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Abstract

This study quantitatively assesses the negative externalities of geothermal power plants by analyzing their impact on local land values in Japan. Using a hedonic pricing approach and a difference-in-differences framework, the analysis finds that land prices within a 2 km radius of a geothermal power plant declined by approximately 7% to 12% after their installation, even after accounting for various fixed effects and robustness checks. The study utilizes data on all 28 large-scale geothermal power plants with a capacity of at least 1,000 kilowatts that were operational in Japan as of 2018, covering a 42-year period from 1983 to 2024. The findings highlight the complex interplay between renewable energy expansion and local economic conditions, emphasizing the need to balance the benefits of clean energy with local stakeholders' concerns to ensure a sustainable energy transition in Japan.

Keywords renewable energy; geothermal power; hedonic analysis; negative externality

JEL Classifications Q24, Q42, Q51

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1. Introduction

In response to global warming, many countries have actively pursued renewal energy development. Among these, geothermal power stands out as a stable and cost-effective base load power source, unaffected by weather or time of day (Boden, 2023). While Japan ranks third in the world for estimated geothermal resources at 23,000 megawatts (MW), behind the United States (30,000 MW) and Indonesia (28,000 MW), it ranks only 10th in terms of installed geothermal power generation capacity at 603 MW (ThinkGeoEnergy, 2021). A major contributing factor to Japan's slow progress is the difficulty in achieving consensus with local stakeholders, primarily due to concerns over negative externalities, particularly the impacts on landscapes and the sources of hot springs (Yasukawa, 2019; Shortall and Kharrazi, 2017; Kubota et al., 2013). Surprisingly, while there is scientific literature on the negative impacts of geothermal energy, economic studies addressing these negative externalities are scant, particularly in comparison to other renewable energies like wind power. This study aims to address this gap by quantifying the negative externalities of geothermal power plants through an analysis of their impact on local land values using Japanese data.

While geothermal energy offers a reliable and cost-effective renewable resource for electricity and heating, it accounted for only 0.5% of the global installed capacity for renewable electricity in 2021, according to the International Renewable Energy Agency (IRENA and IGA, 2023). Several factors contribute to the slow progress in geothermal development, including high initial investments and financial risks associated with exploratory drilling, which often deter investments; environmental concerns such as the release of harmful gases from beneath the Earth's surface; and significant regulatory challenges that complicate project approval and implementation (Kumar et al., 2022).

Regulatory challenges had been the largest obstacle for geothermal development in Japan (Hymans, 2021). Approximately 80% of Japan's geothermal resources are located within national parks, many of which also overlap with hot spring resorts. Consequently, the construction of geothermal power plants is strictly regulated by the National Park Law, aimed at protecting the environment and landscapes, and by the Hot Spring Law, to safeguard hot spring sources. The government has responded with regulatory reforms to foster a more conductive legal environment. Notably, amendments to the National Park Law in 2012 and 2015 expanded the permissible areas for geothermal resource development within national parks from an initial 5% to 50%, according to New Energy and Industrial Technology Development Organization (NEDO, 2019). Additionally, since 2021, the government has been actively reviewing and adjusting rules and guidelines under these laws to further ease the construction of geothermal power plants. Despite these efforts, however, Japan still lags behind in achieving widespread adoption of geothermal energy, due to the challenges of gaining stakeholder consensus, reflecting the complex interplay of environmental, economic, and community interests (Masuhara, 2021).

The construction and operation of geothermal power plants, like other power facilities, impact their surroundings in various ways. According to the U.S. Department of Energy (2014), geothermal plants operate by extracting heated underground fluids through wells. These fluids are separated into steam and hot water; the steam powers turbines to generate electricity. The spent steam is condensed back into water and re-injected into the earth, along with other fluids, to sustain the geothermal reservoir and maintain underground pressure. The Ministry of the Environment in Japan has thoroughly examined and reported on local effects of geothermal plants, identifying principal environmental concerns, such as noise and vibrations from drilling, alteration of underground water sources and hot springs, and landscape degradation due to visible steam plumes released during the steam condensation process (Ministry of the Environment, 2011). These impacts, significant enough to potentially reduce land values in adjacent areas, highlight the critical need for thorough research into the economic externalities of geothermal development, alongside meticulous regulatory oversight and advanced technological measures.

