Solar Expansion Following Coal Phase-outs

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Abstract

This paper examines how coal phase-outs indirectly spur renewable energy growth by reshaping market demand expectations and reallocating capital. We study China's retirement of 123 gigawatts of coal capacity between 2001 and 2020 under capacity thresholds. Using a fuzzy regression discontinuity design, we find each coal unit retirement generates 2.1 new solar plants and 51.3 megawatts of capacity in the same prefecture-year, with effects quadrupling at the province level. Firm-to-firm investment flows show coal closures increase solar investment, particularly from private investors. Firm-level evidence further indicates each coal unit closure raises solar firms' productivity by 6.2%, suggesting broader industrial upgrading.

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1 Introduction

Green industrial policies have profoundly shaped the global supply, demand, and pricing of solar photovoltaic technologies over the past two decades. Beginning in the early 2000s, governments across the world adopted industrial policies to promote renewable energy, including direct subsidies, tax incentives, preferential financing, and public investments in research and development. These measures fueled rapid expansion in solar manufacturing and deployment, driving steep declines in production costs and accelerating the global diffusion of the technology. Rather than focusing on green industrial policies within the solar industry itself (e.g., Gugler et al. [2021], Banares-Sanchez et al. [2023], Gerarden et al. [2025]), this paper examines the role of coal phase-out policies in driving persistent market demand and reallocating resources toward solar energy.

Industrial policies targeting the solar sector, such as consumer and producer subsidies, can be costly to implement and difficult to target efficiently. They often require significant fiscal outlays, raise concerns about rent-seeking, and may generate distortions in trade and competition. Questions also remain about their long-term effectiveness and the consequences of their removal, as solar markets can contract sharply once subsidies are scaled back. An alternative pathway to sustained growth in the solar sector lies in systematic and irreversible shifts in market demand—particularly from the power sector—that can generate larger markets for solar manufacturers and stimulate production and innovation through organic market dynamics.

The past two decades have seen extensive coal phase-out campaigns across many countries, motivated by environmental, health, and efficiency concerns, and often paired with simultaneous expansions of renewable energy. These shifts reshaped the composition of electricity generation, reducing the role of coal while opening space for new capacity from renewables. Figure S1 illustrates these trends, showing coal plant retirements alongside solar plant commissioning. Within each country, we also observe a strong positive correlation between coal exits and solar entry, suggesting that coal phase-outs can function as an indirect industrial policy for solar.

We focus on the impact of the large-scale retirement of coal power plants in China, which represents the largest coal phase-out campaign in history over the last two decades. As the world's largest coal user and a country historically reliant on coal-fired generation, China's shift is particularly significant. Over the past two decades, 123 gigawatts of coal capacity were shut down under policy-imposed capacity thresholds, creating substantial new demand for alternative power sources, including renewables. At the same time, China has become the world's leading producer and exporter of solar panels, supplying most photovoltaic modules to international markets.

Using unit-level information on coal power plant retirements and solar plant commissioning, we document a strong positive correlation between coal closures and solar expansion. To address potential endogeneity concerns from non-random coal retirements, we implement a fuzzy regression discontinuity design that exploits policy-imposed capacity thresholds under successive Five-Year Plans. Specifically, we construct an instrumental variable (IV) based on the number of coal units with capacities below the relevant thresholds, which predicts the likelihood of plant closure. Our IV estimates show that each additional coal unit retirement leads to the commissioning of 2.10 new solar units and 51.3 MW of new solar capacity within the same prefecture-year.

Beyond prefecture-level effects, we find sizable spillovers across cities within provinces, consistent with China's integrated regional electricity demand network. At the province level, the closure of a single coal plant leads to the commissioning of about eight additional solar plants, roughly four times the prefecture-level effect. Dynamic analysis indicates that this response persists for as long as eight years.

To examine how investment and capital reallocation contribute to this input shift in energy generation, we use firm-to-firm investment data from the firm registration database Tianyancha, which records shareholder information, focusing on solar firms as investment recipients. We find that one additional coal unit closure increases log investment by 0.497, equivalent to 9.1% of the sample mean and 0.061 standard deviations. These investments are primarily made by private firms rather than state-owned enterprises, suggesting that the capital reallocation is driven by profit motives rather than government directives—making it more likely to be sustained.

Finally, we explore how coal phase-out policies affect the economic performance of solar manufacturers by using firm-level data from the China Enterprise Survey (CES). We find that one additional coal unit closure increases solar export value by 0.69 million RMB. This suggests that coal retirements drive immediate shifts not only in domestic installation but also in the production of solar goods for international markets. In addition, there is suggestive evidence that coal closures result in significant increases in firms' total factor productivity, while solar subsidies do not generate additional improvements in firms' performance. These results indicate that demand shifts may also promote industry upgrading organically.

This paper contributes to the growing literature on green industrial policies, which have attracted significant attention as tools for fostering sustainable growth. Such policies aim to build green technological capabilities, secure first-mover advantages in emerging sectors, enhance global competitiveness, and create high-quality jobs [Rodrik, 2014]. They are further justified by the need to correct market failures, including unpriced pollution, knowledge spillovers [Gerarden, 2023], and learning-by-doing [Barwick et al., 2025].

Much of the existing literature examines either *push* policies—such as production and R&D subsidies that incentivize producers—or *pull* policies—such as consumer subsidies or renewable portfolio standards (RPS) that stimulate demand for green energy and promote production and innovation within the renewable sector itself[Borenstein, 2017, Abrell et al., 2019, De Groote and Verboven, 2019, Johnston, 2019, Greenstone and Nath, 2020, Gugler et al., 2021, Banares-Sanchez et al., 2023, Gerarden et al., 2025]. For instance, among various U.S. climate policy spending programs, renewable energy subsidies has been shown the highest returns to the government when environmental benefits are considered [Hahn et al., 2024].

