CHALMERS
UNIVERSITY OF TECHNOLOGY

How high feed-in tariffs impacted the capital cost of solar PV in Japan

Citation for the original published paper (version of record):
Kimura, K., Lundberg, L., Kåberger, T. (2025). How high feed-in tariffs impacted the capital cost of solar PV in Japan. Renewable Energy, 244. http://dx.doi.org/10.1016/j.renene.2025.122685

Renewable Energy 244 (2025) 122685

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

How high feed-in tariffs impacted the capital cost of solar PV in Japan

Keiji Kimura [a], Liv Lundberg [b,*], Tomas Kåberger [c]

[a] Osaka Sangyo University, 3-1-1, Nakagaito, Daitoh, 574-8530, Japan
[b] RISE Research Institutes of Sweden, Sweden
[c] Chalmers University of Technology, Sweden

ARTICLE INFO

Keywords:
Feed-in tariff
Solar PV cost
Renewable energy policy
Japan energy policy

ABSTRACT

This study investigates the impact of feed-in tariffs (FITs) on the capital expenditures (CAPEX) of solar photovoltaics (PV) projects in Japan. In 2012, Japan introduced a FIT scheme with the highest tariff levels in the world. Tariffs for a project were set at the time when the project obtained a qualification, but early projects had no deadline for starting operations, and many where not built until many years later. The installed capacity of solar PV in Japan surged under the scheme. However, Japan has suffered from high costs of solar PV compared to the global level. Using survey data from Japanese solar PV projects, and econometric modelling we leverage the fact that projects qualified at different points in time, with different FIT levels, have subsequently been built simultaneously. We find that higher FIT levels are correlated with increased CAPEX, where a 1 JPY/kWh increase in the FIT level is linked to a 3.31 JPY/W rise in CAPEX. This may be due to that developers with guaranteed high tariffs have weaker incentives to reduce costs and/or to strategic pricing by suppliers. Our findings indicate that poorly designed support schemes can counteract the policy goal of reducing renewable energy costs.

1. Introduction

In the last decade, the costs of producing electricity from solar photovoltaics (PVs) and wind power have decreased drastically globally [1]. The development is connected to the rapid expansion of renewable energy and “experience curves,” where the cost of immature technologies is decreased by technological development and economies of scale as well as by the industry accumulating experience and developing skills under competition [2–4].

The exceptional growth of solar and wind power globally has occurred under economic policies designed to support renewable energy. Among these policies, Feed-in Tariffs (FITs)—which guarantee renewable electricity producers a fixed payment per kWh of electricity produced—are, when designed well, one of the most widespread and successful alternatives [5,6]. Since tariff levels often are technology-specific and set to ensure adequate profitability for the producers, FIT schemes reduce risks for investors, create investment incentives [7–10], and have strong impacts on corporate R&D [11]. FITs have positive effects on the deployment of solar PV [12–14]. Conversely, controlling policy costs has been a critical issue under FIT schemes [15].[1]

After the Fukushima Nuclear Accident in 2011, Japan introduced a FIT scheme for renewable electricity in 2012. The tariff levels for solar PV in the scheme was twice as high as the one offered in Germany at the same time and more than three times as high as tariffs in China [16]. Under the scheme, the installed capacity of solar PV in Japan increased from 5 GW in 2011 to 87 GW in 2023 [17,18].

FITs can be a powerful driving force for renewable energy; however, if the tariffs are higher than the marginal cost of electricity production, they create costs for the government or electricity consumers. In Japan, the costs associated with the FIT are passed on to electricity consumers in the form of a FIT surcharge, which is reflected in the unit cost of electricity sold. Between 2012 and 2022, the surcharge rose from 0.22 JPY/kWh to 3.45 JPY/kWh.[2]

FITs have helped lower the cost of solar PV by incentivizing investments, which in turn has enabled technological development and economies of scale; however, Japan provides a case where a lucrative FIT scheme might have slowed or even inhibited cost reductions. According to IRENA [1], the total cost for utility-scale solar PV in Japan in 2021 was approximately twice as high as the global capacity-weighted average cost.

---

* Corresponding author.
E-mail address: liv.lundberg@ri.se (L. Lundberg).

[1] The FiT surcharge for FY2023 was decreased to 1.40 JPY/kWh owing to skyrocketing electricity wholesale prices caused by the high prices of imported fossil fuel.

[2] The expenditures were calculated based on data from the FIT information website (https://www.fit-portal.go.jp/PublicInfoSummary).

https://doi.org/10.1016/j.renene.2025.122685
Received 19 August 2024; Received in revised form 11 February 2025; Accepted 15 February 2025

Cost breakdown analyses of solar PV in Japan are limited. Kimura and Zissler [19] focused on the investment costs of commercial-scale solar PV in Japan, and Friedman et al. [20] focused on system costs of residential solar PV in Japan. Both studies revealed industrial immaturities in the solar PV industry in Japan, which might explain the high costs. Japan is also one of the most expensive countries in the world, with high labor and construction costs that likely also impact the capital expenditures (CAPEX) of solar PV. Another reason is that the topography may increase the competition for suitable land, increasing the cost of development.

A third reason may be the generous FIT. Under Japan's FIT scheme, a generator that plans to start a power-generation project gets a qualification from the Ministry of Economy, Trade, and Industry (METI) prior to the operation (this is further explained in Section 2). The tariff for the plant is determined when the qualification is obtained and then guaranteed for 10–20 years of operation. The early projects had no deadline for when operations had to start. As reported in Chu and Takeuchi [21], this created incentives for project developers to apply for a FIT at an early stage. This might have led to immature projects being accepted, as well as long term strategic behavior, where developers waited to implement the installations pending lower prices of solar panels [22]. Many of those early projects did not become operational until recently, and the qualified and operational solar capacity showed a large gap. The delayed start of many projects, combined with differences in tariffs over time, has led to projects with different tariffs being built at the same time. Wen et al. [23] analyzed the profitability of solar PV plants under the Japanese FIT and found that early qualified projects with higher tariffs had a higher internal rate of return (IRR). Their results were, however, based mainly on average data from official sources and not actual project costs.