Many studies have assessed the externalities of renewable-energy power plants by analyzing changes in land and property prices, especially in the context of wind power. For instance, Jensen et al. (2014) observed that in Denmark, wind turbines adversely affected landscape aesthetics and noise levels, leading to a 5% reduction in housing prices. Similarly, Droes and Koster (2016) reported that housing prices within 2 km of wind farms in the Netherlands declined by an average of 1.4%. Furthermore, Krekel and Zerrahn (2017) found that in Germany, wind turbines had negative externalities ranging from €9–59 (approximately ¥1,100–7,400) per turbine annually. Meanwhile, other studies like those by Vyn (2018) in Ontario, Canada, found a 6% drop in prices within 1 km and a 3% decrease within 4 km of wind farms in areas opposing their construction, with no significant impacts in regions supportive of wind farms. Lang et al. (2014) also found that wind turbines had varying impacts on house values, depending on their proximity to the turbines, in a study conducted in Rhode Island, U.S.

While the majority of research points to a tendency for wind power to reduce land and property values, these findings also underscore that the extent of negative externalities can significantly vary by region. This variability presents important considerations for geothermal development, as it suggests that similar economic impacts could be expected. Therefore, understanding the specific negative externalities associated with geothermal energy is crucial, particularly since existing research predominantly focuses on wind power, leaving geothermal impacts largely unexplored. In Japan, grasping the effects of geothermal power plants on local land values is vital for the government, as it seeks to advance geothermal development and gain regional acceptance.

To empirically assess the economic externalities of geothermal power, we employ a hedonic pricing approach combined with a difference-in-differences framework. Our analysis covers 28 large-scale geothermal power plants, operational as of 2018, and examines their impact on local land prices over a 42-year period (1983–2024). The results reveal a significant decline in land prices within a 2 km radius, ranging from 7% to 12% post-installation, even after controlling for various fixed effects and robustness checks.

The remainder of this paper is organized as follows: Section 2 describes the data, Section 3 outlines the methodology used for the analysis, Section 4 presents the estimation results and interpretation, and Section 5 concludes the study.

2. Geothermal Power Generation

As discussed in Chapter 1, geothermal power has significant potential to contribute to Japan's energy transition, yet its expansion remains limited due to regulatory barriers and concerns over negative externalities, such as its impact on hot springs and local land values. Despite being the third-largest holder of geothermal resources globally, Japan ranks only tenth in installed geothermal capacity, highlighting the persistent challenges hindering its development. To understand these issues in depth, this chapter examines the technical characteristics of geothermal power generation and the key obstacles to its wider adoption.

2.1 Technical Advantages of Geothermal Power

Geothermal power utilizes thermal energy from deep underground, offering a stable and continuous power supply that is unaffected by weather conditions—a major advantage over solar and wind power. The capacity utilization rate of geothermal plants is approximately 70%, significantly higher than that of solar (below 20%) and wind power. Furthermore, Japan has an estimated 23 million kW of geothermal resources, meaning that if fully utilized, geothermal energy could serve as a reliable baseload power source, enhancing Japan’s energy security and carbon neutrality goals.

2.2 Barriers to Geothermal Expansion

Despite these advantages, several major barriers hinder the wider adoption of geothermal power in Japan. These can be categorized into two main areas:

(1) Regulatory Constraints

A significant portion (44%) of Japan's geothermal resources are located within national and quasi-national parks, where strict environmental regulations make development difficult. While policy reforms in 2012 and 2015 eased some restrictions, developers must still comply with stringent environmental assessments and obtain multiple permits. This lengthy and uncertain process discourages investment and slows expansion.

(2) Socioeconomic Challenges & Local Opposition

Local communities, particularly hot spring tourism stakeholders, often oppose geothermal projects due to concerns over changes in water temperature, pressure, or depletion of underground resources. Since both geothermal power plants and hot springs depend on the same geothermal reservoirs, local resistance remains a major obstacle to project approval. Furthermore, there is a lack of empirical research on how geothermal development affects land values and regional economies, leading to uncertainty and delayed decision-making by policymakers and investors.

