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Article

Assessing the impact of Saitama Emissions Trading Scheme on energy consumption and economic performance at the facility level

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ABSTRACT

This study investigates the impact of the Saitama Emissions Trading Scheme (ETS) on energy usage and economic activity among regulated facilities during its first phase (2011–2014) and the first 4 years of its second phase (2015–2018). Focusing on electricity, city gas, and heavy oil, as well as the number of employees as a proxy for economic activity, we apply a difference-in-differences (DID) method to evaluate the impact of Saitama ETS on regulated facilities. The annual average energy consumption indicates that a reduction in city gas and heavy oil consumption was observed after the ETS was implemented, while no notable change was observed in electricity consumption. The average treatment effect on the treated (ATT) estimates indicate that regulated facilities' electricity consumption increased by approximately 3%–4%, city gas consumption rose slightly and then declined by 25.58%, and heavy oil use decreased by 5.69% and 34.82% across the two phases. Although differences in energy consumption between regulated and unregulated facilities are not statistically significant, the analysis of employee numbers suggests that the ETS did not negatively affect economic activity. For all facilities, we found a significant positive effect emerges in the second phase, showing a 5.67% increase in the number of employees.

KEYWORDS

Emissions trading scheme, energy consumption, employment, policy evaluation, Difference-in-Differences, Japan.

1 Introduction

Climate change caused by the emission of greenhouse gases (GHGs) has become a critical issue, exerting significant impacts on economic and social activities. To reduce GHG emissions efficiently, emissions trading schemes (ETS) have been introduced as one of the primary policy instruments. The adoption of ETS is becoming increasingly common. For example, the European Union Emissions Trading System (EU ETS) was launched in 2005 and has entered its fourth phase. The second Emission Trading System (EU ETS 2) will cap emissions in buildings, road transport, and small industries[1]. In the United States, systems such as the Regional Greenhouse Gas Initiative (RGGI) and California's cap-and-trade program have been implemented. Other countries, including New Zealand, Switzerland, Canada, and Kazakhstan, have also launched ETS. In Asia, Republic of Korea and China introduced nationwide emissions trading schemes in 2015 and 2021[2]. Along with the advancement of these policies, numerous empirical studies have begun to quantitatively assess the policy effects of ETSs in various countries[3–5].

Since fiscal year 2023, Japan has implemented a voluntary emissions trading scheme (GX-ETS), under which companies set their own emissions reduction targets[6]. ETS with mandatory participation for large firms is scheduled to begin in fiscal year 2026[7]. As a pioneering regional-level ETS, Tokyo and Saitama Prefecture launched the first phase of their ETS in 2010 and 2011, respectively. Tokyo's ETS was the first in the world to cover the commercial sector and includes penalties for noncompliance by regulated facilities. In contrast, Saitama's ETS focuses on the industrial sector and does not impose penalties for noncompliance, instead encouraging regulated facilities to voluntarily reduce CO_2 emissions. Concerns over potential negative impacts on the national economy, particularly industrial competitiveness, are widely regarded as a key reason for the delay in implementing a national ETS in Japan. The potential adverse impacts of environmental regulations on firms' production activities have long been a subject of concern. However, as an environmental policy instrument designed to internalize externalities through market mechanisms, the ETS has generally not been found to exert significant adverse impacts on production in studies examining ETS implementations in other countries[8–9]. Therefore, when considering the introduction of ETS at the national level, it is essential to balance emissions reduction with the preservation of economic activity.

As noted above, the Saitama ETS was launched in 2011 as Japan's second regional emissions trading scheme. It is designed to impose CO_2 reduction targets on large-scale facilities, defined as those whose annual energy consumption, measured in heave oil equivalent, exceeds 1,500 kiloliters for three successive fiscal years. Since its introduction, the scheme has been implemented in successive compliance phases. The first phase covered 2011–2014, followed by the second phase (2015–2019) and the third phase (2020–2024). The scheme is currently in its fourth phase, which began in 2025 and will conclude in 2029. Additionally, the Saitama ETS further classifies regulated facilities into factories and office buildings. Factories consistently represented the majority of regulated facilities, accounting for 428 of 608 facilities (around 70%) in the first phase and 445 of 630 facilities (around 71%) in the second phase. Most factories are categorized under the industrial sector, which accounted for about 20% of Saitama Prefecture's total CO_2 emissions. It can be observed that although the industrial sector does not account for a particularly large share

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of total CO_2 emissions in Saitama Prefecture, the Saitama ETS emphasizes reducing emissions from this sector, as individual facilities tend to exhibit relatively high levels of energy consumption. An improperly designed ETS risks adversely influencing the economic performance of industries. Notably, the Saitama ETS does not impose penalties for noncompliance and instead encourages voluntary CO_2 emissions reductions by regulated entities. But, for the purpose of confirming achievement with reduction targets and implementing emissions trading, facilities must undergo third-party verification to ensure the accuracy and reliability of their calculated emissions data[10].