The impact of renewable energy policies on renewable energy costs has previously been studied by, for example, Deshmukh et al. [15], Grafström and Lindman [24], Kim et al. [25], and Shrimali and Jenner [26]. Deshmukh et al. [15] qualitatively assessed the factors affecting solar PV cost reductions. Kim et al. [25] and Grafström and Lindman [24] formed learning curve models that revealed cost effects with renewable policies, including FIT. Shrimali and Jenner [26] used a multivariate regression model, and their results indicated that several policy programs were associated with a decline in solar PV costs. In contrast, Söderholm and Klaassen [27] provided an example of when high FITs led to reduced incentives for cost reductions of wind power in Europe. To our knowledge, no previous studies have observed such a pattern for solar PV.

In this study, we use an econometric model, based on survey data, to describe the relationship between tariff levels and solar PV costs in Japan. To study how tariffs affect the projects' costs, we leverage the fact that projects qualified at different points in time, with different tariffs, have subsequently been built simultaneously. The aim is to explore whether high tariffs have impacted the CAPEX of solar PV projects in Japan.

This article contributes to research on renewable energy costs, policy design, and Japan's energy transition. First, it highlights that cost studies should account not only for traditional industrial factors such as learning effects and R&D but also for system design details, including subsidy levels. Second, it emphasizes that renewable energy policy design should consider not just total policy costs but also impacts on technology costs—an often-overlooked perspective in policy studies [28–34]. Additionally, this study advances research on Japan's energy transition by using survey data on solar PV costs, filling gaps in previous studies [21,22]. The findings show that poorly designed FiT schemes can not only raise policy costs but also reduce incentives to lower project costs.

The article provides an overview of renewable energy policy in Japan in section 2. Then, the econometric model is described in section 3; results are presented in section 4, and section 5 focuses on discussing the results and providing policy recommendations.

2. An overview of the FIT policy in Japan

2.1. Background

The history of the FIT introduction in Japan is crucial for understanding why the initial FIT implementation rules were generous. In the 2000s, Japan's support for solar PV deployments came in the form of economic incentives, investment subsidies, and Renewable Portfolio Standard (RPS). The RPS was introduced based on the new national renewable energy target set by the METI in 2001 [35]. However, the volume of electricity that electricity retailers were required to procure was limited to 12.2 TWh (equivalent to 1.2 % of total retail electricity) until 2010. The low requirements of the RPS limited Japan's renewable energy deployment [36]. Moreover, the investment subsidy for solar PV was terminated in 2005.

When it became clear that the renewable electricity target for 2010 would not be met, the investment subsidy for solar PV was reintroduced, along with a FIT system in 2009 [37,38]. Compared to many European schemes, the FIT scheme was restricted as it only allowed solar PV installations under 500 kW to participate, and off-site solar PV plants were not eligible. These limited policy incentives resulted in variable renewables accounting for only 0.7 % of generation in 2010.

These restrictive policies were changed after the regime change in late 2009 and the nuclear reactor core melts in Fukushima in 2011. The Japanese government replaced RPS with a FIT and enacted the FIT as the "Act on Special Measures Concerning Procurement of Electricity from Renewable Energy Sources by Electricity Utilities" (hereinafter FIT Act) in August 2011, which was enforced in July 2012. The METI and nongovernmental organizations (NGOs) played an important role in passing the FIT Act [39].

The system was similar to Germany's EEG2000 legislation, but it featured tariffs that were significantly higher than those in other countries. The backgrounds for this are several. NHK public polls showed that renewable energies were anticipated to replace generation from nuclear power plants following the Fukushima Nuclear Accident [40]. At the same time, cost information on ground-mounted utility-scale solar PV power plants was limited as only two such plants had been built in 2010 [41]. High expectations for solar power to replace nuclear, political tensions between the ruling party and responsible governmental agency, the METI, as well as high-cost estimates provided by the solar power industry contributed to the high tariff levels [22].

Japanese FITs and the German system also had other distinct differences. In Japan, the METI had set tariffs for each technology annually, and tariffs for solar PV have been gradually reduced over time. The initial tariff for solar PV above 10 kW was 40 JPY/kWh, and tariffs in 2023 ranged from 9.5 to 10 JPY/kWh [42]. Project owners must apply for and obtain a FIT qualification from the METI for a certain capacity at each project site. Once project owners obtain the qualification, they are guaranteed a fixed tariff for 10–20 years of operation, regardless of when production starts.

Under the FIT Act, renewable energies have been deployed rapidly [43]. The renewable electricity supplied under the FIT Act increased from 6 TWh in 2012 to 122 TWh in 2022 (Fig. 1). The largest contribution came from solar PV, which reached an annual production of 83 TWh in 2022.

At the same time, the FIT surcharge on electricity consumers has increased. The surcharge is set annually by the METI and is based on an estimated deficit in the balance between the expenditure of the FITs to generators and the avoided costs of electricity. Essentially, FIT surcharges are calculated based on residual deficits, which subtract FIT sales revenues from FIT purchasing expenditures. Before the beginning of the fiscal year, the METI estimates the residual deficits and divides them by the sales volume of electricity to determine the FIT surcharge in JPY per kWh.

The expenditure on FITs increased from 579 billion JPY in 2013 to 3.7 trillion JPY in 2021[3.] The estimated deficit for 2022, was 2.74

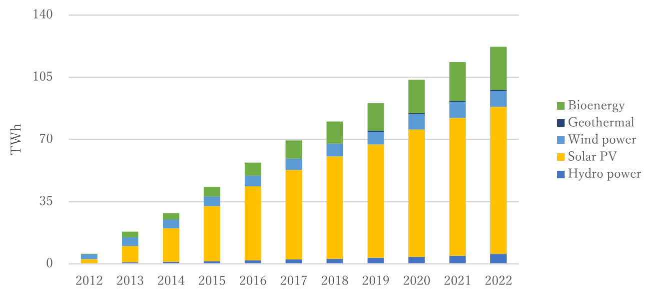

Fig. 1. Electricity supplied under the FIT Act.
Source: disclosure of FIT information website

trillion JPY and the FIT surcharge was set to 3.45 JPY/kWh [42]. The rising surcharge has created a controversy around the FIT scheme and promotion of renewable energies, and political efforts have been required to limit the surcharge increase.

