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Economics of Urban Distributed PV in China

Sino-German Energy Transition Project

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Imprint

This report Economics of Urban Distributed PV in China is a research analysis paper published by GIZ in the framework of the Sino-German Energy Transition Project. The project supports the exchange between Chinese government think tanks and German research institutions to strengthen the Sino-German scientific exchange on the energy transition and share German energy transition experiences with a Chinese audience. The project aims to promote a low-carbon-oriented energy policy and help to build a more effective, low-carbon energy system in China through international cooperation and mutual benefit policy research and modeling. The project is supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) in the framework of the Sino-German Energy Partnership, the central platform for energy policy dialogue between Germany and China on national level. From the Chinese side, the National Energy Administration (NEA) supports the overall steering. The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH leads the project implementation in cooperation with the German Energy Agency (dena) and Agora Energiewende.

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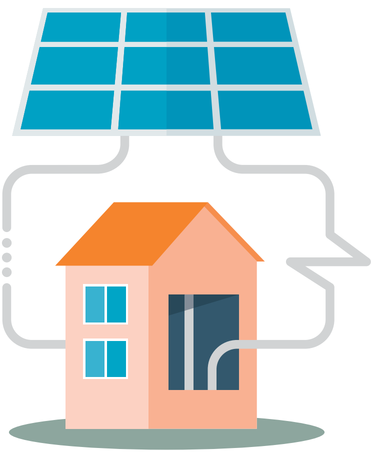
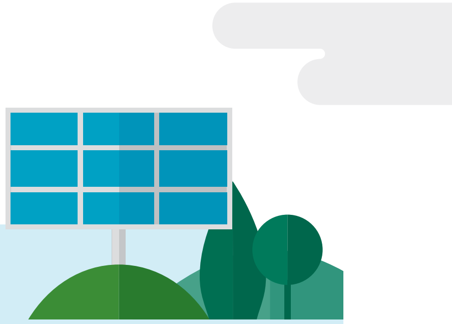


Economics of urban distributed PV in China

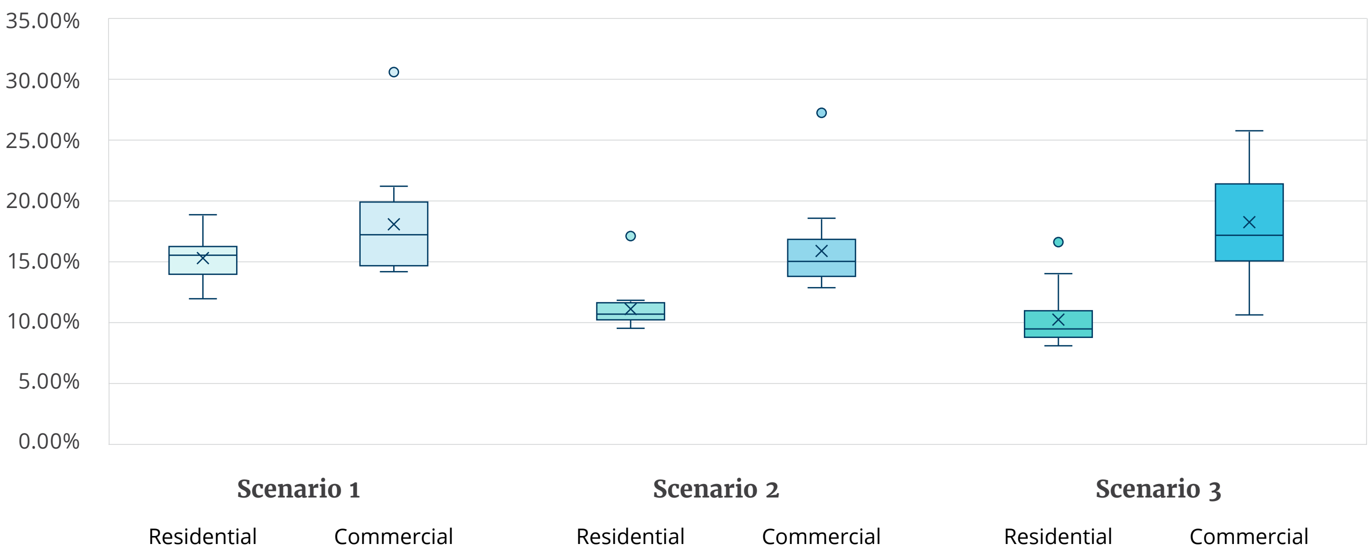


Summary

This report summarizes the results of an analysis of the economics of distributed solar and solar plus storage across many of China's largest cities, given time-of-use pricing presently available for residential and commercial consumers. As prices for energy storage and solar photovoltaic continue to become more economical, distributed solar with or without storage is becoming more common in China. In 2020, China announced plans to peak carbon emissions before 2030 and reach carbon neutral emissions by 2060. Wind and solar are expected to become the center of China's energy system. Already in late 2020, distributed solar—particularly residential solar—has seen remarkable growth, and this is likely to continue in the coming years.

In this analysis, we study the investment returns of self-owned distributed solar PV, either on a stand-alone basis or paired with energy storage, accounting for both present time-of-use (TOU) prices in various Chinese cities, as well as for hourly insolation in each location. We use a threshold of 15% IRR to represent economical returns for such users. Our results show that, for commercial users, at current TOU electricity prices, PV costs, and storage costs, energy storage that can cycle twice per day offers the highest returns in most cities, followed by stand-alone PV. Energy storage that can cycle twice per day can both store peak solar output as well as shift afternoon peak load into off-peak evening hours. On the other hand, storage is presently uneconomical for residential users in most cities. Stand-alone PV is economical (above 15%) for both residential and commercial customers in most regions.