2.3 Evaluating the Economic Externalities of Geothermal Power

Understanding these regulatory and socioeconomic challenges is crucial for evaluating how geothermal power plants impact surrounding land values—a key focus of this study. Addressing these barriers will require policy adjustments, technological innovations, and strategies for building local consensus. The following sections will conduct an empirical analysis of the negative externalities of geothermal power plants, specifically examining their impact on local land values and the broader implications for Japan's energy policy and regional economic development.

3. Data

To analyze the negative externalities of geothermal power plants on surrounding land prices, this study collected data on all 28 large-scale geothermal power plants in Japan with a capacity of at least 1,000 kilowatts (kW) that were operational as of 2018. **Figures 1 and 2** illustrate the locations of large-scale geothermal power plants and the trends in their numbers, respectively. While the number of large-scale geothermal power plants has increased with the relaxation of relevant regulations, development remains slow from a global perspective, as discussed in **Section 1**.

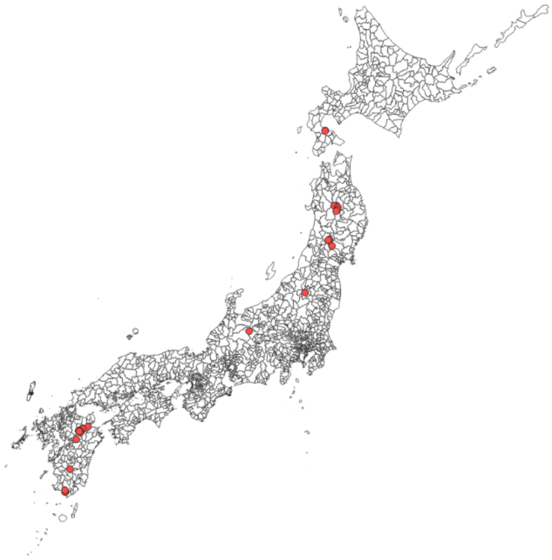

Figure 1: Locations of large-scale geothermal power plants in Japan

Note: The red markers in this map indicate the locations of large-scale geothermal power plants in Japan (capacity of at least 1,000 kW) as of 2024.

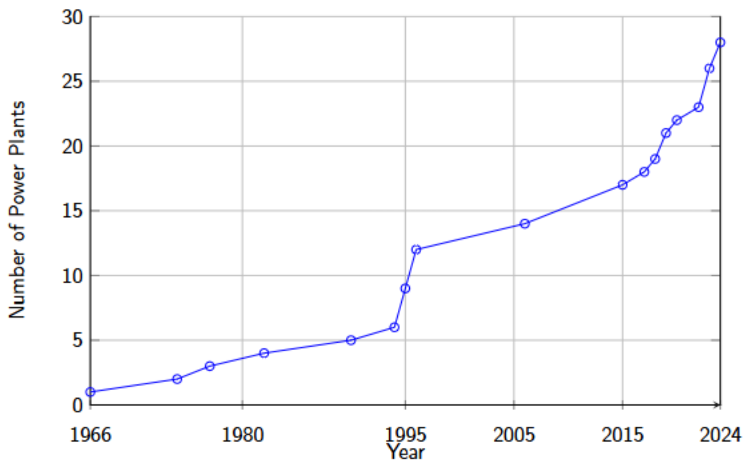

Figure 2: The number of large-scale geothermal power plants in Japan

The data used in this study consists of annual records covering a 42-year period from 1983 to 2024, obtained from publicly available sources. Annual land price data, based on land valuation standard sites, which are widely used designated reference points for assessing land prices in Japan, were sourced from the Ministry of Land, Infrastructure, Transport and Tourism (MLIT)[1]. Land price

[1] Ministry of Land, Infrastructure, Transport and Tourism (MLIT). "National Land Numerical Information Download Service." Available online: https://nlftp.mlit.go.jp/ksj/ (in Japanese).

records have been available since 1983. Although land valuation standard sites are distributed nationwide, we used only those located in municipalities with at least one large-scale geothermal power plant. The locations of the large-scale geothermal power plants were obtained from the Independent Administrative Institution, Japan Organization for Metals and Energy Security (JOGMEC)[2]. All large-scale geothermal power plants included in this study were installed during the sample period from 1983 to 2024.