2.2. *Mechanism behind the rise of FIT surcharges*

The increase in the FIT surcharge in Japan can be explained by a combination of design choices in the setup of the scheme, as described by Wen et al. [23]. High tariff levels were combined with lax requirements for qualifying for the program, and no deadline was established for when an approved project had to come online and start producing electricity. Below are deeper explanations of these factors.

(1) Generous tariffs

Tariffs for renewables under the FIT in Japan have been set based on the estimated costs of producing electricity from renewable energy. Section 2 of Article 3 in the FIT Act (2011–2016) required that “A Procurement Price shall be determined, as a price that enables the supply of Electricity from Sources of Renewable Energy by the relevant renewable energy power generation facility to be conducted stably over the Procurement Period, based on expenses that are recognized as ordinarily required where said supply is efficiently implemented and the estimated quantity of Electricity from Sources of Renewable Energy.”

The FIT scheme created a strong interest in renewable energy investments. In the first fiscal year from July 2012 to March 2013, projects with a total capacity of 19 GW were originally granted tariffs with levels as high as 40 JPY/kWh (Table 1). In the next fiscal year (between April 2013 and March 2014), although the tariff was reduced to 36 JPY/kWh, approximately 46 GW was qualified. In 2014, about 22 GW was qualified under a tariff level of 32 JPY/kWh.

Table 1
Qualified and installed capacity of non-residential solar PV under the FIT scheme in Japan.

Qualified Year	Original Qualified Capacity (GW)	Capacity (as of June 2023)	Installed Capacity (as of June 2023)
2012	19.1	13.8	12.8
2013	46.5	21.6	19.3
2014	22.5	8.3	7.4
2015	6.1	2.4	2.1
2016	8.2	3.6	3.2
2017		1.2	1.1
2018		4.5	3.7
2019		2.2	1.2
2020		0.8	0.2
2021		0.8	0.1
2022		0.7	0.1

Note: The original qualified capacity includes solar PV installations with a capacity of 10 kW and above, while the capacity data as of June 2023 include solar PV installations with a capacity of 20 kW and above.
Source: Original qualified capacity is disclosed information from the METI enquired by one of the authors in 2016. Capacity data as of June 2023 are calculated based on the METI’s Information disclosure website on Qualification under FIT and FIP. https://www.fit-portal.go.jp/PublicInfo

(2) Easy qualifying requirements

A reason for the qualification of such a large capacity in the early years was lax qualification requirements for obtaining the FIT. For the first 3 years (between July 1, 2012 and February 15, 2015), an applicant could obtain FIT qualification for their solar PV project just by specifying the plant’s site and design, securing its operation and maintenance system, and applying for a grid connection to a grid operator in the area where the plant would be located. The applicant did not need a signed contract for the grid connection or to have paid the connection fee. Additionally, applicants for the FIT scheme did not need Forestland Development Permission to qualify. This lack of requirements was a reason why such a massive amount of capacity could be qualified in short periods.

(3) No deadline

Even with lax qualification requirements, a deadline for when the project must start producing electricity would likely have deterred projectors from applying for the FIT scheme in a premature development phase. However, early qualified projects had no such deadline.

2.3. *Rule modifications*

Since the introduction of the scheme in 2012, the rules have been modified by the METI on several occasions to tackle the issue of huge amounts of capacity getting qualified at high tariff levels. For example, since April 2015, tariffs for the qualified projects of solar PV have been finalized at the time when the investors have a signed contract with the grid operator in the installation area [44]. This means that the timing of finalized tariffs is closer to the time when the solar plants start operating. Another important change is that solar PV facilities with a grid connection contract signed after July 31, 2016 have a deadline for when they must start operating [45]. Solar PV installations with 10 kW and over have 3 years from the date that they have qualified until they must start producing electricity. In case of a delay, the procurement period for the producers’ FIT contract will be reduced by the period of the delay.

In June 2016, the FIT Act was revised again, and the term “facility qualification” scheme was replaced with “project plan qualification” scheme. This meant that all qualified facilities, including the existing ones, were required to be qualified under the new qualification scheme. To obtain the new qualifications, projects were required to have a grid-connection contract. In principle, this new qualification scheme swept away old projects without grid-connection contracts that had received facility qualifications before 2015.

In December 2018, the METI introduced a new regulation on qualified solar PV projects, which had not yet started operations [46]. The targeted projects of the regulation were those that qualified between 2012 and 2014, were not regulated under the operational deadline, and were still not operational. If the projects prepared the operation by the specified date set by the METI, they could maintain their tariffs; otherwise, their tariffs were reduced. Additionally, they had to start the operation within a year after the specified date. Under this regulation, projects were required to start operations in 2020.

Despite the METI’s efforts to push out old projects with high tariff levels that have not yet been put into operation, a huge amount of older qualified capacity remains (Table 1). These projects have gradually started operating and have accounted for a large share of the operational capacity for years (Fig. 2). For example, 50 % of the 4.9 GW that became operational in 2020 was qualified between 2012 and 2014.

Data source: The METI’s Information disclosure website on Qualification under FIT and FIP (https://www.fit-portal.go.jp/PublicInfo).

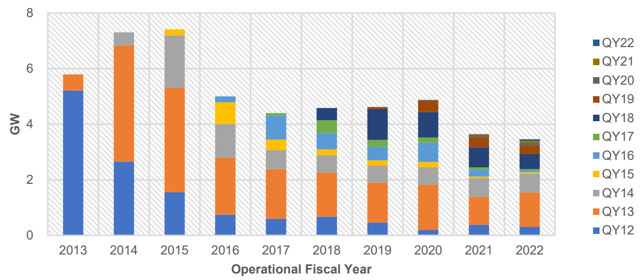

Fig. 2. The solar PV capacity that started operation between 2013 and 2022 was categorized by the qualified year (QY)—the year that the project was qualified for the FIT.