However, sustained industrial expansion ultimately requires crowding in private capital. Less attention has been paid to what drives private investors to reallocate capital into green sectors. This paper connects the macroeconomic literature on demand uncertainty and investment dynamics [Bloom et al., 2007, Jaimovich and Rebelo, 2009, Cascaldi-Garcia, 2025] with the study of green industrial policies. We examine how coal phase-out policies, by improving future demand certainty for renewables, can mobilize private investment. Specifically, we highlight how firm-to-firm investment facilitates solar sector expansion and industry upgrading, showing that coal phase-out policies spur investment and productivity growth, whereas solar subsidies alone do not generate comparable effects.

This paper also relates to the literature on energy transitions, particularly studies examining interactions between energy input markets. Most of this literature focuses on how changes in relative price changes between energy inputs shift demand and generation as the key mechanism [Baylis et al., 2013, Baranes et al., 2017, Knittel et al., 2015, Fell and Kaffine, 2018, Bushnell and Novan, 2021, Bajo-Buenestado et al., 2025]. We extend this literature by identifying capital reallocation as an additional channel through which the transition from coal to renewable energy can occur.

Finally, our paper contributes to the literature on evaluating the costs and benefits of coal fired power plant closures. Existing work has documented local labor market impacts [Hanson, 2023], environmental and health improvements [Li and Jin, 2024] of coal power plant shutdowns, highlighted the possibility of pollution displacement when surviving coal units increase output [Fan et al., 2023], and examined the broader socio economic and well being consequences of the phaseout [Gao et al., 2025]. In contrast to this literature, we focus on the role of coal closures on driving solar expansion. Specifically, we study how the retirement of coal capacity affects renewable capacity expansion and investment intake. To our knowledge, no prior paper provides causal evidence on whether coal retirement accelerates clean energy investment or alters the spatial allocation of capital in the energy sector. Our findings therefore offer new insights into the investment and transition dynamics that shape the speed and effectiveness of China's energy transition.

2 Background

Driven by rapid economic growth, urbanization, and electrification, China's economy became increasingly reliant on energy for the last few decades. Between 1987 and 1997, electricity production more than doubled to 1,134 TWh, with coal-fired power as the dominant source. In 1996, coal alone accounted for 75% of total generation, much of it produced by numerous small and inefficient plants [IEA, 1996]. As a result, coal-fired power plants became a major source of local air pollution, particularly NO_x and SO_2 [Hao et al., 2007].

To improve energy efficiency and reduce pollution from small and inefficient units, the National Energy Administration launched a coal power plant retirement policy requiring the closure of small coal-fired plants below specified capacity thresholds, regardless of age. The aim was to phase out numerous small, inefficient plants and replace them with fewer, larger, and more efficient units. Since 2000, the retirement threshold has been progressively raised in line with the Five-Year Plans: plants under 50,000 kW were targeted in 2001-2005, under 100,000 kW in 2006-2010, under 200,000 kW in 2011-2015, and under 300,000 kW in 2016-2020.

Between 2001 and 2020, approximately 1,100 plants with a combined capacity of 123 GW were decommissioned under the retirement policy (Panels C and D in S2). Since many of these units were retired before reaching their designed lifespans, the policy generated stranded assets estimated at $60-130 billion [Yuan et al., 2019]. Given the capital-intensive nature of coal power plants, the policy not only freed up capital from smaller, inefficient units but also signaled a structural shift in the power sector. This signal may have encouraged investors to reallocate capital away from coal-fired generation toward alternatives, including renewable energy.

The number and capacity of closed units varied across years (Panels C and D in S2), depending on evolving retirement thresholds, which generates temporal variation. Moreover, plant closures were unevenly distributed across prefectures, creating spatial variation (Panel A in S2). This paper exploits both temporal and spatial variation, along with retirement thresholds that induced early plant closures, to apply a fuzzy regression discontinuity approach examining how coal plant retirements affected the expansion of solar energy.

Around the same time of the coal power plant retirement policy, the Chinese government introduced numerous industrial policies to promote renewable energy development aligned with the Five-Year Plans. Since 2006, the start of the Eleventh Fiver-Year Plan, support for solar manufacturing and innovation was mentioned for the first time in the official documents [Banares-Sanchez et al., 2023]. To account for solar expansion driven by these policies, Section A reviews the key industrial policies related to solar energy.

3 Data

3.1 Coal and solar plant tracker

We obtain data on coal power plants from the Global Coal Plant Tracker, January 2024 version [Global Energy Monitor, 2025a]. Each plant unit is recorded with information on plant name, coordinates, capacity, start year, and retirement year. We focus on plants located in China, for which the dataset also provides Chinese names. As of 2024, there are 1,123 retired and 3,146 operating coal units in China, with start years dating back to 1953. Similarly, we obtain data on solar power plants from the Global Solar Power Tracker, June 2024 version [Global Energy Monitor, 2025b].

Figure S2 displays the number of closed coal units and newly commissioned solar units across Chinese prefectures. The number of coal closures is smaller, as coal plants generally have much larger capacity per unit compared to solar. Most retired coal units are concentrated in more developed cities, which had the capacity to build coal plants in earlier decades and now face stronger environmental pressures or energy transition mandates. In contrast, newly added solar units are more evenly distributed across both developed and less developed cities. The northwest region has seen substantial solar expansion, likely due to higher solar radiation and greater land availability.