Table 1 presents the descriptive statistics for all observations, as well as for land valuation standard sites located within and beyond of a 2-kilometer (km) radius of the nearest geothermal power plant. The former constitutes the treatment group, while the latter serves as the control group, as explained later in **Section 3**. The mean land price across all observations is 47,081 Japanese yen (JPY) per square meter (m^2), equivalent to approximately 324 US dollars (USD) as of 2024.

Table 1: Descriptive Statistics

	All		<2km of a Geothermal Power Plant		>2km of a Geothermal Power Plant	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Land Price(JPY/m2)	47081.72	98591.7	87438.46	123581.4	44873.76	96557.78
Distance from the nearest station(m)	3628.641	6802.464	2256.384	1300.156	3703.719	6971.676
Building size(m2)	903.587	4010.191	333.1919	307.8297	934.794	4115.528
Floor area ratio(%)	153.7192	152.0077	223.0303	98.08536	149.9271	153.5171
Building coverage ratio(%)	28.28871	32.69566	45.94949	28.69697	27.32246	32.62643
No. of Observation	19085		990		18095	

To control the differences in the characteristics of land valuation standard sites, we used the distance from the nearest station, building size, floor area ratio, and building coverage ratio. The distance from the nearest station represents the distance from the land valuation standard site to the closest train or subway station, measured in meters (m). The building size refers to the total floor area of a building built on the land valuation standard site, measured in square meters (m^2). This represents the livable space within the building, excluding non-habitable areas such as parking spaces or some storage areas. The floor area ratio is a measure of the building size relative to the size of the land valuation standard site, commonly used in urban planning and real estate to regulate building density. The building coverage ratio represents the proportion of a land plot that a building's footprint can

[2] Japan Organization for Metals and Energy Security (JOGMEC). "Geothermal power in Japan". Available online: https://geothermal.jogmec.go.jp/information/plant_japan/ (in Japanese).

occupy. It is an important regulation in urban planning and zoning laws, restricting the portion of a plot that can be covered by structures.

It is important to note that in the treatment group, the average distance to the nearest station is greater than 2 km, which is considered relatively far in Japan. As expected, geothermal power plants are typically built in rural areas, where land prices tend to be lower. In our regression analysis, differences in average land prices across locations are controlled for using postal code fixed effects, ensuring that location-specific factors do not bias the results.

4. Empirical methodology

To clarify the negative economic impacts on land prices surrounding geothermal power plants, this study employs a hedonic approach. While similar methods have been applied to wind power plants in previous research, they have not yet been applied to geothermal power plants.

We compare the price changes between the treatment and control groups before and after the installation of a geothermal power plant using a standard difference-in-difference approach. The treatment group consists of land valuation standard sites within a concentric ring of radius d around a geothermal power plant installed during the sample period. According to Droes and Koster (2016), wind power plants are approximately 40-50 m tall and visible from up to 2 km away. Since geothermal power plants are of similar height, we assume that they are also visible within a 2 km radius. Consequently, we set the first concentric ring at a radius of 2 km ($d = 2$). We repeated the analysis by changing d to 2 and 3 km (See **Figure 3**).

Figure 3: Example of concentric rings

Note: This figure illustrates a geothermal power plant at the center, a land valuation standard site (i), and concentric rings with radii of 1 km and 5 km (d = 1, 5). The land valuation standard site is located at the end of a red line extending from the power plant.

Source: Map adapted from the Geospatial Information Authority of Japan, with modifications by the authors to include the geothermal power plant, land valuation standard site, and concentric rings.

The first model is specified as follows:

$$\ln(Price_{it}) = \beta_1 + \beta_2 G_{it} + \gamma_i + \delta_t + \epsilon_{it}, \quad (1)$$

where $\ln(Price_{it})$ is the dependent variable representing the log-transformed price of land valuation standard site i in year t. G_{it} is an indicator variable that equals one in the years following the installation of the first geothermal power plant in year t, when site i is located within d km of the plant. Therefore, β_2 captures the average treatment effect. γ_i is a treatment group dummy. Since geothermal generators are typically installed in areas with low land prices, γ_i controls for potential selection effects and remains constant over time. δ_t is the year effect, capturing economic fluctuations, while ϵ_{ijt} is the error term.