3. Method

In this study, we compare projects built in the same year but with different tariffs owing to having qualified for the FIT in different years, to study how tariffs impact the costs of solar PV. To collect the cost data, questionnaire surveys were conducted in December 2018 and July 2021. A translated version of the survey can be found in Appendix A. Both the 2018 and 2021 survey participants were randomly selected businesses that owned solar power plants registered in the projects database under the FIT Act. The survey did not include solar power plants owned by the residential sector. The surveyed power plants began operating between 2017 and 2021. Based on these data, we develop an econometric regression model.

3.1. Data sample and screening

Data for cost analysis are collected through a questionnaire survey targeting solar PV generators with a capacity of 20 kW and more that began operation after 2017. In total, we obtain 119 data samples (n = 119) located all over Japan.

However, the entire sample cannot be used for the analysis. Under the Special Act on Renewable Energy, FITs are determined based on the previous year's costs and the capacity factors of the solar PV plants that started operation. For example, the FIT for 2018 for solar PV was determined based on the costs and capacity factors in 2017; thus, solar PV costs in 2017 affected the FIT in 2018. As we want to avoid cases where FITs are impacted by solar PV costs in the previous year, we only use data for projects that started their operation in 2017 or later and were qualified in 2017 or earlier. Additionally, solar PV auctions began in 2017 for projects with 2000 kW and over. The tariffs provided by the winning auctions are expected to be related to their costs; therefore, solar PV plants that qualified through auctions in 2017 are excluded from the sample. After the screening, 75 samples remained and were used for analysis.

3.2. Cost model

This study uses a regression model to estimate the impact of Japan's FIT on the CAPEX[3] of solar PV in Japan. In the model, we include learning effects, which are approximated by using international solar PV module prices and inverter prices (COM^{in}) as a variable. The model includes factors that impact the CAPEX; all explanatory variables are further explained in the next section. The model can be written as

$$Y_i = b_1 + b_2 FIT_i + b_3 COM_i^{in} + b_4 IC_i + b_5 EPC_i + b_6 SO_i + \varepsilon_i \tag{1}$$

Where Y_i is CAPEX of the sample plant i; FIT_i is the FIT given to the sample plant; COM_i^{in} is the sum of the international solar PV module prices and inverter prices when the sample plant i started construction; IC_i is the interconnection costs of the sample plant; EPC_i is the dummy variable on a form of outsourcing when a single contractor handles all aspects of the sample plant; and SO_i is the dummy variable on a form of outsourcing when a solar PV owner controls the project and outsources tasks to appropriate companies.

3.3. Explanatory variables

(1) Feed-in tariff

The feed-in tariff (FiT_i) is the tariff given to plant i. The FIT's level depends on the year that the project qualified for the support scheme.

(2) International module and inverter price

The costs of solar PV are correlated with the cumulative amount of installed PV, which is recognized as a learning effect. Therefore, the impact of cumulative installed capacity on costs in Japan needs to be considered. As in Grafström and Lindman [24], the learning curve model can incorporate FITs as a policy effect. However, if the FITs and installed capacity are correlated, problems such as the occurrence of multicollinearity arise. Therefore, this study assumes that international learning effects are reflected in international PV module and inverter prices. Then, we incorporate the sum of these international module and inverter prices into our explanatory variable (COM^{in}). We use IEA [47] and IRENA [1] for international module prices, and LBNL [48] for international inverter prices.

The question is at what point in time the international module and inverter prices should be referenced. Optimally, the price at the time when a project signed the purchase contracts for its solar PV modules and inverters should be used, but such information is not available. Instead, we have the option to use either the time when the construction started or that when the plant became operational. Comparing the average annual costs of the sample data with the international prices at the two points in time, we find that the module and inverter prices at the time of the start of construction have a higher correlation coefficient with the sample costs (Table 2). Accordingly, this study uses the prices at the time when the sample plant started construction.

Note: COM^{in}_COY is the international price of modules and inverters when the sample starts construction. COM^{in}_OPY is the price when the sample starts operation.

(3) Interconnection cost

The interconnection cost (IC) is the cost of connecting the plant site to the interconnection point. This point is determined by the transmission and distribution company, and in rare cases, the cost of strengthening the upper grid is also charged.

(4) Proficiency

The level of proficiency differs among power-generation companies. As an indicator to assess such development and construction skills, we incorporate differences in outsourcing (FO) as explanatory variables.

Table 2
Correlation with average costs of modules and inverters for the sample data.

	COM^{in}_COY	COM^{in}_OPY
Correlation	0.374	0.266
t-Statistic	4.387	2.998
Probability	0.000	0.003

---

[3] According to NREL [47], CAPEX includes costs of balance of system, electrical infrastructure and interconnection, generation equipment and infrastructure, installation and indirect, owners, and site.

The forms of outsourcing are the difference between the types of contracts that the project proponents outsource to each process, such as procurement of goods and construction. Three types of contracts can be observed: "Engineering, procurement, and construction (EPC) contract," "Balance of Plants (BOP) contract," and "Separate order." The form of outsourcing may also affect the ICs. Some solar PV generators highlighted the importance of the form of contract for reducing ICs, as the author interviewed them. Additionally, the JPEA Policy Committee [49] argued that contracts by separate orders might be less expensive than EPC contracts.[4]

4. Result and discussion

4.1. *The CAPEX of solar PV installations built between 2017 and 2021*

The mean value of CAPEX in the sample varied from 260 JPY/W[5] in 2017 to 198 JPY/W in 2021. Table 3 shows the mean values from 2017 to 2021 as well as the average system costs for non-residential solar PV in Japan, reported by the Calculation Committee for Procurement Prices [50]. The cost reports from the CCPP are generally indicative of the population, but they are reported as watts in AC. In Ref. [50], only CAPEX, excluding land preparation and interconnection costs, is available for the mean costs in watts DC. The mean land and interconnection cost in DC is, however, available for solar PV plants that became operational in 2022 and is 22 JPY/W [50]. This number is added to the estimated data from the CCPP in Table 3 to enable a better comparison. As seen in Table 3, the sample data deviate partly from the estimates from the CCPP; this is likely due to these factors, in combination with the data screening described in Section 3.1.