3.2 Renewable energy policies

Since the early 2000s, Chinese governments at both the national and local levels implemented a wide range of policies to promote renewable energy development and accelerate the energy transition. To account for policy-driven solar expansion, we compile a database of renewable energy policies scraped from official government documents and announcements. We classify these policies into four categories: (i) solar subsidies, (ii) renewable portfolio standards, (iii) government procurements, and (iv) non-solar renewable energy policies primarily targeting wind and hydropower. Using this data, we generate prefecture-year level binary indicators denoting the presence of each policy category. These indicators are included as control variables in our empirical specifications.

Figure S3 Panel A presents the geographic distribution of solar subsidies across China, along with their exposure duration over our sample period. Government subsidy allocation appears uneven, with greater support concentrated in southeastern coastal cities. In contrast, Figure S3 Panel B shows the distribution of wind subsidies, which are more uniformly allocated across regions with little variation. This suggests that solar development is shaped by more regionally targeted support, so we control for subsidy policies in our empirical analysis.

For the other two solar policies, renewable portfolio standards in China were introduced in 2018 and updated annually. The central government specified both a required share of renewable electricity consumption and a slightly higher target share for each province. However, these targets exhibit limited variation across provinces—as shown in Figure S4—and lack clear enforcement mechanisms. Similarly, government procurement for solar projects occurred primarily in the later years of our sample period and followed a concentrated rollout with limited provincial variation, as presented in Figure S5. From an empirical perspective, both policies are likely to be absorbed by year fixed effects and are therefore not included as separate controls.

3.3 Firm-to-firm investment

We obtain firm-to-firm investment data from Tianyancha, focusing on solar firms as investment recipients. To ensure complete coverage of solar firms, we compile a list from the Global Solar Power Tracker described above and from ENF, which includes Chinese cell and panel manufacturers. Each firm is identified by both its English and Chinese names. Using this list, we query the Tianyancha API to retrieve historical investment records for matched firms. We end up with 1,115 solar firms that appear in both the solar firm list and the Tianyancha database. For each recipient firm, we collect information on its historical investors, including the investment amount, entry date, and end date. We also record investor characteristics, such as whether the investor is a private firm or a state-owned enterprise.

3.4 Firm performance

To measure the impact of coal power plant closures on firm performance, we use firm-level production and output data from 1998 to 2014 from the China Enterprise Survey (CES). The CES, conducted annually by the National Bureau of Statistics, covers all firms with annual sales exceeding five million RMB. It provides detailed information on labor, capital, and output—allowing us to construct measures of labor productivity and total factor productivity (TFP) —as well as other variables such as export activity. In 2004, the CES sample accounted for 90% of industrial output and 70% of industrial employment nationwide [Brandt et al., 2012].

We identify 1,330 solar-related manufacturing firms using keywords associated with solar panels in the energy sector. The first such firm appears in 2003; therefore, our performance analysis covers the period from 2003 to 2014. Labor productivity is measured as output value per employee (1,000 RMB per person), while TFP is calculated at the firm-year level under the assumption of a Cobb-Douglas production function. As shown in Figure S6, both the number of solar firms and their productivity have increased substantially over time.

3.5 Export

To measure changes in exports, we use Chinese customs data at the firm-product-destination country-month level for the period 2000-2016. From 2017 onward, firm-level export data are no longer available; instead, we observe exports at the province-product-destination country-month level. Product granularity is at the HS6 level. We observe export quantities, values, and unit prices. We focus on six HS6 product categories relevant to solar energy systems: 854140 unassembled solar photovoltaic cells, 850440 power inverters used to convert solar-generated direct current to alternating current for grid or household use, 853710 electric controllers used in off-grid solar systems, 761090 aluminum structures used to mount solar panels, 940540 solar-powered lamps and lighting equipment, and 841919 solar thermal water heaters.

4 Empirical strategy

4.1 Baseline model

To estimate the impact of coal closures on solar energy expansion, we use the following specification:

$$Y_{it} = \beta \cdot CoalClosure_{it} + Year_t + City_i + \varepsilon_{it} \tag{1}$$

where the sample is at the prefecture-year level. Y_{it} denotes either the number of newly built solar units or the capacity of new solar plants in prefecture i starting in year t. In addition to flow measures, we also use the stock of operating solar units or total installed solar capacity as dependent variables to better interpret the cumulative impact of coal closures on solar energy expansion.

On the right-hand side, the treatment variable of interest $CoalClosure_{it}$ is defined as either the number of closed coal units or the associated capacity. We control for year and prefecture fixed effects to account for national annual shocks and time-invariant local characteristics. The coefficient of interest is β, which captures the association between coal closures and solar capacity, and is expected to be positive given the demand shock induced by reduced coal electricity generation.

For robustness checks, we further control for prefecture-year level solar subsidy incidence, which may affect solar capacity but is unlikely to be correlated with the coal closures of interest. We also replace $CoalClosure_{it}$ with province-year level closure counts to account for potential spillover effects from closures in other cities within the same province. Additionally, in the mechanism and economic consequence analyses, we replace solar capacity with investment, productivity, and export outcomes as dependent variables.

4.2 Fuzzy regression discontinuity design

The closure of coal power plants in China is typically implemented by local governments under the guidance of the central government. Plants with smaller capacity are more likely to be targeted for closure due to their lower efficiency and lack of economies of scale. Based on this policy targeting, we construct an instrumental variable for $CoalClosure_{it}$. Specifically, when using the number of units closed as $CoalClosure_{it}$, the instrument is defined as the number of operating coal units in prefecture i that fall below the policy threshold and have not yet been closed at the beginning of year t. When using the capacity of closed coal units as the endogenous regressor, we define the instrument as the total capacity of operating units below the threshold. As described in Section 2, we use a 50 MW threshold for 2001-2005, 100 MW for 2006-2010, 200 MW for 2011-2015, and 300 MW for 2016 onward when identifying small-scale units subject to closure.