In the second model, we use a source of exogenous variation to control for differences in land valuation standard site composition between the control and treatment groups. Using a hedonic approach, the model is specified as follows:

$$\ln(Price_{it}) = \beta_1 + \beta_2 G_{it} + \alpha x_{it} + \gamma_i + \delta_t + \epsilon_{it}, \quad (2)$$

where x_{it} is a set of characteristics of land valuation standard sites, including the distance from the nearest station, building size, floor area ratio, and building coverage ratio.

Geothermal power plants are not randomly distributed across the country. They are often placed in less desirable areas, which may introduce selection bias. Since many unobserved factors, such as zoning regulations, characterize treatment areas and influence land prices, incorporating more granular location fixed effects is preferable. Accordingly, we specify the third model as follows:

$$\ln(Price_{it}) = \beta_1 + \beta_2 G_{it} + \alpha x_{it} + \tau_{ij} + \delta_t + \epsilon_{it,} \quad (3)$$

where τ_{ij} represents the five-digit postal code area j of site i, capturing location fixed effects. In Japan, a five-digit postal code typically covers a small section of a neighborhood, comparable to a census block in the United States. The treatment group dummy γ_i from equations (1) and (2) is excluded from this model, as it is nearly collinear with the location fixed effects captured by τ_{ij}.

5. Results

The results section is organized as follows. In **Section 4.1**, we present our baseline estimates for the average treatment effect. In **Section 4.2**, we check the robustness of the results under different identifying assumptions. In **Section 4.3**, we examine whether anticipation and adjustment effects play a significant role.

4.1 Estimated negative externalities from geothermal power plants

Table 2 contains the regression estimates based on equations (1)-(3). Column (1) reports the regression estimates of equation (1), the difference-in-difference model. The results in column (1) indicate that, on average, land prices were 29% lower in areas within 2km of a geothermal power plant after its installation, compared to areas without a nearby geothermal power plant. In column (2), we added characteristics of land valuation standard sites as additional control variables. The average treatment effect (12%) was smaller than the previous estimate in column (1). The larger effect in column (1) (29%) may have been partially inflated due to omitted variables that influenced land prices. In column (3), we included location fixed effects captured by five-digit postal codes specified in equation (3). By controlling time-invariant locational characteristics, we removed unobserved factors that might influence land prices. As a result, the estimated impact of geothermal power plants became smaller: the treatment effect was a 7% decrease in land prices.

To identify the causal effect of a geothermal power plant on land prices, columns (4), (5), and (6) extended the distance threshold from 2 km to 3 km from the geothermal power plant ($d = 3$). The average treatment effects in columns (4), (5), and (6) were similar to the results for the 2 km threshold. A statistical test confirmed that the difference between the coefficients of ***Geothermal Within<2km×After*** and ***Geothermal Within<3km×After*** was not statistically significant at the 5% level, indicating that the impact on land prices remained consistent across these distance thresholds.

Table 2: Estimated negative externalities from geothermal power plant

	Land price (log)					
	(1)	(2)	(3)	(4)	(5)	(6)
Geothermal Within<2km×After	-0.290***	-0.127***	-0.0724**			
	(0.0495)	(0.0352)	(0.0345)			
Geothermal Within<2km	0.283***	0.343***				
	(0.0402)	(0.0237)				
Geothermal Within<3km×After				-0.234***	-0.207***	-0.111***
				(0.0318)	(0.0220)	(0.0195)
Geothermal Within<3km				0.447***	0.342***	
				(0.0302)	(0.0187)	
Distance to the station (log)		-0.165***	-0.103***		-0.167***	-0.105***
		(0.00605)	(0.00595)		(0.00610)	(0.00600)
Building size (log)		-0.0499***	-0.0135		-0.0482***	-0.0110
		(0.0105)	(0.00930)		(0.0104)	(0.00924)
Floor Area Ratio		0.00272***	0.00196***		0.00264***	0.00193***
		(5.02e-05)	(4.46e-05)		(4.98e-05)	(4.38e-05)
Building Coverage Ratio		-0.000252	-0.00394***		-0.000131	-0.00394***
		(0.000218)	(0.000193)		(0.000218)	(0.000193)
Constant	9.618***	11.14***	11.28***	9.613***	11.13***	11.27***
	(0.0658)	(0.0896)	(0.0881)	(0.0658)	(0.0887)	(0.0879)
Municipality Fe	Yes	Yes	No	Yes	Yes	No
Time Fe	Yes	Yes	Yes	Yes	Yes	Yes
Zip_code Fe	No	No	Yes	No	No	Yes
Number of Observations	19,085	17,836	17,836	19,085	17,836	17,836
R-squared	0.301	0.584	0.774	0.308	0.586	0.775

Note: The values in parentheses represent robust standard errors. ** indicates significance at the 5% level, and * at the 10% level.