Table 4 shows the summary statistics of all variables from the data. The maximum value of the FIT variable is 40 JPY/kWh, which was the tariff in 2012. The tariff then decreased yearly, and the minimum value was 21 JPY/kWh, which was the tariff in 2017. As mentioned above, solar PV plants that qualified for subsidies through auction in 2017 are not included in the study.

The mean international solar PV module and inverter prices ($\boldsymbol{COM^{in}}$) account for approximately 30 % of the CAPEX. Meanwhile, the interconnection costs (***IC***) account for a relatively small part of the CAPEX, but these costs show a large variance due to site-specific factors.[5]

4.2. *The impact of tariff levels on the CAPEX of solar PV*

The effect of tariff levels on CAPEX for solar PV projects was analyzed using a multiple regression model (see Table 5). The results show that higher tariffs are correlated with higher CAPEX. Specifically, the FIT coefficient is approximately 3.31 (statistically significant at $p < 0.05$), which indicates that a 1 JPY/kWh increase in the FIT is associated with a 3.31 JPY/W rise in CAPEX. This increase in CAPEX subsequently raises the LCOE of solar PV by about 0.16 JPY/kWh.[6]

An example of the impact on solar PV costs in Japan can be seen by comparing projects that began operation in 2022 but were approved under different FIT rates. Most solar PV projects that started operation in 2022 were qualified in 2013, as shown in Fig. 2, with a FIT of 36 JPY/kWh. The modeled impact of this tariff on the LCOE is 5.76 JPY/kWh. In comparison, solar PV projects that qualified in 2022 were awarded a FIT of 10 JPY/kWh, and the modeled impact on a LCOE is 1.60 JPY/kWh. Consequently, the difference in LCOE between projects approved in 2013 and 2022, yet operational in 2022, is estimated at 4.16 JPY/kWh.

Table 3
Mean CAPEX: Sample Data vs. CCPP Report.

	2017	2018	2019	2020	2021
Sample data (JPY/W)	260	215	226	320	198
Estimated from CCPP Data (JPY/W)	272	246	213	186	168

Note: CAPEX of CCPP data for each year are calculated as the system costs for each year plus the land preparation costs and interconnection costs in 2022.

We find two potential explanations as to why high tariffs are associated with high CAPEX costs: lower incentives for cost reduction and strategic behavior among suppliers.

First, plant developers have low incentives to reduce costs because they are compensated with a guaranteed high tariff. This also affects site selection as even if land conditions are poor or grid connection costs are high, the profit to be gained may still be sufficient. Such lack of incentives to reduce costs and to choose land conditions that reduce costs have been found for wind-power installations with high FITs in Europe [27]; Wen et al. also propose this as an explanation for the high costs of solar PV in Japan [23].

Second, commodity suppliers can already know the remuneration tariff that the developer will receive prior to signing the contract with the developer. The suppliers may then offer higher prices to the developers, who are guaranteed a higher remuneration price to increase their profits. This is more effective when the developer does not have sufficient knowledge of the products.

Regarding other explanatory variables in the model, the international module and inverter prices (COM^{in}) and interconnection costs (IC) are statistically significant. An increase in the international price of module and inverters of 1 JPY/W is associated with a 0.71 JPY/W increase in CAPEX. The theoretical coefficient value of the international module and inverter prices should be 1.00, but some data bias may cause distortion.

The interconnection costs have a strong impact on the CAPEX in the model, and a 1 JPY/W higher interconnection costs is associated with a 2.22 JPY/W higher CAPEX. This is likely due to the fact that solar PV plants with high interconnection costs tend to be sited in remote areas where land conditions are unfavorable, such as mountainous areas. The unfavorable land conditions increase the CAPEX through the increase of land-preparation costs.

Although we examine the impact of different outsourcing methods on costs as an indicator of differences in proficiency, we do not find statistically significant differences. As the p-value of separate order (*SO*) is lower than 0.1 and the coefficient is −46 JPY/W, separate order might have a negative impact on CAPEX. Increasing the sample size might allow to demonstrate that separate ordering can lead to lower solar PV costs, which also aligns with findings from the JPEA Policy Committee [49].

5. Conclusion and policy implications

In 2021, the cost for utility-scale solar PV in Japan was almost twice as high as the global average [1]. This can be attributed to industrial immaturities [19,20], high labor and construction costs, and competition for suitable land [21]. In addition to these factors, the findings in this paper suggest that high FIT levels might have also contributed to the elevated costs of solar PV in Japan.

The FIT scheme in Japan initially offered high tariffs and lacked a deadline for when projects had to start operations. This has resulted in many solar PV projects that qualified for high tariffs in the early years having started operations much later; as an example, most of the projects that went online in 2022 had tariffs that had been set in 2013.

By studying solar PV projects in Japan that were built at the same time but awarded tariffs at different times and subsequently had different tariff levels, with an econometric model, we find that higher tariffs are associated with higher CAPEX costs. This is likely due to the fact that plant developers have lower incentives to reduce

---

[4] In this study, all capacity values are expressed in DC watts, unless stated otherwise. Watts in DC refer to the nominal capacity of a solar PV module, while watts in AC indicate the power delivered to the grid.

[5] The following assumptions are made in the LCOE calculations: WACC is 3 % and the capacity factor is 15 %.

Table 4
Summary statistics of variables.