In terms of emissions reduction, the effectiveness of the Saitama ETS has been demonstrated by both publicly available data and empirical analyses. Hamamoto[11] conducted a quantitative analysis combining data from the regulated facilities in Saitama ETS and Gunma Prefecture's reporting program for annual GHG reduction plans and found that the Saitama ETS led to approximately a 14% reduction in CO_2 emissions among regulated facilities during the first phase. Furthermore, this research showed that the Saitama ETS not only encouraged emissions reductions among regulated facilities during the first phase but also served as an incentive to reduce energy consumption among unregulated facilities. Sadayuki & Arimura[12] used facility-level data to examine within-firm carbon leakage under the Tokyo and Saitama ETS programs. Their analysis revealed that firms with regulated facilities under the ETS reduced emissions not only at those facilities but also at their unregulated facilities located outside Tokyo and Saitama, compared to firms without regulated facilities. Their research also suggest that a larger entity is more capable of reducing emissions from facilities in regions with less stringent regulations. However, the effects of the Saitama ETS on the energy consumption and production activities of regulated firms have not been sufficiently discussed.

Several studies have attempted to quantify how ETS affects energy consumption and economic activity at the facility or firm level. Focusing on manufacturing, Petrick & Wagner[13] used German data to estimate the causal effect of the EU ETS on CO_2 emissions and found that regulated firms reduced their emissions by one-fifth compared to unregulated firms. This reduction was mainly achieved through improvements in energy efficiency and reductions in the use of natural gas and petroleum products, while electricity use remained unchanged. In addition, no evidence of negative impacts on employment, total output, or exports was found. Hu et al.[14] investigated the effects of China's ETS pilot policy on energy conservation and emission reduction. Their results showed that energy consumption in regulated industries in pilot regions decreased by 22.8% compared to those in non-pilot regions, and CO_2 emissions declined by 15.5%. In the context of Japan, Abe and Arimura[15] analyzed the Tokyo ETS using facility-level data and estimated its effects on energy use and economic activity. Their findings indicated that while both regulated and unregulated facilities reduced energy use, the ETS did not negatively affect the economic activity of regulated entities. Overall, while the existing literature generally finds that ETS contributes to CO_2 emissions reductions, the evidence on its effect on energy consumption remains mixed.

Moreover, ETS can also have impacts on fuel substitution and other energy efficiency factors, which may further shape energy consumption patterns and other performance indicators. As a study about the EU ETS, Delarue et al.[16] suggest that in the early stages of the EU ETS, it induced fuel switching from coal to gas in the power sector, leading to substantial CO_2 reductions. Firm-level evidence from the Hubei ETS pilot in China suggests that ETS can reduce overall energy consumption while gradually promoting energy transition. In particular, the primary peak of relative coal consumption declines markedly, whereas the share of electricity consumption rises, indicating a switch from coal to electricity. Overall, ETS contributes to lowering energy-induced CO_2 emissions and may facilitate the decoupling of economic growth from fossil energy use[17]. In Japan, Hamamoto[18] investigated whether the ETS promoted the adoption of low-carbon technology using data on manufacturing facilities in Saitama Prefecture. The results suggest that the introduction of high-efficiency equipment was promoted during the first three years of the second phase. This implies that while relatively low-cost abatement plans were adopted during the first phase, regulated facilities may have invested more capital and resources in the second phase to implement higher-efficiency technologies. The above studies highlight the importance of examining the impacts of the Saitama ETS on energy consumption as well as the potential mechanisms.

This study examines the policy impact of the Saitama ETS on energy consumption and economic activity at the facility level during the first phase (2011–2014) and the first four years of the second phase (2015–2018), using panel data from 2007 to 2018. Specifically, the analysis focuses on facilities located in Saitama Prefecture, dividing them into two groups—regulated and unregulated facilities—and applies a difference-in-differences (DID) approach to estimate the effects of the ETS on electricity, city gas (piped natural gas supply provided to households and businesses), and heavy oil consumption. In addition, the number of employees at each facility is used as a proxy for economic activity and is also analyzed using the DID method.

The main contributions of this study are as follows. Since no study has examined the impact of the Saitama ETS on economic activity, this paper is the first to address this topic. By simultaneously considering both energy consumption and economic activity, the study makes it possible to assess not only the effect of the ETS on energy consumption reduction, but also whether the scheme has any adverse effects on production. In addition, by focusing on the Saitama ETS, which adopts a voluntary target-setting approach, this study enables an evaluation of how such a scheme affects energy consumption in the industrial sector. Furthermore, by conducting an empirical analysis using panel data, the study contributes to a better understanding of the impact of ETS regulation in Japan and offers insights for ongoing policy discussions.