Internal rate of return (IRR) for three scenarios of residential and commercial distributed PV

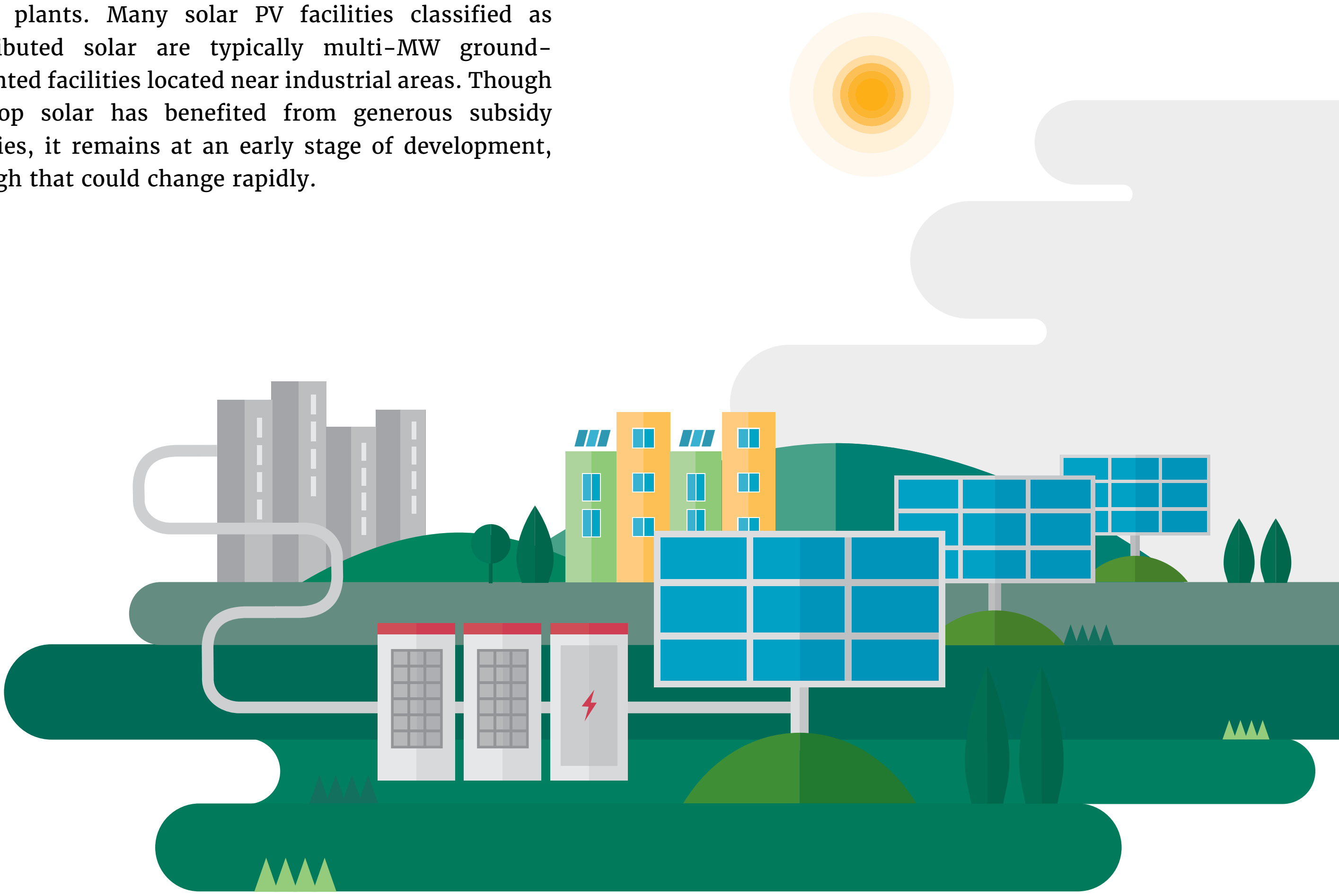


Note: Scenario 1 represents stand-alone PV, scenario 2 represents PV paired with storage charging once daily at midday and discharging in the afternoon; scenario 3 represents PV paired with storage charging twice daily. The range of values represents the returns across 13 Chinese cities studied.

Source: Liu Yuzhao, Anders Hove, and Liu Qingyang, GIZ, 2021

Introduction

Distributed energy is a central element of the energy transition paradigm. According to this vision, energy production and consumption will gradually shift from an extensive, central layout in which customers play a purely passive role, to one in which consumers and prosumers actively participate in energy production, storage, and demand response. Though there is little precedent for such a transition, other than analogues of decentralized infrastructure such as the Internet, several countries and regions such as Germany, California, and South Australia have seen a boom in rooftop solar and household energy storage. China's renewable energy expansion, which leads the world in most respects, relies mainly on centralized, utility-scale plants. Many solar PV facilities classified as distributed solar are typically multi-MW ground-mounted facilities located near industrial areas. Though rooftop solar has benefited from generous subsidy policies, it remains at an early stage of development, though that could change rapidly.



Pairing distributed storage with solar is a worldwide trend in regions with high renewable penetration

The development of solar energy in many parts of Europe and North America in the early 2000s initially began with a higher policy emphasis on distributed residential solar, despite the relatively high cost of rooftop solar compared to ground-mounted, utility-scale solar. Only recently have these regions seen stronger interest in pairing energy storage with residential solar. Storage has taken off for reasons that include policy, utility tariff design, and concerns about power outages in some areas. Falling cost of battery energy storage have constituted a prerequisite for this development. Prices for lithium-ion batteries for residential energy consumption have fallen steadily, reaching Euro 1,100/kWh in 2019—still a substantial premium over vehicle batteries, potentially indicating further room to fall.[1]

Markets for distributed, PV-tied energy storage in Germany evolved in part due to policy support and tariff design. Residential retail electricity tariffs are over Euro 0.30/kWh. Sending power from PV into the grid earns just a fraction of the retail tariff, giving residential PV system owners a substantial incentive to store self-produced PV output rather than sending it to the grid. In addition, residential consumers could obtain rebates from a portion of energy storage capital costs, though the subsidy has declined over time.[2]

Today, almost 70% of new home solar PV installations in Germany come with battery energy storage. The country's residential storage market represented around 2.3 GWh of installed capacity by the end of 2020.[3] According to figures from the German energy storage association, there are now more than 300,000 battery storage systems installed in German households, with the average installation size around 8-9 kWh in 2019 and 2020. Germany may install 150,000 residential batteries in 2021, accounting for around two-thirds of the country's battery installations by capacity for 2021—1.5 GW out of 2.1 GW total.[4]