To test whether being below the policy threshold increases the likelihood of plant closure, we conduct a regression discontinuity (RD) analysis at the coal unit-year level. We construct a balanced panel by duplicating each coal unit across the years 2000-2020. The outcome variable is a binary indicator equal to one if the unit is retired in a given year and zero otherwise. To avoid mechanically assigning zeros to already closed units, we drop all unit-year observations that occur after the actual closure year, so that zeros only capture operating units. The running variable is defined as the difference between the unit's capacity and the relevant policy threshold in that year. This design leverages exogenous policy thresholds that guide local governments in targeting small coal units for retirement. Since the thresholds are not strictly enforced, the design constitutes a fuzzy RD, where being below the threshold increases but does not deterministically dictate the probability of closure.

Figure 1 Panel A shows our graphical results. We observe a low probability of closure when the distance to the capacity threshold is positive, namely for larger coal units. The probability remains close to zero as capacity decreases until the distance approaches zero. At that point, we observe a sharp increase. For negative distances, the dummy for being closed in a given year reaches as high as 0.03. Table S1 Column (1) and (2) report estimates on the discontinuity. Using a bandwidth of 500 MW, being below the threshold increases the probability of closure by 0.0074, representing a 97% increase relative to the average value of 0.00764. Results are similar when using alternative bandwidths. This is consistent with our intuition of coal closure targeting smaller units.

Alternatively, instead of using newly closed units as the outcome, we analyze the cumulative stock of closures. We use a balanced unit-year panel over 20 years, where the dependent variable equals one if the unit has already been retired by a given year and zero otherwise. Unlike the previous specification, we include post-closure units in the estimation. In Figure 1 Panel B, we observe a similar discontinuity pattern: units below the threshold are more likely to have been retired, consistent with policy targeting. In Table S1 Column (3) and (4), results show that being below the threshold increases the probability of being closed by 0.077, 101% of the outcome mean value of 0.0762. The magnitude is similar to that using new closure dummy as dependent variable, both suggesting falling below the capacity threshold doubles a unit's likelihood of retirement.

Motivated by the observed discontinuity pattern, we implement an instrumental variable strategy in later sections to examine the effect of coal closures on solar energy expansion. For each prefecture-year, we construct two instruments: the number of operating coal units below the policy threshold when the endogenous variable is the number of closures, and the total capacity of those sub-threshold units when the endogenous variable is closed capacity.

5 Results

5.1 Effects on solar capacity

We begin by estimating the association between coal plant closures and solar capacity expansion using the OLS regression in Equation (1). Table 1 Panel A Column (1) shows that the number of new solar units is positively but imprecisely correlated with coal closures at the prefecture-year level. Similarly, Column (3) replaces the treatment with the capacity of coal units retired and also yields a small, statistically insignificant coefficient. These OLS estimates likely underestimate the true effect, due to endogeneity concerns: electricity demand may simultaneously delay coal closures and drive solar expansion, biasing the estimated coefficient downward.

Therefore, we instead use an instrumental variable for $CoalClosure$, motivated by policy thresholds that guide the retirement of small coal units. Specifically, we construct two instruments at the prefecture-year level: the number of operating coal units below the relevant policy threshold, and the total capacity of these sub-threshold units. Table S2 reports the first-stage relationship. We find one additional sub-threshold coal unit increases the number of closures by 0.071 units, and an additional 1 MW of sub-threshold capacity increases closures by 0.055 MW. Both estimates are statistically significant at the 1% level, providing suggestive evidence that the instruments have strong predictive power for closures and are relevant for IV estimation.

Using these IVs, Table 1 Panel A Columns (2) and (4) present the 2SLS estimates with the number and capacity of coal closures as endogenous variables. Column (2) indicates that each additional coal unit retirement leads to the construction of 2.10 new solar units. This effect is economically large, amounting to 1.50 times the sample mean (1.40) and 0.32 standard deviations (6.515). The elasticity above one likely reflects the relatively small size of typical solar units compared to coal units. In Column (4), using retired coal capacity as the regressor, the estimate implies that closing 1 MW of coal increases the number of solar units by 0.019, which represents 1.4% of the mean and 0.003 standard deviations.

Panel B of Table 1 turns to new solar capacity as the outcome. Column (2) estimates that one additional coal unit closure results in 51.3 MW of new solar capacity, which is 1.86 times the mean (27.559) and 0.45 standard deviations (112.838). Column (4) using coal capacity as the treatment shows that retiring 1 MW of coal leads to a 0.59 MW increase in new solar capacity, equivalent to 2.1% of the mean and 0.005 standard deviations. These results suggest a large same-year, same-prefecture response in solar capacity following coal unit closures.

To test whether the observed increase in new solar projects is large enough to affect the overall solar base, we turn to stock outcomes. Table 1 Panels C and D use the total number and capacity of active solar units as dependent variables. Column (2) of Panel C shows that one coal unit closure increases the number of active solar units by 9.62, which represents 1.57 times the mean (6.136) and 0.46 standard deviations (20.905). Column (4) of Panel D estimates that retiring 1 MW of coal leads to an increase of 2.51 MW in operating solar capacity, equal to 2.3% of the mean (110.344) and 0.006 standard deviations (396.152).

5.2 Spillover, dynamics, and robustness

Electricity production in China is primarily local but often spans multiple cities within the same province due to shared transmission infrastructure and coordinated planning. As a result, closing coal power plants may not only affect energy demand and solar expansion in the same prefecture but may also generate spillover effects on neighboring prefectures within the province. To test for such spillovers, we re-estimate Equation (1) using prefecture-year data but replace the treatment variable with the number or capacity of coal units retired at the province-year level. Results reported in Table S3 show that one additional coal unit closure at the province level leads to an increase of 0.93 new solar units per prefecture, while retiring 1 MW of coal capacity increases the number of solar units by 0.008. These coefficients are 44% and 42% of the baseline effects in Table 1. This suggests that while there are modest regional spillovers from coal plant retirements, the majority of the solar expansion is concentrated in the same locality as the closure.