The structure of the paper is as follows. Section 2 describes the empirical model and data, and provides an overview of trends in energy consumption of facilities in Saitama. After presenting the results in section 3, we will discuss them and draw conclusions in section 4.

2 Data and empirical model

2.1 Data

This study uses data from fiscal years 2007 to 2018 from the Statistical Survey of Energy Consumption, compiled annually by the Agency for Natural Resources and Energy of Japan. This survey targets business facilities across the country, covers approximately 180,000 facilities. The survey includes detailed information on energy consumption and expenditure by energy source—such as electricity, city gas, heavy oil, and gasoline—as well as variables representing economic activity, including the number of employees, floor area, and revenue. This study uses survey data from fiscal years 2007 to 2018.

This study focuses on electricity, city gas, and heavy oil as the main energy types. These three energy sources are important inputs for the production activities of business facilities. Given their different emission factors, facilities may thus adjust their consumption of each to different extents in efforts to reduce CO_2 emissions. Compared to heavy oil, city gas has a lower emission factor. Electricity can provide energy with comparatively lower emissions, depending on the method of generation, including the potential use of renewable sources. By examining these three energy types, the analysis not only captures overall energy consumption but also indirectly observes changes in the composition of energy use as regulated facilities adjust their energy mix to reduce emissions. In addition, the number of employees is used as a dependent variable to evaluate economic activity. Employment levels are notably responsive to environmental regulations, reflecting differences in production processes and compliance costs, and exhibit heterogeneous responses across different industries[19].

Table 1 reports descriptive statistics for the log-transformed data. Panels A, B, and C of the table show the distributions of electricity, city gas, and heavy oil consumption, respectively, while Panel D presents the distribution of the number of employees. Based on the average energy consumption and average number of employees, it is clear that regulated facilities are larger than those not covered by the scheme. This is because the ETS targets large-scale facilities that have consumed at least 1,500 kiloliters of heave oil equivalent for three consecutive years, resulting in relatively high energy consumption. There is a substantial difference in the average characteristics between the treatment and control groups, which arises from the regulatory criteria used to determine ETS regulation coverage. As such, simple comparisons would not correctly capture the policy effect, making it necessary to employ a difference-in-differences (DID) approach. The specific empirical strategy is detailed in Section 2.2.

Table 1 Descriptive statistics.

	Number of facilities	Mean	SD.	Min.	Max.
Panel A. ln(Electricity)					
Unregulated	363	6.926	1.106	0	10.345
ETS regulated	165	8.973	1.081	0	11.285
Panel B: ln(City gas)					
Unregulated	77	4.041	1.876	0	9.622
ETS regulated	92	6.476	1.702	0	10.182
Panel C: ln(Heave oil)					
Unregulated	37	3.914	1.603	0	6.589
ETS regulated	35	4.714	2.065	0	8.75
Panel D: ln(Employees)					
Unregulated	366	4.774	0.609	0	7.245
ETS regulated	166	5.435	0.919	2.639	7.555

Note: The dataset was processed by trimming the top 1% of the distribution to address extreme values in electricity generation. Observations with negative values for energy consumption and employment, which are not feasible in practice, were also treated as outliers. To facilitate logarithmic transformation, all values were increased by one before taking logs.

To further explain energy consumption, it is necessary to examine the annual trends in average energy use for regulated and unregulated facilities. Figures 1, 2, and 3 show the annual average consumption trends for electricity, city gas, and heavy oil, respectively. In addition, to analyze the impact on production activity in the industrial sector, the annual average energy consumption trends are summarized separately for manufacturing facilities. Overall, electricity consumption among all facilities shows relatively little variation over time. For ETS-regulated facilities, electricity consumption exhibits a slight upward trend during the second phase compared to unregulated facilities, with manufacturing facilities showing a broadly similar pattern. In contrast, city gas consumption fluctuates more than electricity. Starting from the second year of the first phase, both regulated and unregulated facilities show a downward trend in city gas use, while the decline is evident among regulated facilities. Moreover, during the second phase, city gas consumption continues to decrease among regulated facilities, while it remains largely unchanged among unregulated ones. Furthermore, changes in heavy oil consumption are more pronounced than for the other two energy sources. For unregulated facilities, consumption remains largely unchanged across the periods before and after the introduction of the ETS. In contrast, regulated facilities exhibit a substantial decline in heavy oil consumption after the start of the first phase. In addition, as the prices of the three energy types may cause fluctuations in consumption, we compiled the trends of unit energy prices for comparison (see Figure A1 in Appendix)[19–21]. The energy price data indicate that periods of lower prices did not correspond to higher energy consumption.