Australia has also been a leading market for distributed energy storage, again often linked to residential PV installations. An estimated 15% of Australian households had rooftop solar systems installed by 2020. In 2020, Australia added roughly 31,000 new residential energy storage systems, reaching around 145,000 total installed residential systems. Stoddart, a building materials supplier, offers battery systems bundled with PV installations, and property developer Stockland has worked with battery-maker Sonnen to include batteries on newly-built homes. Such deals are often accompanied by sign-up to Virtual Power Plants (VPPs), which aim to orchestrate large numbers of household solar-plus-battery systems for the financial benefit of their owners and the stability of the grid.[5]

Three factors have driven the distributed energy storage market in Australia: good solar resources, high residential tariffs in remote regions, and electricity reliability concerns. Storage may receive a further boost if the Australian Energy Market Commission (AEMC) imposes fees on exported power at particular times, such as at midday when there is a surplus of solar output. By adding energy storage, customers can

maximize the amount of solar that they self-consume, rather than export to the grid, as well as enjoy off-grid power when power from the grid is cut off. Power outages have become increasingly frequent for remote communities given the increasing number of large and severe bushfires.[6]

Similar forces have also started to propel the market for distributed storage in the U.S. In California and Texas, recent power outages and the likelihood of future outages has helped encourage more storage installations, not always linked to home solar. California's Self-Generation Incentive Program offers rebates for solar combined with storage, especially targeted at fire-prone areas where power cuts are common in fire season.[7] Incentives are also available in Texas.[8] Tariff design, such as time-of-use pricing, has also pushed solar owners to install storage in many regions: 70% of new PV systems in Hawaii come with storage, and 40% in California.[9] Some states have experimented with innovative programs for homes and businesses to employ storage for virtual power plants that can help balance grid load. Vermont offers such a program for owners of Tesla Powerwalls: in exchange for a rebate for the Powerwall, the owner agrees to allow the utility to dispatch the battery to feed power into the grid at times of high demand, while retaining the ability to use the battery for home energy backup.[10]

In all three of the above regions, residential storage and utility-scale storage have driven the storage markets, partly due to tariff design. In China, where residential tariffs are low and commercial tariffs are higher, the commercial and industrial markets are likely to be far more important as an early driver—particularly due to safety concerns surrounding battery fires.

China's distributed solar industry is booming

China had 253 GW of installed solar PV at the end of 2020. Until 2017, over 80% of PV installations were central, utility-scale plants. The proportion of distributed solar in newly-added solar rose above 25% starting in 2017, when problems with curtailment and restrictions on new building in some provinces shifted investment to distributed solar.[11] According to the China National Energy Administration (NEA), of 48.2 GW of new PV additions in 2020, distributed solar accounted for 15.5 GW, or 32%.[12] Whereas household rooftop solar accounted for a small share of all distributed solar in prior years, 2020 saw a major boom in residential solar additions, which accounted for an astonishing 10.1 GW of additions for the full year.[13] Almost all of this was added in the 4Q, due to a rush to take advantage of distributed solar subsidies before a year-end cut.[14]

According to industry estimates, in 2021 residential solar installations could reach 15 GW and distributed solar might total 25 GW.[15] As the market share of distributed solar rises, over the next five years distributed solar could add an average of 30 GW per year.[16]


Subsides for solar have fallen as economics improve

The government started subsidizing PV in 2013, when distributed solar projects could earn a direct subsidy of RMB 0.42/kWh for all electricity produced, whether self-consumed or sent to the grid. This subsidy level was maintained through the beginning of 2018, when the government reduced it only modestly to RMB 0.37/kWh.[17] In mid-2019, energy authorities further reformed the distributed solar subsidy, setting it at RMB 0.10/kWh for commercial and industrial (C&I) customers and RMB 0.18/kWh for residential.[18] The subsidy further declined to RMB 0.5/kWh for (C&I), for self-consumption only. The residential subsidy dropped to RMB 0.08/kWh.[19] In 2021, the subsidy continues for residential, but at just RMB 0.03/kWh, and the subsidy is no longer available for commercial and industrial distributed solar. In 2022, residential solar subsidies will also be discontinued.[20]

Barriers

Distributed solar has faced various barriers

Though China's policy environment offers many advantages to distributed solar, the promotion of distributed solar faces several main barriers:

- Relatively high cost for households due to high soft costs:[21] Soft costs include rooftop rent, financing costs, system design, installation, operation, and maintenance. In addition, local authorities and grid companies may require lobbying and costly studies to permit installation and connection.[22]

- Low electricity prices for residential electricity users: In many cities, the residential electricity price averages around RMB 0.45-0.50/kWh, compared to commercial prices that range from RMB 0.65-0.70/kWh. Lower electricity prices result in reduced savings for residential solar as compared to commercial and industrial solar.

- Limited financing options: Many banks have perceived solar as having high revenue risk and long payback periods.[23] Because the financial returns for many solar projects have depended on the relatively favorable economics of self-consumption, revenue risk includes the risk that the solar owner cannot use all the electricity produced by the system.[24] For household solar, the lack of a fully developed consumer lending market has also hindered solar finance.[25]

- Owner-occupant dilemmas: For rental units, occupants typically rent on a yearly basis, and thus lack motivation to invest in PV with a payoff that takes several years. Occupants of rental units in large commercial properties may pay electricity bills based on floor area rather than on metered usage, and therefore see no financial benefit to installing solar. As in most countries, renters rarely consider energy or environmental factors when selecting a rental property.