Similarly, we test the dynamic effect across years by checking how later years' solar capacity is affected by this year's coal closure, still focusing on the same prefecture. Table S5 shows that the estimated coefficients on $CoalClosure$ remain positive and statistically significant up to eight years after retirement, and become small and imprecise in year nine. The magnitudes increase gradually from year 0 through year 5, indicating a persistent and growing response. Specifically, one coal unit closure leads to 2.59 additional solar units five years later, larger than the contemporaneous effect of 2.10 units. These results suggest that solar responses to coal retirements accumulate over time, consistent with construction delays, permitting processes, and staggered project implementation.

To construct "cleaner" control groups so that they are not influenced by prior coal plant closures, we apply the Local Projections Difference-in-Differences (LP-DiD) approach proposed by Dube et al. [2025]. This method allows us to trace the dynamic impacts of coal closures at the province-year level on prefecture-level solar expansion. As illustrated in Figure 2, the closure of a single coal unit induces a gradual increase in both the number of new solar installations and installed capacity over the subsequent eight years. Specifically, one coal unit closure corresponds to an average of 2.75 additional solar units in affected cities.

In addition, as a robustness check, we control for the existence of solar subsidy programs that may affect local solar expansion patterns. Table S4 adds a binary indicator for whether a solar subsidy was active in a given prefecture-year. Across all specifications, coefficient on $CoalClosure$ remains stable in both magnitude and statistical significance. The estimates on $SolarSubsidy$ are positive and statistically significant when using the number of new or active solar units as the dependent variable, but statistically imprecise when using new or active solar capacity. This suggests that subsidies may encourage the construction of additional solar units, particularly smaller-scale installations, but have a limited impact on total installed capacity. Overall, these results indicate that the observed relationship between coal closures and solar expansion is not driven by concurrent subsidy policies.

As an alternative, we employ a synthetic difference-in-differences approach that is robust to staggered rollout designs, following Arkhangelsky et al. [2021], rather than the fuzzy regression discontinuity approach. This method constructs a synthetic control to address the endogeneity of coal closures, rather than relying on evolving capacity thresholds. Because the framework accommodates only binary treatments, we define coal closure as equal to 1 if at least one coal power unit was closed in a prefecture-year. Table S6 shows that coal closures significantly increase solar units and in the total number of active units.

5.3 Mechanism via investment

How did coal plant closures affect solar energy expansion? One possible channel is the mechanical demand shift: when coal plants retire, the resulting reduction in electricity supply must be offset by other sources, potentially creating space for renewables. However, the intention of the coal retirement policy was not to promote renewables, but rather to phase out numerous small, inefficient plants and replace them with fewer, larger, and more efficient coal units. Consistent with this, Table S8 shows that each 1 MW of retired coal capacity results in only about 0.6 MW of new solar capacity—far short of one-for-one replacement, which implies that demand alone cannot explain the pattern. Therefore, the growth of solar energy reflects not only the substitution of retired coal capacity, but also forward-looking investment that anticipates future demand.

To formally test whether solar expansion was driven beyond simple supply substitution, we examine the impact of coal plant retirements on new coal investment using the same fuzzy regression discontinuity approach. Columns (1) and (3) in Table S9 show that the closure of one coal plant results in the opening of 0.19 new coal plants in the same year, though the effect is not statistically significant. However, each kilowatt of retired coal capacity is linked to 2.62 kilowatts of new coal capacity. This suggests that smaller and less efficient plants were indeed replaced by larger, likely more efficient ones. Moreover, the additional new coal capacity appears sufficient to compensate for the retired capacity, suggesting that the expansion of solar power cannot be explained solely by substitution away from coal.

In addition, we examine how coal plant closures affect solar manufacturing exports. If solar expansion were driven primarily by meeting the domestic demand shift from coal to renewables, we would expect little change in exports. However, using both firm-level data and aggregate province-product level data, we find a significant increase in exports. Section 6 discusses this in greater detail.

Another potential channel is through the reallocation of capital. Forward-looking investors focused on the energy sector may shift resources toward solar projects in response to future demand rise in renewable energy. Anticipating increased demand and improved returns after closures, they may accelerate investment in solar infrastructure in affected regions.

To test this mechanism, we examine changes in new investment activity using historical investment data from Tianyancha. We aggregate solar investment data from the recipient-investor-year level to the prefecture-year level and use the log of newly initiated solar investments as the dependent variable. Table S7 presents 2SLS estimates. Column (1) shows that one additional coal unit closure increases log investment by 0.497, which corresponds to 9.1% of the sample mean and 0.061 standard deviations. Column (2) reports that retiring 1 MW of coal capacity increases log investment by 0.007, equivalent to 0.13% of the mean and 0.0009 standard deviations.

While most coal power plants are owned by state-owned enterprises, our historical investor data show that solar investments are primarily made by private firms, which account for 27% of the total investment amount. Figure S7 also shows that both the number of investors and the investment amount have been increasing in the renewable energy firms, suggesting greater interests from investors in these firms. These results suggest that coal closures lead to measurable increases in solar investment activity, consistent with a forward-looking capital reallocation mechanism that supports the broader expansion of solar capacity documented in previous sections.

6 Economic consequences

6.1 Firm performance

Over the past two decades, the global cost of solar photovoltaic modules has fallen dramatically, declining from about five dollars per watt (2019 USD) in 2000 to less than 0.5 dollars per watt in 2019. Increased competition in global markets, particularly the rapid expansion of Chinese manufacturing capacity, accelerated these cost reductions [Banares-Sanchez et al., 2023]. To examine factors that contribute to this decline beyond industrial policies in the solar sector, this paper investigates whether coal phase-out further helps improvements in solar firm productivity.