Figure 4 shows the trends in the number of employees for both regulated and unregulated facilities. The graph first indicates that there is no evident declining trend in employment before and after the introduction of the policy. During the second phase, the number of employees in regulated facilities shows a slight increase.

2.2 Empirical strategy

This paper estimates the causal impact of the Saitama ETS on energy consumption and economic activity. To identify these

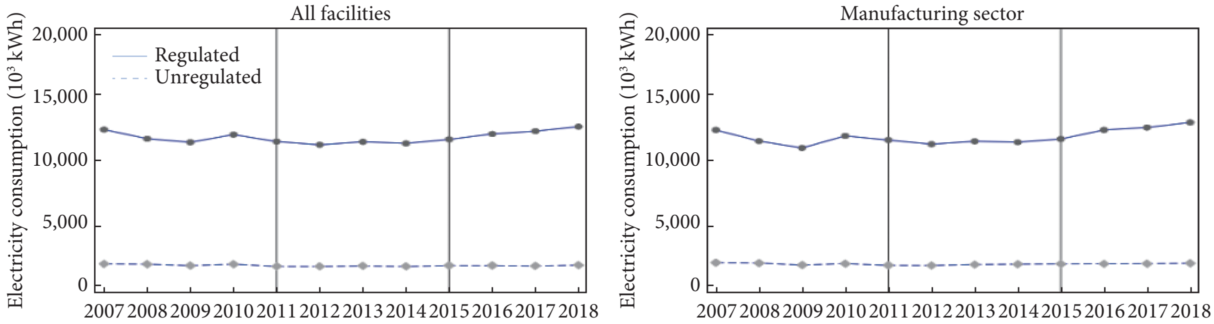

Fig. 1 Annual average electricity consumption (1,000 kWh).

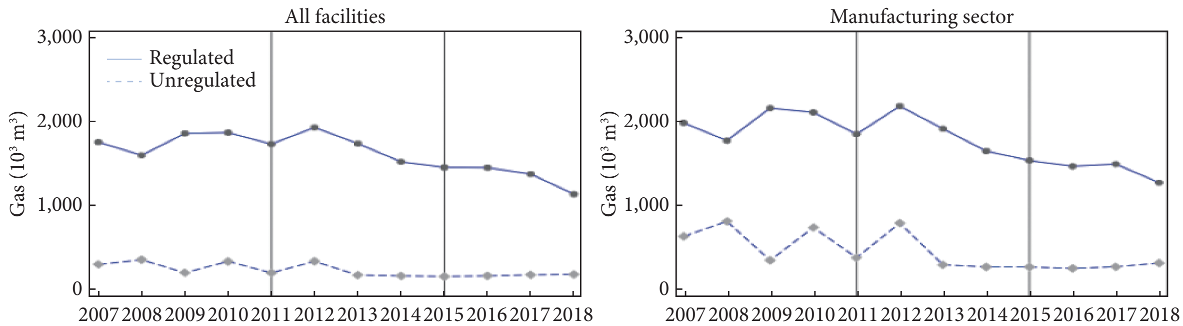

Fig. 2 Annual average city gas consumption (1,000 m^3).

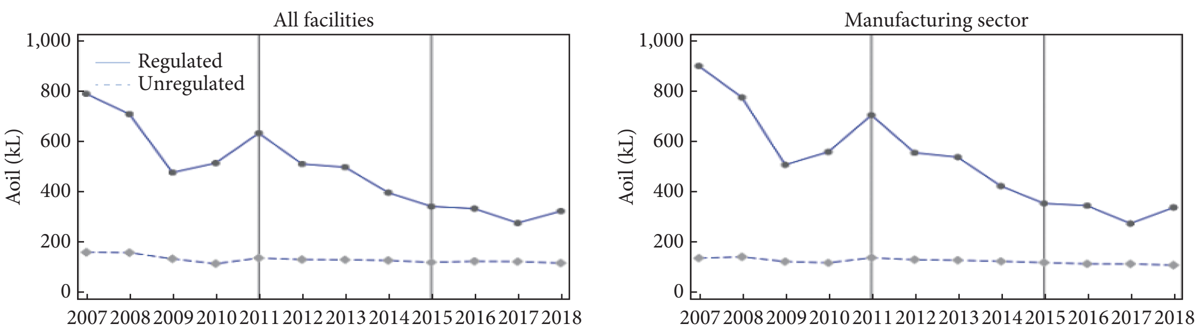

Fig. 3 Annual average heavy oil consumption (kL).