Variables	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
CAPEX **(JPY/W)**	248.987	235.695	477.127	98.667	83.442	75
FiT **(JPY/kWh)**	26.613	24.000	40.000	21.000	6.022	75
COM^{in} **(JPY/W)**	74.977	81.757	122.190	27.209	23.577	75
IC **(JPY/W)**	9.331	4.930	54.781	0.000	11.826	75
Prof. dummy	1.640	1.000	3.000	1.000	0.864	75

Note: In our dataset, contract types representing the level of proficiency are encoded using the following dummy variables: 1 for EPC contracts, 2 for BOP contracts, and 3 for Separate order contracts.

Table 5
Results from the regression model.

Variable	Coefficient	Std. Error	t-Statistic	Prob.	
b_1	79.523	48.666	1.634	0.107	
FiT_i	3.313	1.365	2.427	0.018	*
COM_i^{in}	0.714	0.345	2.069	0.042	*
IC_i	2.216	0.684	3.242	0.002	[a]
EPC_i	30.599	24.367	1.256	0.213	
SO_i	−46.044	27.203	−1.693	0.095	

[a] Prob. < 0.01, * Prob. < 0.05.

costs—including in choosing a suitable site for the plant—when they are guaranteed a high tariff. Strategic behavior among suppliers of equipment and project services—including setting higher prices for actors with high tariffs—may also contribute to the high CAPEX.

Kim et al. [25] and Grafström and Lindman [24] demonstrated that the impact of FITs on the installed cost of renewables is marginal and statistically insignificant. Conversely, Shrimali and Jenner [26] found that financial incentives can help reduce Balance of System (BOS) costs for residential solar PV. These findings, which show that FITs and other financial incentives can help lower the costs of renewable energy, are likely true for many subsidy schemes. Meanwhile, previous studies on flaws of FIT tariff levels in European countries [51], the U.K. [52], and countries in other regions, such as Vietnam [53], have primarily examined whether the tariff is relatively high or low. Others have studied how FIT schemes have been adapted over time to improve efficiency and reduce costs, in countries such as China [54], Germany [55] and Italy [56]. These types of adaptions have also taken place within the Japanese FIT scheme. FIT levels have been gradually decreased and sharp deadlines have been introduced for start of operations. In our study, we do however exploit the unique situation in Japan and examine projects that began operations in the same year but received varying levels of subsidies. This setup effectively creates a natural control group, allowing us to compare projects with similar material costs but different subsidy levels and we find that higher subsidy levels are associated with higher CAPEX for solar PV projects.

A similar connection, between FIT levels and costs of solar PV project were found by Antonelli and Desideri [57]. They conducted a survey, assessing economic data of Italian solar PV projects, and found that changes in FIT levels, rather than the overall market volume, seemed to impact the cost of PV installations, they did however not compare project that were subjected to different tariff levels at the same time. Söderholm and Klaassen [27] also found examples where high FITs lead to reduced incentives for cost reductions but for wind power in Europe.

Our results show that the time when the remuneration level of a FIT is determined is important in the consideration of a support scheme. However, other work focused on how FIT schemes should be designed, such as that by Kreycik et al. [58] and del Río [59], includes little description of this issue. Setting tariffs at the start of operation or enforcing strict deadlines for project completion, as seen in some other FIT schemes, can prevent issues such as those encountered in the Japanese system, where projects with high tariffs were built long after their tariffs were set. If the tariff is not fixed until the start of operation, projects cannot exploit high tariffs set earlier while commencing operations later, when module prices have decreased. While the remuneration value not being set until the point of operation is a risk for the generator, it provides a strong incentive for actors to begin construction works to obtain the highest possible tariff.

In conclusion, while most studies indicate that FITs effectively stimulate renewable energy investment, Japan's experience shows that overly generous and poorly designed subsidies can lead to inefficiencies. The risk of inefficiencies from overly generous subsidies extends beyond solar PV to other renewable technologies like wind, biomass, and emerging sectors such as hydrogen. If subsidies are too high or poorly designed, developers may lack incentives to innovate or reduce costs, potentially inflating capital expenditures and hindering long-term market competitiveness.

CRediT authorship contribution statement

Keiji Kimura: Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Liv Lundberg:** Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization. **Tomas Kåberger:** Writing – review & editing, Writing – original draft, Conceptualization.

Data statement

Due to the sensitive nature of the questions asked in this study, survey respondents were assured raw data would remain confidential and would not be shared.

Funding

This work was supported by JSPS KAKENHI [grant number 20H00649]. Economic support from Formas -a Swedish Research Council for Sustainable Development is also gratefully acknowledged (2020–00184_Formas).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

We would like to extend our profound gratitude to the solar PV generators who took the time to provide information on their plants and the costs of their plants.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.renene.2025.122685.

References

[1] IRENA (International Renewable Energy Agency), Renewable Power Generation Costs in 2021, 2022.

[2] C.O. Wene, Experience Curves for Energy Technology Policy, OECD, 2000.

[3] B.A. Sandén, C. Azar, Near-term technology policies for long-term climate targets?—Economy wide versus technology specific approaches, Energy Policy 33 (2005) 1557–1576, https://doi.org/10.1016/j.enpol.2004.01.012.

[4] G.F. Nemet, Beyond the learning curve: factors influencing cost reductions in photovoltaics, Energy Policy 34 (2006) 3218–3232, https://doi.org/10.1016/j.enpol.2005.06.020.

[5] T. Couture, Y. Gagnon, An analysis of feed-in tariff remuneration models: implications for renewable energy investment, Energy Policy 38 (2010) 955–965, https://doi.org/10.1016/j.enpol.2009.10.047.

[6] R. Haas, G. Resch, C. Panzer, S. Busch, M. Ragwitz, A. Held, Efficiency and effectiveness of promotion systems for electricity generation from renewable energy sources – lessons from EU countries, Energy Policy 36 (2011) 2186–2193, https://doi.org/10.1016/j.energy.2010.06.028.