To measure firm-level productivity, we use annual firm-level input and output data from the China Enterprise Survey (CES). Labor productivity is defined as output value per employee (1,000 RMB per person), while total factor productivity (TFP) is estimated at the firm-year level under a Cobb-Douglas production function. As shown in Figure S6, both the number of solar firms and their productivity increased substantially over time.

We apply the same fuzzy regression discontinuity approach to estimate the effect of coal closures at the province-year level on firm-level outcomes, including productivity, input use, output, and exports. Columns (1) and (3) in Table S9 indicate that one unit of coal closure in a province leads to a 0.098 unit increase in TFP, equivalent to about 6.21% of the sample average, a sizable effect. But there is no significant change in labor productivity. Columns (2) and (4) report similar patterns when using closed capacity rather than the number of units as the treatment variable.

In addition, Column (5) shows that one coal plant closure results in a 52.97 million RMB increase in firm output. Moreover, column (7) shows that coal closure is linked to an average increase of 25.687 million RMB in firm exports, which is around 12.34% of average annual exports. However, there is no significant change in capital or labor input, as shown in Columns (9) and (10). Columns (6), (8), (10), and (12) display similar patterns when using closed capacity, rather than the number of units, as the treatment variable.

It is important to note that the measure of capital here differs from the investment data discussed in Section 5.3. Specifically, the capital measure comes from the China

CES and, particularly before 2007, captures only the value of fixed assets. It excludes other forms of capital, such as R&D spending and patents. This makes it a much narrower measure of capital and its interpretation should therefore be treated with caution.

Furthermore, we examine the interaction between the coal phase-out policy and solar subsidies to understand how they jointly affect firm performance. Column (3) in Table S10 shows that the closure of one coal plant in a province results in a 0.207-unit increase in TFP in the absence of solar subsidies, equivalent to 13.12% of the sample mean. However, additional solar subsidies themselves do not generate a substantial further improvement in TFP.

A similar pattern appears for firm output. Column (5) indicates that, without concurrent solar subsidies, one coal plant closure leads to a 105.06 million RMB increase in firm output. The additional provision of solar subsidies does not produce significant incremental gains. Finally, column (7) shows that one coal plant closure corresponds to a 68.39 million RMB increase in exports when no solar subsidies are present. However, additional solar subsidies reduce exports by 53.69 million RMB, suggesting that these subsidies may shift production toward domestic markets rather than in international markets.

6.2 Export

Given China's important role in the global solar market, especially after 2012, we examine whether coal plant closures further increase China's solar product exports. If closures accelerate solar deployment and manufacturing activity, they may also contribute to export growth. Table S11 Column (1) presents estimates at the province-year level using solar export value as the outcome. We find that one additional coal unit closure leads to a 0.69 million RMB increase in solar export value. This suggests that coal retirements cause immediate shifts in the same year not just in domestic installation, but also in the production of solar goods for external markets.

We next assess whether this export response intensifies over time by estimating dynamic effects. Columns (2) to (5) of Table S11 include up to four leads of the coal closure variable. The estimated coefficients increase gradually, with the effect rising from 0.69 million RMB in the closure year to 1.24 million RMB two years later. This temporal pattern suggests that export gains build over time, potentially reflecting production expansion, supply chain adjustment, or delayed project completion following the closure of coal plants.

These results highlight broader economic consequences of China's energy transition. Coal plant closures not only drive local solar investment but also contribute to growth in solar exports, reinforcing China's position in the global supply chain. In contrast, we do not observe significant changes in export prices, indicating that the observed increase in export value is largely driven by rising export volumes rather than price effects. This underscores how domestic energy policy can generate long-term industrial and trade impacts beyond the power sector itself.

7 Conclusion

This paper shows that coal phase-out policies can function as an indirect form of industrial policy for renewables by reshaping market expectations and redirecting capital, thereby fostering sustainable growth in renewable energy. Exploiting China's coal retirement thresholds as a natural experiment, we find that each coal plant closure is followed by substantial solar expansion, with effects that persist and magnify over time and across regions. Beyond capacity growth, we document evidence of increased private investment into solar firms, higher export values, and improvements in firm productivity.

Our findings contribute to the literature on green industrial policies and energy transitions by identifying coal phase-outs as a novel channel for supporting renewable growth. Whereas traditional industrial policies often rely on costly subsidies with uncertain long-term effectiveness, supply-side retrenchment of fossil fuels can create enduring demand for renewables and channel capital toward cleaner technologies. For policymakers, this highlights the importance of aligning fossil fuel phase-out strategies with renewable energy development to achieve both climate and industrial objectives.

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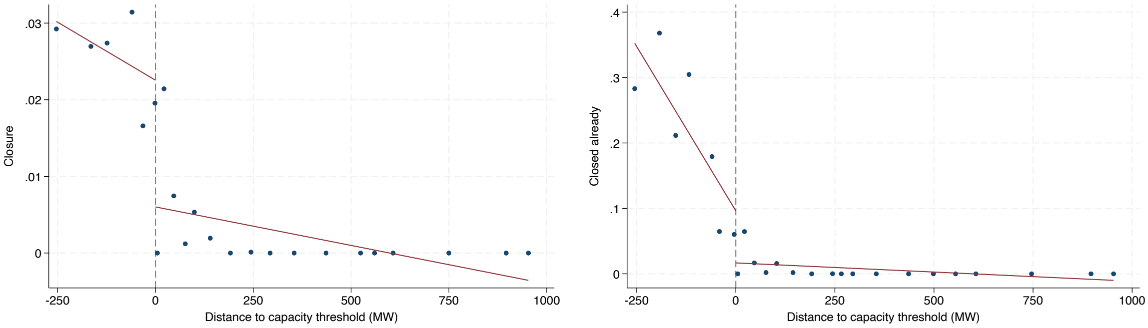
Figures and tables