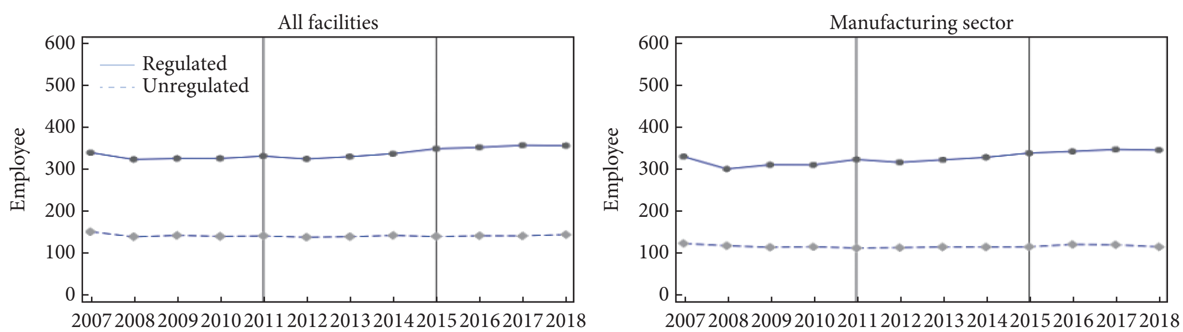

Fig. 4 Annual average number of employees.

impacts, we employ a difference-in-differences (DID) approach, which is widely used for policy evaluation[22, 23]. In this study, $treat_i$ denotes a dummy variable that indicates whether facility i is regulated by the Saitama ETS, taking the value 1 if regulated and 0 otherwise. Similarly, $post_t$ is a dummy variable that equals 0 for the pre-policy period and 1 for the ETS phase. The interaction term $treat_i \times post_t$ shows whether facility i is regulated under the Saitama ETS in year t. Let Y_{it} denotes the energy consumption or economic activity of facility i in year t[13,15]. To distinguish between ETS phases, we define $ETS_{kt} = treat_i \times post_t$ where k denotes the phase. Specifically, when $k = 1$, it corresponds to the first phase. In this case, $treat_i = 1$ if facility i is subject to the ETS during the first phase, and $post_t = 1$ for the years 2011 to 2014. Similarly, when $k = 2$, it indicates the second phase, with $treat_i = 1$ if facility i is regulated during the second phase, and $post_t = 1$ for the years 2015 to 2018. Based on these definitions, we specify the estimation Eq. (1).

$$Y_{it} = \alpha + \beta_0 \boldsymbol{X}_{it} + \beta_1 ETS_{1t} + \beta_2 ETS_{2t} + \tau_i + \delta_t + \varepsilon_{it} \quad (1)$$

Y_{it} denotes the dependent variable for facility i in year t. In this study, the dependent variables include electricity consumption, city gas consumption, heavy oil consumption, and the number of employees. $\boldsymbol{X}_{it}$ denotes a set of control variables capturing facility characteristics, such as the number of employees and total floor area. When estimating equations where the number of employees is the dependent variable, this variable is excluded from $\boldsymbol{X}_{it}$. In addition, τ_i is facility fixed effects (FE), and δ_t is year FE. ε_{it} is the error term for facility i in year t, capturing unobserved factors that affect the dependent variable.

3 Results

3.1 Empirical result

This section presents the estimation results derived from the empirical model described in Section 2. Given that the manufacturing sector is characterized by substantial energy demand, the analysis separately estimates the effects for all facilities and for the manufacturing sector. Tables 2 and 3 report the DID estimation results for these two groups, respectively. Each column in the tables displays the estimated impacts on electricity, city gas, and heavy oil consumption. For all facilities, the estimation results in each column indicate that the coefficients are not statistically significant across energy types. However, the estimates for heavy oil show a negative tendency in both the first and second phases, while the estimates for city gas exhibit a negative tendency in the second phase. These patterns are generally consistent with the trends in energy consumption described in Section 2. Similarly, for manufacturing facilities, although none of the estimates are statistically significant, the results for heavy oil and city gas also display negative tendencies. This phenomenon can be attributed to the differing emission characteristics of the three energy sources. Heavy oil imposes a relatively high environmental burden and has exhibited a long-term declining trend. In contrast, city gas is more cost-effective and entails a lower environmental burden in terms of air pollution. For these reasons, heavy oil is more likely to be the first energy source that firms seek to reduce. This tendency is also evident from emission factors: heavy oil has the highest emission factor, followed by city gas, and both are higher than the emission factor of electricity supplied in Saitama Prefecture (based on TEPCO's emission factor)[24,25].

Table 2 Estimation results for all facilities.

