notes* in Figure 2.

5. Conclusion

This study quantifies the influence of temperatures on residential electricity consumption and assesses variations in temperature impacts across different climate conditions. Our analysis reveals a U–shaped relationship between temperatures and residential electricity consumption. Specifically, we find that the effect of cold temperatures is more pronounced in cities with colder climates, while the opposite holds true for cities with warmer climates. These findings underscore the importance of considering heterogeneity across different dimensions when policymakers simulate future electricity consumption under climate change scenarios, emphasizing the need for tailored and efficient energy policies.

These findings prompt significant consideration for addressing pressing issues regarding energy usage under climate change. The increasing demand for electricity under climate change is anticipated to intensify air pollution and carbon dioxide emissions, further exacerbating the challenges of climate change. While transitioning to renewable energy presents a solution, the initial investment can prove to be prohibitively expensive. Despite the potential for long–term energy cost savings, these initial costs pose a significant barrier for many. Additionally, efforts to increase access to energy and provide financial assistance may help alleviate energy poverty, but political and technical obstacles may hinder progress.

Prioritizing energy efficiency emerges as a pivotal strategy for combating climate change, curbing energy expenses, and fostering sustainable economic development. However, the initial high costs can deter households and businesses from implementing efficiency measures. To surmount these challenges, it is imperative to raise awareness and education on energy efficiency, provide financial incentives and support, advance energy–efficient technologies, and enact supportive policies and regulations.

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7. Appendix

Figure A1. Distribution of residential electricity consumption

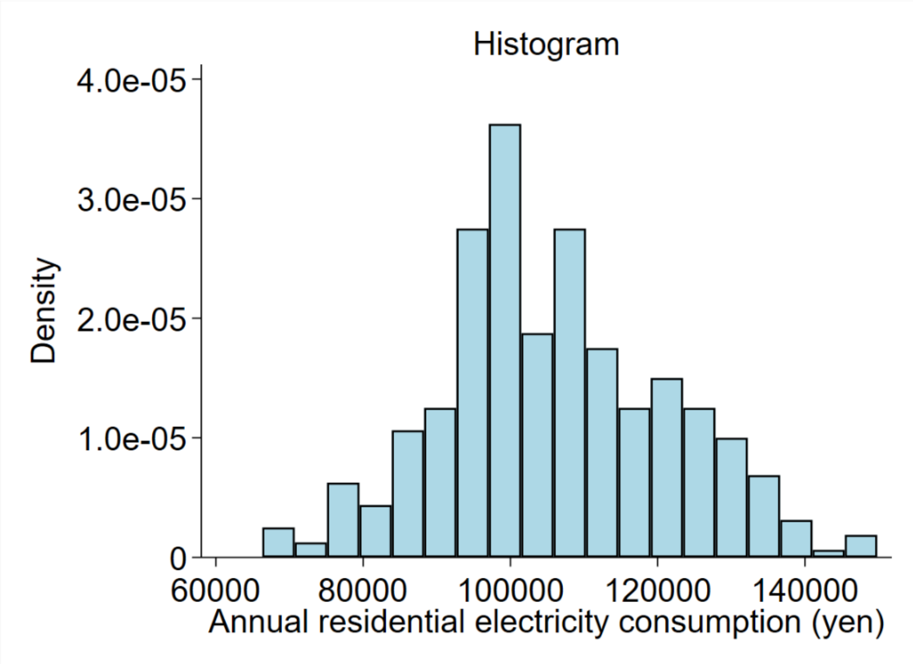
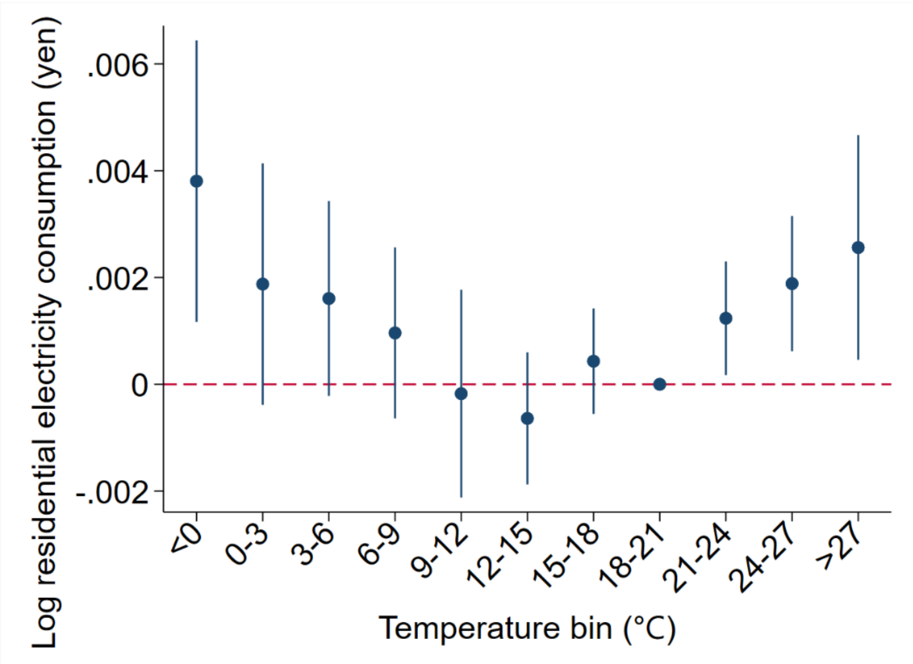


Figure A2. Relationship between temperature and log electricity consumption



Notes: Estimates display the change in log residential electricity consumption under an extra day of exposure to a given ℃ temperature bin relative to a day spent at base temperature bin. The lines are 95 percent confidence intervals.