- Mismatched lease periods: Commercial and industrial building and rooftop lease periods typically last 5-10 years, whereas solar might last 20 or more years.[26]

- Roof ownership: In some cases, roof ownership is either unclear, or the industrial or commercial roof is owned by a separate entity from the property occupant.[27] A similar problem faces residential properties in many urban areas.[28]

- Industrial park policies: In many regions, industrial parks provide subsidized central heating, steam, and electricity to attract businesses, which reduces the incentive to adopt solar.[29] Often, industrial parks own their own coal plants, and to protect revenue for these facilities may either discourage or even prohibit businesses from adopting solar, in some cases citing safety considerations.[30]

- Low acceptance: In many cases, it has been necessary to obtain permission from all or the majority of residents for permission to install rooftop solar on multi-unit dwellings. Some owners have raised objections over safety of solar in windy or snowy condition, while others have objected to solar on the grounds that it would occupy public space or detract from the aesthetics of a property.[31]

- Permitting and interconnection barriers: Some communities have restricted residential rooftop solar for various reasons, citing safety or quality standards.[32] Grid connection has also been a barrier.[33] In some regions, the grid connection process has required multiple application and permitting steps, and could take a year or longer.[34]

Over the years, the Chinese government and grid companies have taken various steps to resolve these barriers to distributed solar. For example, in 2017, the National Energy Administration established a hotline to respond to customer complaints about barriers to distributed energy installation and found that slow interconnection and late subsidy payments were the main issues. Interconnection required six different visits to the electricity supply bureau to apply for grid connection, survey site power consumption, approve the power supply and purchase contract, and installation of a new meter. In practice, even more visits were typically required.[35] Subsequently, in 2018, China's largest grid company, State Grid, launched a distributed PV mobile app aimed at reducing interconnection and payment barriers. In addition to easing interconnection, the app includes site evaluation, equipment selection and procurement, installation, electricity billing, subsidy payment, and operations and maintenance.[36] By streamlining these procedures, the grid company has gradually eased some of the barriers to distributed energy adoption for smaller customers.

The entry of newer players into distributed solar has also benefited the development of the market. Given the importance of coordinating with various grid and local government entities, it is significant that several large state-owned players are now participating in the distributed PV market. Both State Grid and China Southern Grid have major distributed solar subsidiaries. In addition, provincial energy SOEs have established distributed energy subsidiaries, as have major real estate and construction players such as Chint, and conventional solar companies such as Sungrow and Longi.[37] The involvement of such companies, with their large balance sheets and exposure to diverse geographics and customer types, can help reduce the risk associated with large-scale deployment of distributed solar, improving customer awareness and reducing marketing expense.

Distributed storage also faces barriers

Because self-consumption of electricity from distributed solar generally offers favorable economics in China, analysts have long considered energy storage as a potential path for improving solar economics.[38] Energy storage could both store excess midday solar production for later consumption at night, while also enabling load shifting and price arbitrage to take advantage of low electricity prices in evening hours. However, though the price of energy storage has declined rapidly since 2010, the economics of distributed storage remains challenging. Electricity prices are one reason: not only are retail electricity prices low for many customers, but the peak-valley price differential for many customers is too small to benefit energy storage for load shifting or peak shaving.[39]

In the future, energy regulators are likely to utilize time-of-use rates to encourage greater uptake of energy storage. For example, in July 2018, the National Development and Reform Commission issued a new policy on using peak and valley tariffs to encourage energy storage by expanding the peak-valley price differential, encouraging time-of-use-based bilateral energy contracts, as well as providing compensation for ancillary services.[40] In 2021, NDRC issued a new notice on implementing Time-of-Use (TOU) power prices to encourage more flexibility.[41] The policy suggests that retail electricity prices should enlarge the gap between the peak rate and trough rate to as high as 4-to-1, compared to around 3-to-1 in most Chinese cities currently. This could substantially improve the economics of distributed energy storage and provide much greater incentive for reducing peak loads.

Distributed energy storage has also faced other barriers, among which safety has been a leading concern. In April 2021, for example, a large user-sited lithium-iron-phosphate battery caught fire at a suburban shopping mall in Beijing, leading to the deaths of several firefighters. Following the incident, the Beijing municipal government suspended approval of user-sited energy storage.[42]

China still lacks national and industrial standards for energy storage, and also lacks a uniform process for permitting and approval for energy storage.[43] However, there has been progress in recent years. In 2019, the Ministry of Construction assigned the Tianjin Fire Research Institute of the Ministry of Emergency Management and other organizations to draft a national standard. The draft includes requirements related to energy storage such as spacing of storage in and design of fire suppression equipment.[44] In 2020, NEA issued a new guidance on establishing a new energy standard system, including new standards for energy storage.[45] Further, Chinese analysts have pointed to the adoption of safety standards for energy storage in the U.S. as potential model and reference for Chinese standards.[46]

The economics of distributed solar and storage in China

As solar and storage prices have fallen, the economics of distributed energy has improved gradually, and in many regions of China distributed solar is already economical. As noted above, self-consumption of solar electricity production is currently the main business model for distributed solar, due to the relatively low prices offered for solar sent into the grid as compared to retail electricity tariffs.

Though China is gradually adopting market reforms in wholesale power markets, for most smaller customers retail electricity prices are still regulated by NDRC. Local electricity tariffs vary by location and typically include time-of-use pricing tailored to the load curve of the region. Time-of-use pricing was piloted in the 1980s and became widespread in the 1990s.[47] Commercial and small-industrial customers typically have time-of-use prices with peak rates in the morning and late afternoon/early evening, with a shoulder period in midday. Residential customers typically have lower peak rates and no midday shoulder price period.

China's present TOU prices reflect the need to reduce peak loads and encourage consumers to flatten their load curves, but the introduction of large amounts of variable renewable energy—both distributed and centralized—could eventually result in changes to TOU prices to reflect the need to match loads to energy production. In 2013, California's grid operator released a report on how the growth of solar power affects the state's energy balance over the coming years, introducing the concept of the duck curve, which portrays a midday drop in net load caused by solar, and a steep increase in early evening as solar fades and demand peaks.[48] The duck curve in California is regarded as the state power grid's biggest challenge over the rest of the decade, yet the TOU pricing system in California failed to adjust to this evolving change.

In China, as distributed solar, utility-scale solar, and other types of renewable sources gradually take up a larger share in the national energy structure, China's net power load could gradually develop into a similar duck curve shape. Under this scenario, the peak-and-valley tariff periods in China could evolve accordingly, such as with a lower price during midday periods on the sunniest days to encourage users to adjust consumption patterns. Such pricing adaptations would also encourage storage at the utility scale and distributed storage.