Energy type	(1) ln(Electricity)	(2) ln(City gas)	(3) ln(Heavy oil)
ETS_{1t}	0.0459 (0.0356)	0.075 (0.0890)	−0.0569 (0.1345)
ETS_{2t}	0.0344 (0.0482)	−0.2558 (0.1548)	−0.3482 (0.2379)
ln(Employees)	0.1778*** (0.0448)	0.0451 (0.1343)	0.0387 (0.2231)
ln(Floorspace)	0.1374* (0.0837)	0.1084 (0.3118)	−0.0386 (0.1058)
Cons.	5.3873*** (0.8221)	4.2072*** (3.0070)	4.7712*** (0.6846)
N	5,729	1,783	825
R^2 Adjust	0.9103	0.8449	0.8249
Facility FE	YES	YES	YES
Year FE	YES	YES	YES

Note: Robust standard errors are in parentheses. N denotes the number of observations. (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$).

Table 3 Estimation results for manufacturing sector.

Energy type	(1) ln(Electricity)	(2) ln(City gas)	(3) ln(Heavy oil)
ETS_{1t}	0.0051 (0.0440)	0.0342 (0.1073)	−0.027 (0.1473)
ETS_{2t}	−0.0262 (0.0536)	−0.1214 (0.1816)	−0.2383 (0.2709)
ln(Employees)	0.2886*** (0.0790)	0.0973 (0.2836)	0.0149 (0.2757)
ln(Floorspace)	0.1147* (0.0629)	0.197 (0.2481)	0.3860* (0.1847)
Cons.	5.3536*** (0.6791)	3.8167 (2.8256)	0.9851 (2.2098)
N	3,871	1,109	674
R^2 Adjust	0.8766	0.7505	0.8106
Facility FE	YES	YES	YES
Year FE	YES	YES	YES

Note: Robust standard errors are in parentheses. N denotes the number of observations. (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$).

Moreover, the estimates on the control variables indicate that electricity consumption is positively associated with the number of employees, while among manufacturing facilities, heavy oil consumption is positively related to floor area. These relationships are consistent with expectations, as facilities with more employees typically require greater electricity use for operations, and larger manufacturing facilities are likely to consume more heavy oil due to the scale of production processes. The absence of statistically significant reductions in energy consumption may suggest that regulated facilities achieved emission reduction goals through channels other than direct energy use reduction. Possible explanations include fuel substitution toward lower-emission energy sources, improvements in energy efficiency that allow the same level of production with less CO_2 emission. This pathway would not necessarily result in a measurable decrease in total energy consumption, yet still contribute to lower carbon emissions. As discussed in Section 2.2 on data characteristics, the observed decline in heavy oil use alongside a tendency for increased electricity consumption following the introduction of the ETS may partly indicate a shift in the energy composition. However, further analysis is needed to explicitly examine the extent of substitution among different energy sources.

Table 4 summarizes the DID estimation results for employment, evaluating the economic impact across all facilities and within the subset of manufacturing facilities. For all facilities, no statistically significant effects are observed during the first compliance phase, whereas a significant positive effect emerges in the second phase. In contrast, for manufacturing facilities, no significant estimates are found in either phase. These findings suggest that the ETS may have contributed to an increase in the number of employees in other factors. Empirical studies have shown that the implementation of carbon taxes reduces employment in carbon-intensive sectors but generates employment dividends in low-carbon-intensity industries, thereby contributing to an overall increase in employment[26]. Such effects may also arise under the implementation of an ETS. In the empirical results of this study, the positive employment impact of the Saitama ETS appears in the second phase, which may be attributable to a mitigation of frictional unemployment and the emergence of employment dividends during that period. Another alternative hypothesis is that unregulated firms may reduce their economic activities in order to avoid becoming subject to the ETS. Conversely, regulated facilities are able to expand their activities while maintaining compliance by acquiring additional allowances, a mechanism that could potentially translate into positive employment effects.

Table 4 Estimation results for number of employees.

Energy type	(1) All facilities	(2) Manufacturing sector
ETS_{1t}	0.0111 (0.0179)	−0.0066 (0.0178)
ETS_{2t}	0.0567** (0.0252)	0.018 (0.0271)
ln(Floorspace)	0.1505** (0.0624)	−0.0515 (0.0191)
Cons.	3.6059*** (0.5657)	4.4748*** (0.1752)
N	5,857	3,979
R^2 Adjust	0.9085	0.9339
Facility FE	YES	YES
Year FE	YES	YES

Note: Robust standard errors are in parentheses.Ndenotes the number of observations. (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$).