Figure 1: Distance to policy threshold and coal unit closure



Panel A: New closure

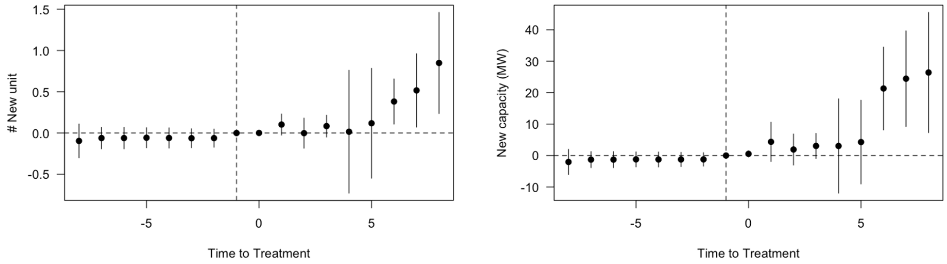
Panel B: Already retired

Notes: This figure shows the relationship between a coal unit's distance to the policy capacity threshold and its retirement status. Panel A uses an unbalanced panel where each coal unit is duplicated for each year from 2001 to 2020. The dependent variable equals one in the year a unit retires and zero otherwise. For already retired units, post-closure years are dropped. Panel B uses a balanced panel of all unit-years from 2001 to 2020. The dependent variable equals one in all years after a unit retires and zero otherwise. The running variable in both panels is the distance to the threshold in that year.

Figure 2: Dynamic effect of coal closure on solar expansion

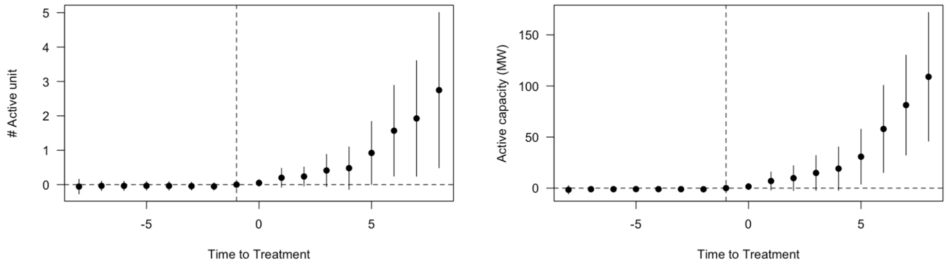
Panel A: #New unit

Panel B: New capacity



Panel C: #Active unit

Panel D: Active capacity



Notes: These figures show the dynamic effects of coal plant closures at the province-year level on the annual number of new and active solar units and capacity at the prefecture level, estimated using the Local Projections Difference-in-Differences approach proposed in [Dube et al., 2025].

Table 1: Effects of coal closure on solar energy

	Panel A: #New unit			
	OLS	IV	OLS	IV
Coal closure	0.0235	2.0961**	0.0003	0.0190*
	(0.0534)	(0.9725)	(0.0008)	(0.0102)
Observations	5940	5940	5940	5940
R-square	0.310	0.253	0.310	0.234
F-stat		12.444		13.581
Y-mean	1.435	1.435	1.435	1.435
Y-sd	6.515	6.515	6.515	6.515
	Panel B: New capacity			
	OLS	IV	OLS	IV
Coal closure	1.8138	51.3354*	0.0060	0.5866*
	(1.7665)	(29.1082)	(0.0163)	(0.3058)
Observations	5940	5940	5940	5940
R-square	0.268	0.158	0.268	0.022
F-stat		12.444		13.581
Y-mean	27.559	27.559	27.559	27.559
Y-sd	112.838	112.838	112.838	112.838
	Panel C: #Active unit			
	OLS	IV	OLS	IV
Coal closure	0.7604	9.6187**	0.0034	0.0828*
	(0.4676)	(4.3744)	(0.0029)	(0.0432)
Observations	5940	5940	5940	5940
R-square	0.438	0.336	0.437	0.303
F-stat		12.444		13.581
Y-mean	6.136	6.136	6.136	6.136
Y-sd	20.905	20.905	20.905	20.905
	Panel D: Active capacity			
	OLS	IV	OLS	IV
Coal closure	11.3474	219.9307*	0.0495	2.5149*
	(7.2153)	(126.9088)	(0.0550)	(1.3390)
Observations	5940	5940	5940	5940
R-square	0.437	0.279	0.437	0.077
F-stat		12.444		13.581
Y-mean	110.344	110.344	110.344	110.344
Y-sd	396.152	396.152	396.152	396.152
IV		#Coal unit below threshold		Coal capacity below threshold
Prefecture FEs	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y

Notes: This table reports OLS and IV estimates of the effects of coal plant closures on solar energy deployment at the prefecture-year level from 2001 to 2020. Panel A examines the number of newly constructed solar units, Panel B the newly installed solar capacity (MW), Panel C the number of active solar units, and Panel D the total active solar capacity (MW). In Columns (1) and (2), the endogenous regressor is the number of coal units closed in a given prefecture-year; in Columns (3) and (4), it is the total capacity of coal units closed. The IV strategy instruments coal closures using the number (or capacity) of coal units below officially mandated retirement thresholds. All specifications include prefecture fixed effects and year fixed effects. Standard errors are clustered at the prefecture level.