5.2 Robustness checks

To more rigorously test the causal impact of geothermal power plants on land prices, we conducted several robustness checks.

First, we examined various fixed effects by redefining the treatment and control groups. The results in **Section 4.1** may still be influenced by unobserved factors, such as changes in zoning regulations, which could affect our estimates. To address this, we restricted our sample to land valuation standard sites within 4 km of a geothermal power plant and varied the control groups by changing d. The estimated coefficients for these models are presented in columns (1)-(2) of **Table 3**.

Table 3: Sensitivity analysis

	Land price (log)				
	(1)	(2)	(3)	(4)	(5)
	2km circle,2-4 km control group	3km circle,3-4 km control group	Municipality×year FE	Municipality×year trends	Municipality×decade
Geothermal Within<2km×After	-0.0772*		-0.0957**	-0.1121	-0.128***
	(0.0426)		(0.0403)	-0.0405	(0.0396)
Geothermal Within<2km	0.0828***		0.343***	0.3599***	0.358***
	(0.0267)		(0.0261)	-0.0264	(0.0262)
Geothermal Within<3km×After		-0.128***			
		(0.0306)			
Geothermal Within<3km		0.266***			
		(0.0235)			
Distance to the station (log)	-0.0926***	-0.147***	-0.156***	-0.153	-0.156***
	(0.0124)	(0.0156)	(0.00584)	-0.00577	(0.00596)
Building size (log)	0.0564***	0.0181	-0.0513***	-0.0532	-0.0517***
	(0.0216)	(0.0200)	(0.0102)	(0.0102)	(0.0102)
Floor Area Ratio	0.00208***	0.00198***	0.00288***	0.00290***	0.00285***
	(0.000112)	(8.56e-05)	(5.30e-05)	(5.30e-05)	(5.28e-05)
Building Coverage Ratio	-0.00111**	-0.000936**	0.000531**	0.000521**	-9.32e-05
	(0.000478)	(0.000436)	(0.000237)	(0.000237)	(0.000229)
Constant	9.037***	9.929***	11.06***	11.635***	11.04***
	(0.230)	(0.253)	(0.145)	-0.084	(0.0862)
Municipality Fe	Yes	Yes	No	No	No
Time Fe	Yes	Yes	Yes	Yes	Yes
Municipality×year	No	No	Yes	No	No
Municipality×yeartrend	No	No	No	Yes	No
Municipality×decade	No	No	NO	No	Yes
Number of Observations	3,260	3,924	17,836	17,836	17,836
R-squared	0.637	0.676	0.610	0.610	0.598

Note: The values in parentheses represent robust standard errors. ** indicates significance at the 5% level, and * at the 10% level.

In column (1) of **Table 3**, the treatment group consists of land valuation standard sites within a concentric ring of radius $d = 2$ km around a geothermal power plant, while the control group includes sites located between 2 km and 4 km from the geothermal power plant. The results indicate that geothermal power plants reduced land prices by 7%, a statistically significant effect at the 5% level. In column (2), the treatment group consists of sites within a concentric ring of radius $d = 3$ km around a geothermal power plant, and the control group includes sites located between 3 km and 4 km from the geothermal power plant. The model estimates that geothermal power plants reduced land prices by 12.8%, with statistical significance at the 5% level. Note that these results may still be underestimated, as the impact of geothermal power plants could extend beyond the sample limit of 4 km, potentially introducing a downward bias in the estimated coefficients.

Next, we examined our assumption that any remaining unobserved time-varying factors did not influence the treatment effect. The relationship between distance and land prices may be affected by unobserved time-varying characteristics of the location (e.g., economic conditions, infrastructure development) or by shifts in the implicit prices of housing characteristics (e.g., changes in how buyers value factors like house size or proximity to amenities over time). To control for these potential biases, we included municipality × year fixed effects and municipality-specific linear time trends to account for time-varying unobserved factors at the municipality level. Additionally, since our data span over 40 years, it is likely that many unobservable factors have changed over time. To address this, we incorporated fixed effects for each municipality and decade combination (1983–1993, 1994–2004, 2005–2015, 2016–2024) to capture long-term trends. The estimated coefficients for these models are presented in **Table 3**, columns (3)-(5).