Given the growing distributed PV market and the government encouragement of energy storage, this study aims to investigate the economics of distributed solar in eastern provinces of China under different application scenarios. The result will provide a map for distributed PV investment attractiveness given the internal rate of return (IRR) of the investment. The calculation considers local PV output, capital cost, local TOU prices, government subsidies, and the use of battery storage.

Because large, heavily populated, and economically prosperous coastal regions are likely to be the first to prioritize distributed solar energy as a strategy for early carbon peaking, this analysis focuses on these regions.

Main assumptions:

- 10 kW distributed solar PV system.
- Optimal panel orientation and tilt.
- PV capital cost of RMB 5000/kW.
- 4-10 kWh (usable capacity) battery energy storage on-site for the one-charge model.
- 20 kWh (usable capacity) battery energy storage on-site for the two-charge model.
- Battery energy storage capital cost of RMB 1500/kWh of usable capacity.
- System lifespan of 20 years.

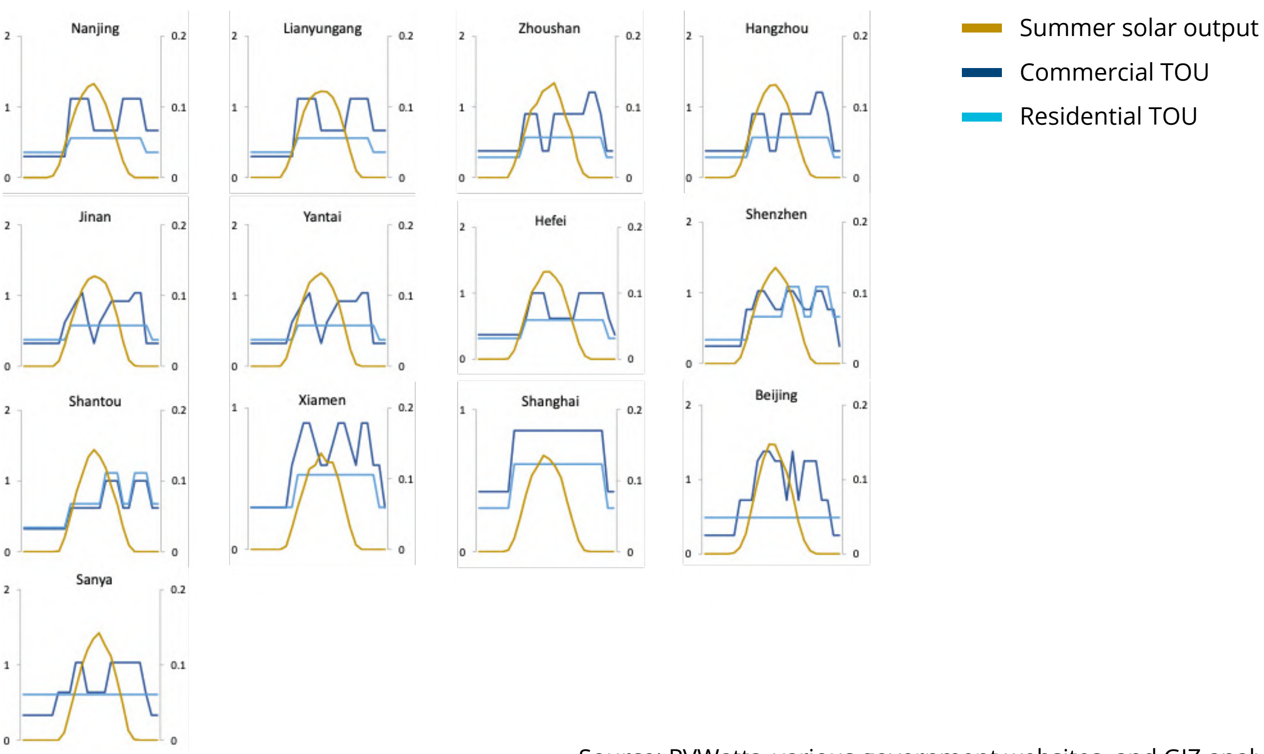
- PV system degradation of 1% per year.
- System residual value of 20% of initial investment after 20 years.
- Electricity price escalation of 1% per year.
- Round-trip efficiency of the battery of 91% (representing an average of LFP, NCA and NMC batteries in one study).[49]
- Constant TOU price times and peak-valley differentials.
- The subsidy in year 2021 for distributed solar is RMB 0.03/kWh for residential, and there is no subsidy for commercial. Starting from 2022, there will be no more subsidies for newly added distributed solar.[50]
- No local subsidies are included.
- Daily and hourly solar insolation at each site based on data from PVWatts.

Time-of-use rates play a significant role in the economics of distributed solar, yet these are often ignored in calculating the economic returns of solar. It is especially worth noting that time-of-use prices in most cities offer higher rates during the daytime, which benefits solar self-consumption. For a typical residential customer, we estimate the PV-production-weighted-average time-of-use prices during a full year for residential customers are 22% higher than the full-day average residential price across all hours. For commercial customers, the PV-production-weighted average time-of-use price is 21% higher than the full-day unweighted average price.

The peak-shoulder-trough price differentials also play a critical role in whether storage is economical. The differential is equal to the difference of peak price and trough price divided by the tough price. Most cities offer a midday shoulder price for commercial customers, while residential customers have only a peak daytime rate and a trough rate at night. The average peak-trough differential across the cities we examined is 227% for commercial customers and 86% for residential customers. The average peak-shoulder differential for commercial customers is 109%.

Many cities provide differing price schedules on a seasonal basis, typically winter and a shorter summer peak season. For example, Yantai city has higher rates in June-August. In this analysis, we considered the change in solar radiation for each season, using the monthly average solar PV output for each hour for each period.