Figure A3. Average temperature trend: Hokkaido and Tohoku vs Outside the two

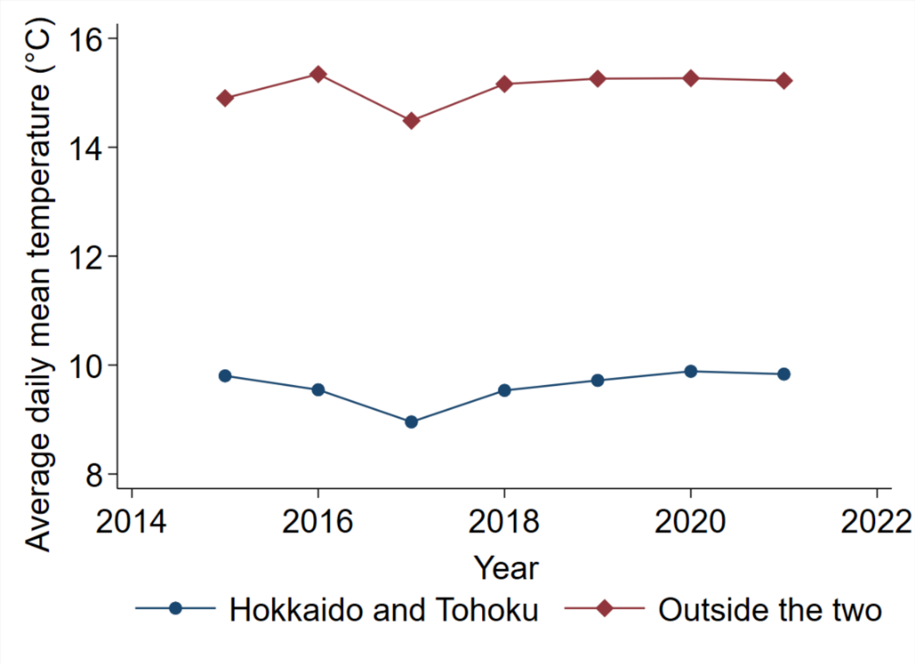


Table A1. Hausman specification test

	(1) Coefficient: FE (b)	(2) Coefficient: RE (B)	(3) Difference (b-B)	(4) Standard error sqrt (diag(V_b-V_B))
<0℃	426.68	256.94	169.74	147.10
0–3℃	215.20	193.31	21.89	118.60
3–6℃	190.62	192.40	-1.78	108.09
6–9℃	126.25	154.97	-28.72	86.736
9–12℃	-10.84	46.10	-56.94	77.36
12–15℃	-53.44	9.57	-63.01	50.32
15–18℃	78.12	89.53	-11.42	27.92
21–24℃	121.00	93.81	27.19	18.44
24–27℃	185.69	152.41	33.28	33.71
>27℃	242.00	199.25	42.75	44.17
Precip	3.8063	7.8014	-3.9951	1.7450
$Precip^2$	-0.0010	-0.0013	0.0003	0.0003
Persons	24803.36	27507.87	-2704.51	1578.43
Persons above 65	22303.39	21887.45	415.94	1536.43
Electricity price	10.08	6.50	3.58	0.76
Income	0.03	0.04	-0.01	0.003

b = Consistent under H0 and Ha; obtained from xtreg.

B = Inconsistent under Ha, efficient under H0; obtained from xtreg.

Test of H0: Difference in coefficients not systematic

chi2 = 53.51

Prob > chi2 = 0.0000

Notes: FE refers to fixed effect while RE is random effect.

Table A2. Heterogeneity of temperature impacts on residential electricity consumption

	(1) Hokkaido & Tohoku	(2) Outside Hok. & Toh.
<0℃	2264.15***	252.22
	(502.94)	(152.64)
0–3℃	1775.19***	201.00
	(439.40)	(130.45)
3–6℃	1732.46***	162.47
	(223.86)	(107.84)
6–9℃	1140.90**	144.12
	(320.83)	(90.88)
9–12℃	1292.62***	62.27
	(164.17)	(116.60)
12–15℃	1198.00***	-16.82
	(272.97)	(74.17)
15–18℃	416.08*	81.68
	(176.02)	(49.82)
21–24℃	-243.34	143.26**
	(377.09)	(60.89)
24–27℃	-29.22	190.32***
	(218.98)	(70.07)
>27℃	986.38	251.95**
	(679.43)	(123.54)
Obs.	49	315
Control var.	Yes	Yes
Adj. R^2	0.9024	0.8868

Notes: ***, **, and * denote 1 percent, 5 percent, and 10 percent significant level, respectively. All specifications are estimated with city and year fixed effects. Columns 2 includes additional control variables shown at the bottom; see main text for details. The excluded category is the daily mean temperature in the 18–21℃ range. Standard errors clustered at the city level are reported in parentheses.

Japan Residential Electricity Consumption in Response to Climate Change

令和 6 年 3 月発行

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