In column (3), which includes municipality × year fixed effects, the model estimates that geothermal power plants reduced land prices by 12%, a statistically significant effect at the 5% level. In column (4), which includes municipality-specific linear time trends, the estimated effect was -11.2%, while in column (5), which includes municipality × decade fixed effects, the effect remained -11.2%. These results were also statistically significant at the 5% level. However, these effects were slightly smaller than our baseline estimate in column (1) - (3) of **Table 3**, likely because part of the treatment effect was absorbed by the municipality × year fixed effects, municipality-specific linear time trends, or municipality × decade fixed effects.

Overall, these robustness checks confirmed that the reliability of our original results in **Table 2**, reinforcing the negative externalities of geothermal power plants on land prices.

5.3 Event study

Land prices may decline not only after a geothermal power plant is installed but also during the planning and construction phases. To address this, we estimated a model that decomposes the treatment effect before and after the installation of a geothermal power plant. The model is formulated as follows:

$$\ln(Price_{it}) = \beta_1 + \sum_{\sigma=-10}^{10} \beta_{i\sigma} G_{i\sigma} + \alpha x_{it} + \tau_{ij} + \delta_t + \epsilon_{it}, \tag{4}$$

where σ represents event time in years. Although σ in our sample ranges over potentially long period, we focus on the effects within the range of $-10 < \sigma < 10$, with $\sigma = -1$ as a reference year. One issue with data availability is that land valuation standard sites have changed over the years, resulting in cases where land price data are unavailable for the treatment group ($d = 2$) in certain years. Consequently, not all event times can be estimated.

Figure 4 presents the results. The pre-treatment coefficients are close to zero, indicating no significant effects on land prices six, five, and four years before the power plant was installed. However, land prices show a sharp decline in the first year after installation. Despite this trend, the standard errors are quite large, suggesting that these estimates may not be precise, and the differences between the treatment and control groups may not be statistically significant. Additionally, an increase in land prices two years before the installation of power plant is concerning, as it raises questions about potential biases in the analysis.

Figure 4: Years before/after construction geothermal power plants

Notes: This figure depicts the difference in land price changes between the control (>2km of a power plant) and treatment group (within 2 km of a power plant) in years to/after installation of a power plant. The vertical dashed lines represent 95% confidence intervals.

6. Conclusions

This study quantitatively assessed the negative externalities of geothermal power plants by examining their impact on local land values in Japan. Using a hedonic pricing approach and a difference-in-differences framework, we analyzed how land prices within proximity to geothermal power plants were affected after their installation. Our results indicate that, on average, land prices within a 2 km radius of geothermal power plant declined by approximately 7% to 12%, even after accounting for various fixed effects and robustness checks.

These findings provide important policy implications for Japan's renewable energy development. While geothermal energy is a stable and cost-effective base-load power source, its expansion is hindered by concerns over environmental and economic externalities, particularly in regions with high tourism value due to hot springs. The observed decline in property values suggests that local communities bear significant costs associated with geothermal power plants, which could contribute to resistance against new developments.

From a regulatory perspective, our results highlight the need for compensatory measures or improved planning strategies to mitigate these externalities. Policymakers should consider strategies such as revenue-sharing mechanisms, enhanced compensation for affected homeowners, or stricter zoning regulations to minimize the impact on residential areas. Additionally, investing in technologies that reduce visual and environmental impacts, such as improved steam re-injection techniques, could help alleviate some of the negative perceptions associated with geothermal power.

Despite the limitations of our study, such as potential unobserved factors influencing land prices and the geographical constraints of geothermal resources, the findings offer a crucial step toward understanding the economic consequences of geothermal energy deployment. Future research could further refine these estimates by incorporating survey-based approaches to assess public perceptions or examining long-term socio-economic impacts beyond land prices.

Overall, this study underscores the complex interplay between renewable energy expansion and local economic conditions. As Japan seeks to increase its geothermal capacity, balancing the benefits of clean energy with the concerns of local stakeholders will be critical to achieving sustainable energy transitions.

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