Time-of-use prices and PV output, residential and commercial summer



Source: PVWatts, various government websites, and GIZ analysis, 2021

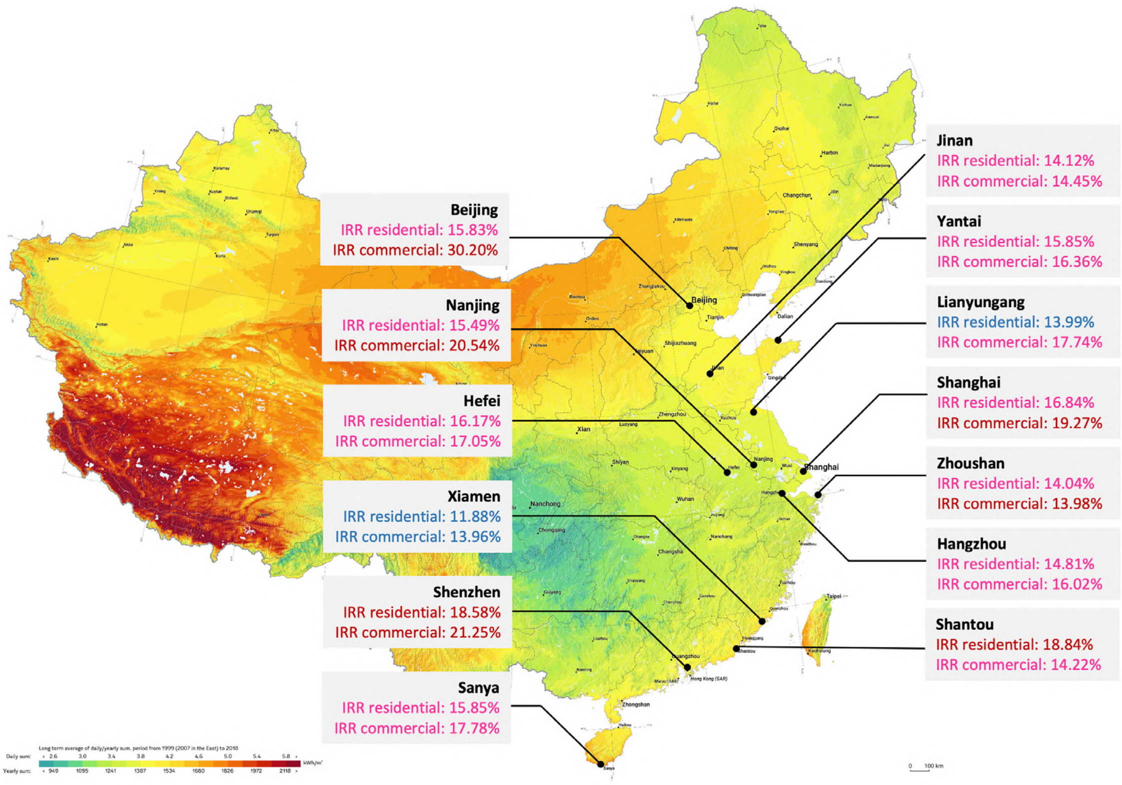
Daily output in most cities varies considerably depending on local weather, resulting not only in greater or lower output, but also affecting the ability of storage to operate one or two cycles. Based on hourly PV production schedules for a full year, our one-charge analysis assumes that on cloudy days storage will not necessarily charge full. For this reason, under the one-charge scenario, we set the battery size in each city such that the battery will charge full from solar output on 90% of the days, with a maximum battery size set at 10 kWh.

Scenarios modelled:

- **Scenario 1:** PV only. This scenario only considers the IRR of a 4-10 kWh solar unit (varying based on solar irradiation in different cities), assuming all electricity is self-consumed.
- **Scenario 2:** PV plus storage, one charge per day. The battery will be charged once at midday when the TOU price is lower until it is fully charged, and the charged electricity will be consumed by the user when the TOU price is the highest during evening. On days when insufficient solar energy production in the morning peak hours leaves the battery only partially full, only this energy is considered for discharge—in other words, the battery never charges from the grid.
- **Scenario 3:** PV plus storage, two charges per day. The first charge uses electricity from the grid at midnight when the TOU price is the lowest, and discharges in early morning when TOU is higher. The second charge first takes place during midday as in the second scenario and then the battery charges from the grid until full. The charged electricity will be consumed by the user when TOU price is the highest during evening.

At present solar PV prices and subsidy levels, distributed solar is economical in many regions we studied. The economics of pairing solar with energy storage are more uneven, and generally best for commercial users with two charges per day.

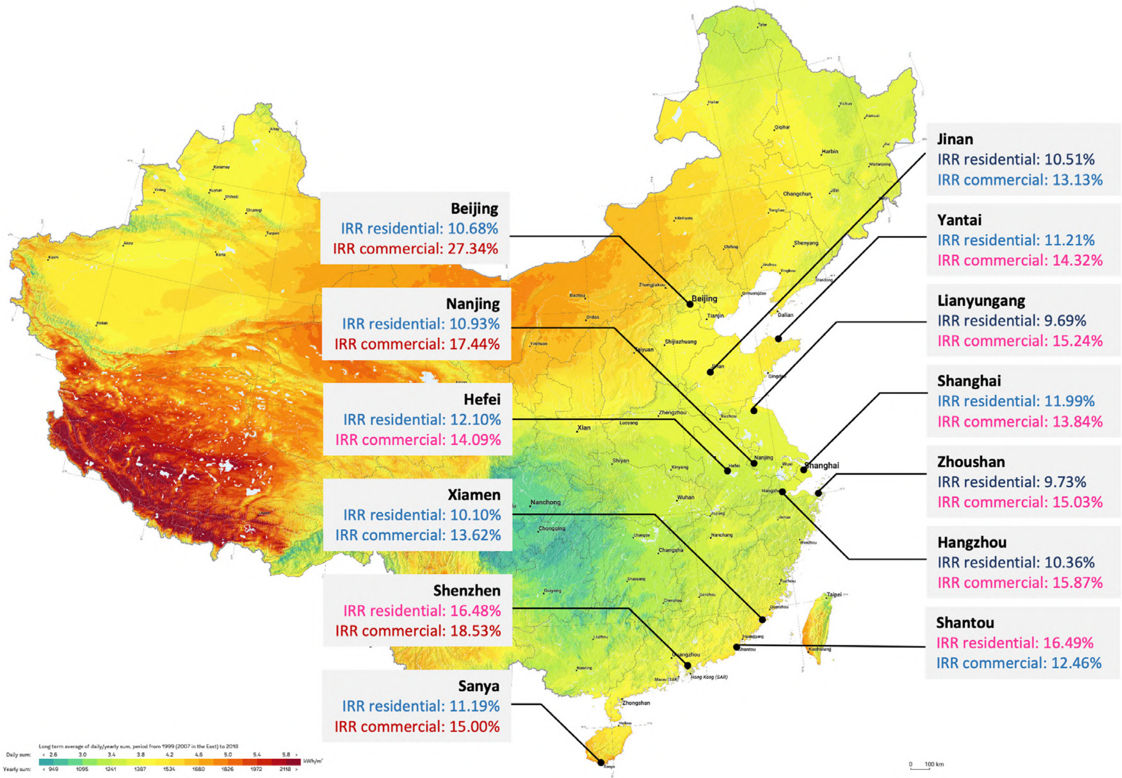
Scenario 1 — IRR of stand-alone distributed solar PV systems in selected Chinese cities in 2021