[7] C. Mitchell, D. Bauknecht, P.M. Connor, Effectiveness through risk reduction: a comparison of the renewable obligation in England and Wales and the feed-in system in Germany, Energy Policy 34 (2006) 297–305, https://doi.org/10.1016/j.enpol.2004.08.004.

[8] L. Butler, K. Neuhoff, Comparison of feed-in tariff, quota and auction mechanisms to support wind power development, Renew. Energy 33 (2008) 1854–1867, https://doi.org/10.1016/j.renene.2007.10.008.

[9] F. Polzin, F. Egli, B. Steffen, T.S. Schmidt, How do policies mobilize private finance for renewable energy? — a systematic review with an investor perspective, Appl. Energy 236 (2019) 1249–1268, https://doi.org/10.1016/j.apenergy.2018.11.098.

[10] N. May, K. Neuhoff, Financing power: impacts of energy policies in changing regulatory environments, Energy J. 42 (2021), https://doi.org/10.5547/01956574.42.4.nmay.

[11] D. Azhgaliyeva, J. Beirne, R. Mishra, What matters for private investment in renewable energy? Clim. Policy 23 (2022) 71–87, https://doi.org/10.1080/14693062.2022.2069664.

[12] E. Dijkgraaf, T.P. Dorp, E. Maasland, On the effectiveness of feed-in tariffs in the development of solar photovoltaics, Energy J. 39 (2018) 81–99, https://doi.org/10.5547/01956574.39.1.edij.

[13] K. Gillingham, T. Tsvetanov, Hurdles and steps: estimating demand for solar photovoltaics, Quant. Econom. 10 (2019) 275–310, https://doi.org/10.3982/QE919.

[14] T. Gerarden, Demanding innovation: the impact of consumer subsidies on solar panel production costs, Manag. Sci. 69 (2023) 7799–7820, https://doi.org/10.1287/mnsc.2022.4662.

[15] R. Deshmukh, R. Bharvirkar, A. Gambhir, A. Phadke, Changing sunshine: analyzing the dynamics of solar electricity policies in the global context, Renew. Sustain. Energy Rev. 16 (2012) 5188–5198, https://doi.org/10.1016/j.rser.2012.04.020.

[16] Reuters, Japan approves renewable subsidies in shift from nuclear power. https://www.reuters.com/article/us-energy-renewables-japan-idUSBRE85H00Z20120618, 2012. (Accessed 11 October 2023).

[17] IRENA (International Renewable Energy Agency), Renewable Capacity Statistics, 2021.

[18] IRENA (International Renewable Energy Agency), Renewable Capacity Statistics, 2024.

[19] K. Kimura, R. Zissler, Comparing Prices And Costs Of Solar Pv In Japan And Germany: The Reasons Why Solar PV Is More Expensive In Japan, Reneweable Energy Institute, Tokyo, 2016, p. 25.

[20] B. Friedman, R. Margolis, J. Seel, Comparing Photovoltaic (PV) Costs and Deployment Drivers in the Japanese and US Residential and Commercial Markets, NREL, Golden, Colorado, 2014.

[21] L. Chu, K. Takeuchi, The non-operating solar projects: examining the impact of the feed-in tariff amendment in Japan, Energy Policy 160 (2022) 112712, https://doi.org/10.1016/j.enpol.2021.112712.

[22] A. Li, Y. Xu, H. Shiroyama, Solar lobby and energy transition in Japan', Energy Policy 136 (2019) 110950 https://doi.org/10.1016/j.enpol.2019.110950.

[23] D. Wen, W. Gao, S. Kuroki, Q. Gu, J. Ren, The effects of the new Feed-In Tariff Act for solar photovoltaic (PV) energy in the wake of the Fukushima accident in Japan, Energy Policy 156 (2021) 112414, https://doi.org/10.1016/j.enpol.2021.112414.

[24] J. Grafström, Å. Lindman, Invention, innovation and diffusion in the European wind power sector, Technol. Forecast. Soc. Change 114 (2017) 179–191, https://doi.org/10.1016/j.techfore.2016.08.008.

[25] K. Kim, E. Heo, Y. Kim, Dynamic policy impacts on a technological-change system of renewable energy: an empirical analysis, Environ. Resour. Econ. 66 (2017) 205–236, https://doi.org/10.1007/s10640-015-9946-5.

[26] G. Shrimali, S. Jenner, The impact of state policy on deployment and cost of solar photovoltaic technology in the U.S.: a sector-specific empirical analysis, Renew. Energy 60 (2013) 679–690, https://doi.org/10.1016/j.renene.2013.06.023.

[27] P. Söderholm, G. Klaassen, Wind power in Europe: a simultaneous innovation–diffusion model, Environ. Resour. Econ. 36 (2007) 163–190, https://doi.org/10.1007/s10640-006-9025-z.

[28] C. Chen, Weighing the Costs and Benefits of State Renewables Portfolio Standards in the United States: A Comparative Analysis of State-Level Policy Impact Projections, Lawrence Berkeley National Laboratory, 2009.

[29] H. Fell, J. Linn, Renewable electricity policies, heterogeneity, and cost effectiveness, J. Environ. Econ. Manag. 66 (2013) 688–707, https://doi.org/10.1016/j.jeem.2013.03.004.

[30] J. Novacheck, J. Johnson, The environmental and cost implications of solar energy preferences in Renewable Portfolio Standards, Energy Policy 86 (2015) 250–261, https://doi.org/10.1016/j.enpol.2015.06.039.

[31] C. Crago, I. Chernyakhovskiy, Are policy incentives for solar power effective? Evidence from residential installations in the Northeast, J. Environ. Econ. Manag. 81 (2017) 132–151, https://doi.org/10.1016/j.jeem.2016.09.008.

[32] M. Castañeda, S. Zapata, A. Aristizabal, Assessing the effect of incentive policies on residential PV investments in Colombia, Energies 11 (2018) 2614, https://doi.org/10.3390/en11102614.