However, given the limitations of the dataset used in this study, it is not possible to identify the specific factors behind this increase. One possibility is that employment related to improved environmental performance under the ETS may have risen, although this warrants further investigation. To further assess whether the policy has contributed positively to firms' overall production performance, a more detailed analysis focusing on production activities is necessary. Importantly, there is no evidence that the ETS led to job losses, indicating that the policy did not exert a negative impact on the economic performance of facilities.

In addition to what was discussed above, two additional factors may have influenced the empirical findings. First, the observed reductions in city gas and heavy oil consumption in the trends of annual average energy use could partly be attributed to the impact of the 2011 earthquake. However, given that these reductions have continued over time and that electricity consumption does not show a similar downward trend, it would be inappropriate to conclude that the ETS had no effect on energy efficiency. Second, due to a relatively high rate of invalid responses in the survey data, the dataset used in this analysis contains a considerable amount of missing values, making it difficult to fully capture the policy impact at the empirical stage. This represents one of the limitations of this study. Second, due to a relatively high rate of invalid responses in the survey data, the dataset used in this analysis contains a considerable amount of missing values. Moreover, to ensure that the panel data remain balanced over the study period, additional observations had to be excluded. These factors limit the number of observations available for the estimation, making it difficult to fully capture the policy impact at the empirical stage. This represents one of the key limitations of this study.

3.2 Verification of the parallel trends assumption

This section presents the ATT estimates obtained for each year based on the model described earlier, which allows us to assess whether the parallel trends assumption holds. Figures 5, 6, 7, and 8 show the ATT estimates for electricity, city gas, heavy oil consumption, and the number of employees, calculated relative to the baseline year of 2010, which is the last year before ETS was introduced. The ATT estimates before the introduction of the ETS policy are not statistically significant, indicating that the parallel trends assumption is satisfied. This result supports the reliability of the DID estimates.

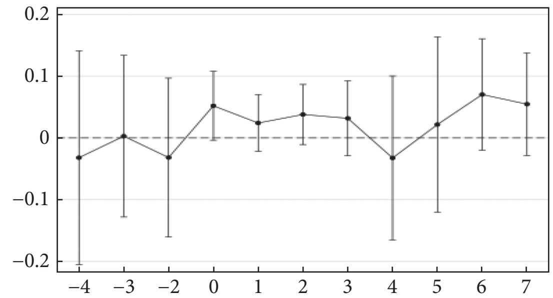

Fig. 5 Dynamic ATT estimates across periods (electricity).

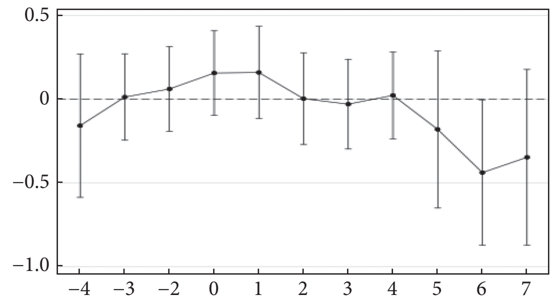

Fig. 6 Dynamic ATT estimates across periods (city gas).

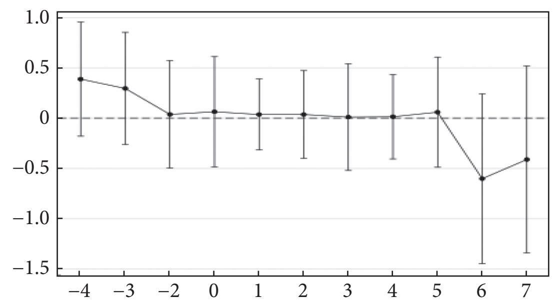

Fig. 7 Dynamic ATT estimates across periods (heavy oil).

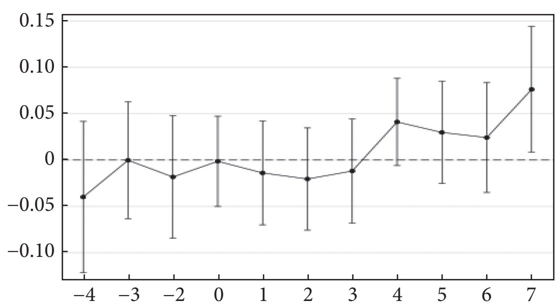

Fig. 8 Dynamic ATT estimates across periods (employees).

4 Conclusions

This study conducted an empirical analysis of the impact of the Saitama ETS on energy consumption and employment at regulated facilities during the first and second compliance phases, using facility-level panel data from 2007 to 2018. Compared to unregulated facilities, regulated facilities exhibited a slight upward tendency in electricity consumption during the second compliance phase, while the city gas consumption showed a notable decline. Furthermore, whereas heavy oil consumption among unregulated facilities remained largely unchanged before and after the implementation of Saitama ETS, regulated facilities experienced a substantial reduction after the implementation. These patterns suggest that the emissions trading scheme may have contributed to a shift away from heavy oil, thereby facilitating CO_2 emissions reductions.