Source: Anders Hove, Liu Yuzhao, and Liu Qingyang, GIZ, 2021
Note: The map is accessed from Solar GIS, April 2021, at https://solargis.com/maps-and-gis-data/download/china.

Scenario 2

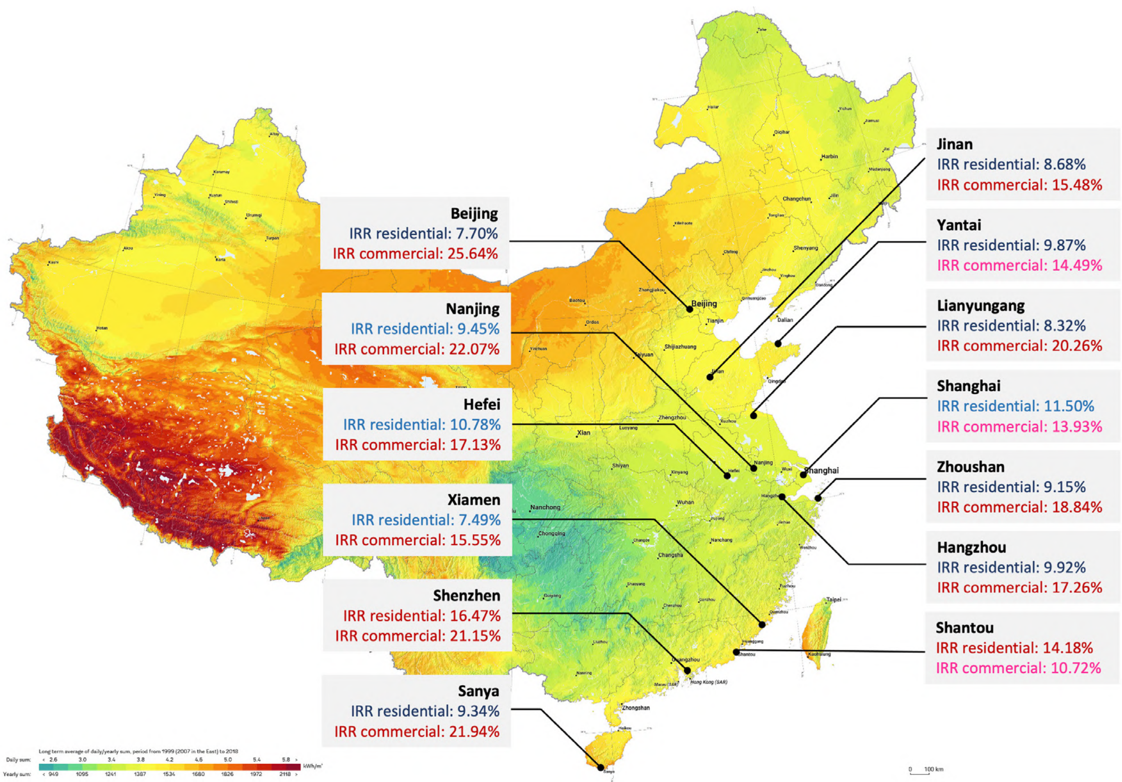
IRR of distributed solar PV and storage in selected Chinese cities in 2021, one-charge assumption



Source: Anders Hove, Liu Yuzhao, and Liu Qingyang, GIZ, 2021

Scenario 3

IRR of distributed solar PV and storage in selected Chinese cities in 2021, two-charge assumption



Source: Anders Hove, Liu Yuzhao, and Liu Qingyang, GIZ, 2021

In general, the IRRs for stand-alone PV are in the range of 14–22% for commercial customers and 11–19% for residential. For scenario 2, in which energy storage charges once daily, IRRs range from 12–19% for commercial customers and from 9–12% for residential. For scenario 3, the two-charge scenario, IRRs range from 10–26% for commercial and 7–15% for residential. A few locations offer IRRs over 20% for PV paired with 20kWh storage for commercial customers: Beijing, Shenzhen, Sanya, Lianyungang, and Nanjing. Beijing, Nanjing, and Shenzhen also feature commercial IRRs over 20% for stand-alone solar systems.

A sensitivity analysis of these results shows that the IRR is more sensitive to time-of-use change than the change in battery cost. In Nanjing, which has the highest commercial IRR for scenario 3, doubling the range for TOU and lower the cost of battery cost to half of its original cost will lead to a 10% increase for IRR.