[33] K. Neuhoff, N. May, J.C. Richstein, Renewable Energy Policy in the Age of Falling Technology Costs, Deutsches Institut für Wirtschaftsforschung, 2018. https://ssrn.com/abstract=3227734. (Accessed 15 January 2025).

[34] O. Ozdemir, B. Hobbs, M. Hout, P. Koutstaal, Capacity vs energy subsidies for promoting renewable investment: benefits and costs for the EU power market, Energy Policy 137 (2020) 111166, https://doi.org/10.1016/j.enpol.2019.111166.

[35] ACNRE (Advisory Committee for Natural Resources and Energy), Future energy policy report (2001).

[36] K. Kimura, Policy issues of Japan's renewable portfolio standard: market conditions until the end of 2005, Res. Environ. Disruption 36 (2007) 53–63.

[37] F. Muhammad-Sukki, S.H. Abu-Bakar, A. Munir, S.H. Mohd Yasin, R. Ramirez-Iniguez, S. Mcmeekin, B. Stewart, N. Sarmah, T. Mallick, R. Rahim, M. Karim, S. Ahmad, R. Tahar, Feed-in Tariff for solar photovoltaic: the rise of Japan, Renew. Energy 68 (2013) 636–643, https://doi.org/10.1016/j.renene.2014.03.012.

[38] J. Huenteler, T.S. Schmidt, N. Kanie, Japan's post-Fukushima challenge – implications from the German experience on renewable energy policy, Energy Policy 45 (2012) 6–11, https://doi.org/10.1016/j.enpol.2012.02.041.

[39] S. Okura, L. Tkach-Kawasaki, Y. Kobashi, M. Hartwig, Y. Tsujinaka, Analysis of the policy network for the "feed-in tariff law" in Japan: evidence from the GEPON Survey, J. Contemp. East. Asia 15 (2016) 41–63, https://doi.org/10.17477/jcea.2016.15.1.041.

[40] M. Masaki, Attitudes on nuclear power plants after the severe accident and the summer of saving electricity-from the survey on attitudes on nuclear power and energy, Broadcasting Culture Research Institute (2012). https://www.nhk.or.jp/bunken/summary/research/report/2012_01/20120102.pdf. (Accessed 27 August 2023).

[41] ANRE (Agency for Natural Resource and Energy), Survey on trends in the diffusion of solar PV systems, etc (2011).

[42] METI (Ministry of Economy, Trade and industry) 2022, decision on FiTs and surcharge under renewable energy Act. https://www.meti.go.jp/press/2021/03/20220325006/20220325006.html. (Accessed 27 August 2023).

[43] K. Knüpfer, S. Dumlao, M. Esteban, T. Shibayama, K. Ishihara, Analysis of PV subsidy schemes, installed capacity and their electricity generation in Japan, Energies 14 (2021) 2128, https://doi.org/10.3390/en14082128.

[44] ANRE (Agency for Natural Resource and Energy), Revision of the operation of the Feed-in Tariff Scheme and Equipment Qualification for FY 2014, 2014.

[45] ANRE (Agency for Natural Resource and Energy), Detailed system design, etc. of the revision of the feed-in tariff scheme, doc. 1. Ninth meeting of the subcommittee on institutional reforms related to the promotion of renewable energy introduction, Energy Policy Subcommittee, Advisory Committee for Natural Res. Energy (2016).

[46] ANRE (Agency for Natural Resource and Energy), Measures to reduce consumers' burden caused by existing qualified projects (2018).

[47] IEA (International Energy Agency), Evolution of solar PV module cost by data source, 1970–2020, https://www.iea.org/data-and-statistics/charts/evolution-of-solar-pv-module-cost-by-data-source-1970-2020, 2020. (Accessed 27 August 2023).

[48] LBNL (Lawrence Berkeley National Laboratory), U.S. solar photovoltaic system and energy storage cost benchmark: Q1 2020, 2021.

[49] JPEA Policy Committee, Possibility study on cost reduction of Solar PV. https://www.jpea.gr.jp/wp-content/uploads/JPEA_report220225.pdf, 2022. (Accessed 27 August 2023).

[50] CCPP (The Calculation Committee for Procurement Prices), Opinions on procurement prices, etc. since FY2023, 2023.

[51] A. Pyrgou, A. Kylili, P. Fokaides, The future of the Feed-in Tariff (FiT) scheme in Europe: the case of photovoltaics, Energy Policy 95 (2016) 94–102, https://doi.org/10.1016/J.ENPOL.2016.04.048.

[52] L. Haar, Design flaws in United Kingdom renewable energy support scheme, Energies (2021), https://doi.org/10.3390/EN14061657.

[53] Hang Thi-Thuy Le, et al., Critical assessment of feed-in tariffs and solar photovoltaic development in Vietnam, Energies 15 (2) (2022) 556.

[54] A.H. Zhang, S.M. Sirin, C. Fan, M. Bu, An analysis of the factors driving utility-scale solar PV investments in China: how effective was the feed-in tariff policy? Energy Policy 167 (2022) 113044.

[55] J. Hoppmann, J. Huenteler, B. Girod, Compulsive policy-making—the evolution of the German feed-in tariff system for solar photovoltaic power, Res. Pol. 43 (8) (2014) 1422–1441.

[56] V. Di Dio, S. Favuzza, D. La Cascia, F. Massaro, G. Zizzo, Critical assessment of support for the evolution of photovoltaics and feed-in tariff (s) in Italy, Sustain. Energy Technol. Assessments 9 (2015) 95–104.

[57] M. Antonelli, U. Desideri, Do feed-in tariffs drive PV cost or viceversa? Appl. Energy 135 (2014) 721–729.

[58] C. Kreycik, T.D. Couture, K.S. Cory, Innovative feed-in tariff designs that limit policy costs, National Renew. Energy Laboratory, CO (2011), https://doi.org/10.2172/1017104. USA.

[59] P. del Rio, The dynamic efficiency of feed-in tariffs: the impact of different design elements, Energy Policy 41 (2012) 139–151, https://doi.org/10.1016/j.enpol.2011.08.029.