According to the estimation results, there was no statistically significant difference in energy consumption reductions between regulated and unregulated facilities under the Saitama ETS during either the first or second compliance phase. Abe and Arimura[15] similarly examined energy consumption reductions under the Tokyo ETS. While the conclusion is consistent with the findings of this Saitama ETS study, it is noteworthy that the reduction in electricity consumption observed in Tokyo was not evident in Saitama. One possible explanation is that the Tokyo ETS covered a large number of office buildings, for which electricity represented the primary source of energy consumption, making reductions in electricity use essential to meet CO_2 reduction targets. In contrast, the Saitama ETS primarily regulated the industrial sector. Rather than cutting overall energy use and potentially compromising production activity, regulated facilities in Saitama may have sought to achieve emissions reductions by shifting their energy mix toward lower-emission sources. This transition may be accompanied by a reduction in the use of fossil fuels and an increase in electricity consumption[17], which could also explain the observed increase in electricity consumption.

Moreover, there is no evidence that regulated facilities reduced their number of employees relative to unregulated facilities during either the first or second compliance phase. This indicates that the Saitama ETS did not have a negative impact on economic activity. The conclusions of this study are consistent with previous research on manufacturing under the EU ETS and the Tokyo ETS[13,15,27]. Rather than reducing employment, regulated facilities may have achieved emission reductions by lowering their overall energy consumption or by shifting to energy sources with lower emission factors. Furthermore, the distinctive characteristics of Japan's employment system, particularly its downward rigidity in labor adjustments, may help cushion the potential negative impacts of the policy on employment. Also, existing empirical studies indicate that employment effects induced by environmental policies generally take the form of job reallocation across sectors rather than reductions in overall employment levels[28,29]. To advance the understanding of these employment impacts, further research should examine them at a more detailed industry level, provided that sufficiently large samples are available.

In addition, the voluntary nature of the Saitama ETS may have facilitated firms' compliance by allowing them greater flexibility. The Saitama ETS, with a voluntary nature, has proven effective in terms of achieving its emission reduction targets. This effectiveness may be partly attributable to the relatively modest reduction targets compared to those set in the third and fourth compliance phases. Also, facilities tended to adopt lower-cost abatement options, which allowed them to avoid substantial disruptions to their production activities. In this regard, the results of our analysis show no discernible negative effects on production activities. At the same time, the voluntary design, in the absence of strict penalties for noncompliance, may have limited the extent of measurable reductions in overall energy use. When faced with more stringent emission reduction targets, a voluntary ETS carries the risk of becoming ineffective. Accordingly, the voluntary nature of the scheme should be carefully considered in the design of future ETSs.

We acknowledge several limitations. First, due to data constraints, the analysis focuses only on the number of employees as a variable representing facility characteristics. Incorporating additional variables that capture other facility attributes could allow for a more precise analysis. Also, because the dataset from the Statistical Survey of Energy Consumption contains substantial missing values and outliers, constructing a balanced panel required excluding such observations, which in turn limited the sample size available for analysis. As a result, the generalizability of the empirical findings may be limited.

Furthermore, the small sample size restricted the range of empirical methods that could be applied. In addition to the DID analysis conducted in this study, it would have been desirable to verify the robustness of the results using a DID approach based on propensity score matching (PSM-DID). However, this was not feasible given the limited number of observations. Addressing these limitations would require access to a dataset with a larger number of observations.

Appendix

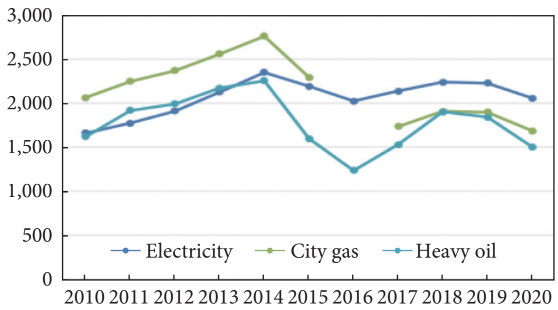

Fig. A1 Comparison of energy price trends (JPY/GJ) Note: The 2016 data for city gas are unavailable due to missing records.

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Author contribution statement

Xinyue Yang is responsible for data curation, formal analysis, writing—original draft, and methodology. Toshi H. Arimura is responsible for conceptualization, writing—reviewing and editing, supervision, data acquisition and funding acquisition.

Data availability

Not applicable.

Use of AI statement

During the preparation of this work, Xinyue Yang used ChatGPT in order to assist with language editing and clarification of academic expressions. After using this tool, the author reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

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