Sensitivity Analysis

Nanjing	Commercial				
			Change of TOU ranges		
			TOU	1.5 TOU	2 TOU
	Battery Cost	750	27.27%	38.20%	48.04%
		1000	25.26%	35.45%	44.60%
		1250	23.51%	33.06%	41.62%
		1500	21.96%	30.96%	39.00%

Beijing	Commercial				
			Change of TOU ranges		
			TOU	1.5 TOU	2 TOU
	Battery Cost	750	33.49%	41.13%	49.76%
		1000	31.06%	38.17%	46.19%
		1250	28.95%	35.61%	43.10%
		1500	27.09%	33.36%	40.40%

Hangzhou	Commercial				
			Change of TOU ranges		
			TOU	1.5 TOU	2 TOU
	Battery Cost	750	22.23%	25.67%	29.13%
		1000	20.54%	23.76%	27.00%
		1250	19.07%	22.10%	25.14%
		1500	17.77%	20.63%	23.50%

Shenzhen	Commercial				
			Change of TOU ranges		
			TOU	1.5 TOU	2 TOU
	Battery Cost	750	25.25%	35.56%	44.67%
		1000	23.37%	33.00%	41.47%
		1250	21.73%	30.76%	38.69%
		1500	20.28%	28.80%	36.25%

Source: GIZ China, 2021

Economic analysis of distributed PV and storage under today's TOU prices: findings

- Larger differences in the peak-shoulder tariff constitute the most important factor leading to more profitable utilization of the battery storage, which results in higher IRR for cities.
- The amount of solar irradiation each city receives is an important variable affecting the economics of the project, especially the stand-alone scenario. Regions with yearly solar irradiation over 1100 kWh can yield a stand-alone PV system commercial IRR over 15%.
- In general, commercial projects are more profitable than residential projects, due to the higher electricity price for commercial users and larger differences in the peak-shoulder tariffs.
- The model shows that for both commercial and residential uses, the one-charge scenario is least profitable due to high capital cost of the battery and PV panel with moderate amount of electricity bill saving. On the other hand, the results of the two-charge model show divergent pathways for commercial and residential customers. With high differentials between peak and shoulder tariff rates, the two-charge model yields high IRRs for commercial customers. As many cities have little to no differences between peak and shoulder residential rates, the two-charge model is least favorable for residential consumers. One exception is Shantou, Guangdong, where commercial tariff rates are lower than that of residential ones, resulting in higher residential IRRs throughout the three scenarios.
- If the net load curve in China gradually evolves into a duck curve shape like that of California, regulators government may consider developing a shoulder price for residential customers to encourage a load shifting from morning and evening peaks to midday. If such a shoulder price is in place, a one-charge scenario could become more attractive for residential and commercial customers. Residential customers can also adopt an economical two-charge scenario.

Policy analysis of the notice on implementing Time-of-Use (TOU) power prices to encourage more flexibility

A new Time-of-Use (TOU) power price policy could encourage both supply and demand to become more flexible and respond to the rising share of variable renewables.[51] The policy notice, issued on 29 July by the National Development and Reform Commission, suggests that retail electricity prices should have higher ratios between the peak rate and trough rate—specifically, that the ratio should be at least 4:1 in regions where the generation difference between peak and trough is higher than 40%.

Some provinces in China still don't have TOU power prices, such as Heilongjiang and Shenyang in the Northeast. The notice states that places with large variations in seasonal and wet-dry power consumption should establish TOU tariff schemes. Under the TOU tariff schemes, TOU prices are not static but could be adjusted throughout the year to reflect real-time net power load and spot market signals.

The policy also suggests that China's mid-to-long-term contracts between generators and large consumers, which currently account for most of the electricity market, should include some aspects of TOU prices. If implemented fully, this would match one recommendation of a recent report from the Regulatory Assistance Project, which suggested altering mid-to-long-term contracts to feature a time-of-use element, to ensure that these contracts do not become an obstacle to flexibility.[52] Currently, generators and grid companies both prefer to match flat loads with generators that produce stable output, which hinders the development of a fully-integrated power system that rewards flexibility rather than paying a premium for stable but inflexible loads or generators, which are incompatible with fluctuating grid conditions with high penetrations of variable renewables.

Using the same methodology from this report, we calculated the change in IRR for distributed solar paired with energy storage under the new policy. The calculation shows that if Nanjing and Hangzhou's commercial tariff peak-trough ratios increase from today's levels to a peak-trough ratio over 4:1, the IRR of Nanjing's distributed solar PV would increase from 22.24% to 23.80% and that of Hangzhou would increase from 17.26% to 19.19%. This will also improve the economics of thermal energy storage, such as for data centers.

Concluding remarks

China's distributed energy and distributed storage markets have reached an inflection point. PV and storage costs have fallen steadily, and at today's retail time-of-use tariffs solar combined with storage is either economically attractive today or likely to become economical in the next few years. Further, the recent surge in distributed PV installations, enabled by supportive policies at the national level and in certain provinces, is likely to continue. Though distributed solar and storage are inappropriate for central city locations where high-rises predominate, China's urban areas also feature vast peripheral industrial, commercial, and suburban residential zones with ample rooftop area to support distributed energy.

Distributed energy in China has always faced numerous barriers, only some of which have been resolved. Owner-occupant dilemmas, difficult grid connection, safety regulations, and lack of official motivation will continue to pose problems for distributed PV and storage—both for residential and commercial applications. These issues are unlikely to be resolved nationally for some time, implying that certain regions, such as those with a local solar and battery manufacturing industry, and those with an existing network of installers and service companies, are more likely to take the lead. New policies to promote distributed energy pilot projects will also help facilitate leadership at the regional level.

Lastly, the market for distributed energy and distributed storage will depend on electricity market reforms. Spot market reforms already underway could help promote distributed energy in several respects, particularly if distributed energy sources are able to participate via aggregation service companies or virtual power plants. Reforms to promote sharing of distributed renewable energy at the village or neighborhood level could incentivize installation by customers with less constant electricity load, substantially expanding the market.

At the same time, reforms to retail power prices could help or hinder storage, depending on the impact on time-of-use price policies. If some regions of China develop a Duck Curve of midday solar production, and adopt time-of-use prices to incentivize shifting generation output to the evening hours, this would greatly expand the market for distributed storage. On the other hand, flatter time-of-use prices or opt-in TOU rates can disincentivize distributed energy and storage.
Ultimately, economics will determine the trajectory of distributed PV and distributed storage. If solar and battery costs continue to fall, the worldwide market for distributed energy will expand exponentially. As the world's largest manufacturer of solar and batteries, China will certainly be onboard.

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