Online Appendix

A Other policies in the renewable energy sector

Subsidies. Subsidies—including production, demand, and R&D subsidies—were provided to both consumers and producers to support renewable energy. Figure S3, Panel A, shows the geographic distribution of solar subsidies across China at the provincial level. Subsidy intensity, measured by exposure duration over the sample period, was unevenly distributed, with greater support concentrated in southeastern coastal provinces. This pattern differs from coal plant closures, which were more geographically dispersed. By contrast, wind subsidies (Figure S3, Panel B) were more uniformly allocated across regions, with little variation. These patterns suggest that solar development was shaped by more regionally targeted support, motivating us to control for subsidy policies in the empirical analysis.

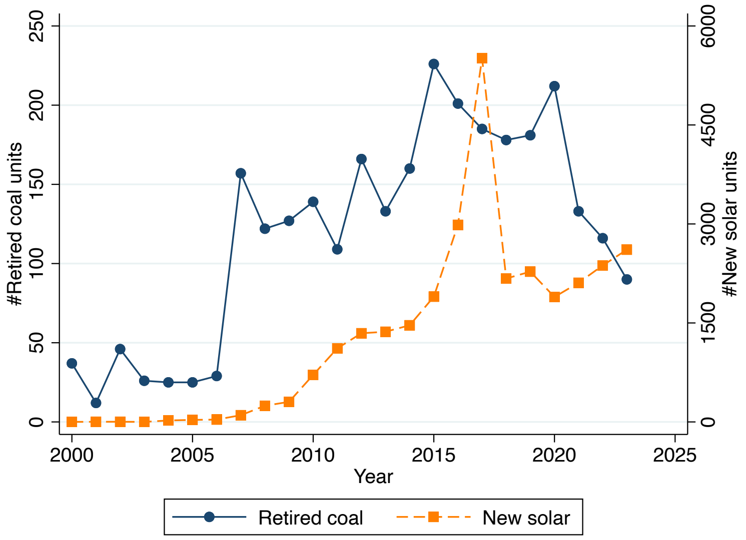
Renewable portfolio standards. To stimulate demand for renewable energy, China introduced renewable portfolio standards (RPS) in 2018, which have been updated annually. The central government set a required share of renewable electricity consumption for each province, along with a slightly higher target share. However, as shown in Figure S4, these targets exhibit limited variation across provinces. Moreover, enforcement mechanisms and penalties for non-compliance remain unclear. Since RPS was implemented only near the end of our sample period, it is included as a control variable in the robustness analysis and is largely absorbed by time fixed effects in our main specifications.

Government procurements. In addition to develop the solar industry through industrial policies, China promoted solar energy in low-income counties as an alternative income source to alleviate poverty. The policy involved procuring and subsidizing rooftop solar installations for low-income households, with surplus electricity fed back into the grid to generate household income. However, concerns arose regarding its cost-effectiveness and the fiscal burden on local governments. As a result, public procurement was significant only in 2017 and was concentrated primarily in three provinces—Shandong, Guangdong, and Henan—as shown in Figure S5. From an empirical perspective, the impact of government procurement on solar expansion is likely absorbed by year fixed effects and is therefore not included as a separate control.

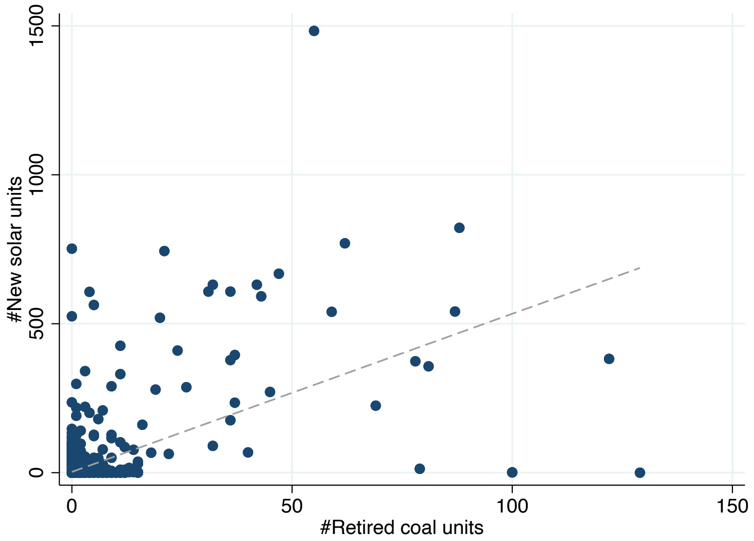
B Additional figures

Figure S1: Coal closure and solar expansion

Panel A: Time series

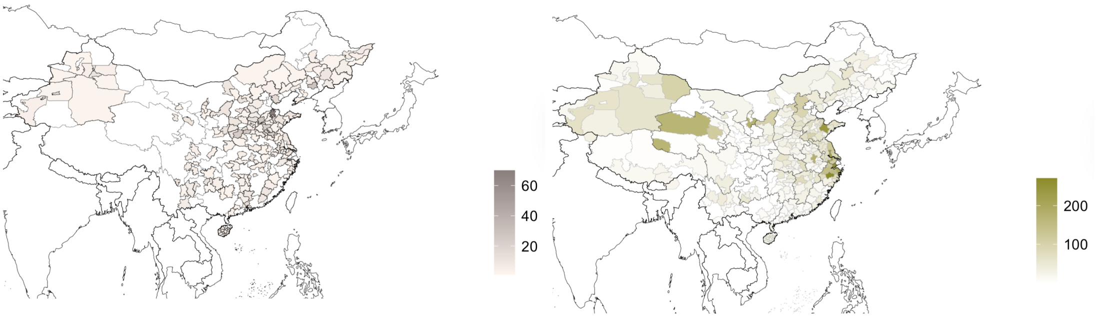


Panel B: Correlation at the country-year level



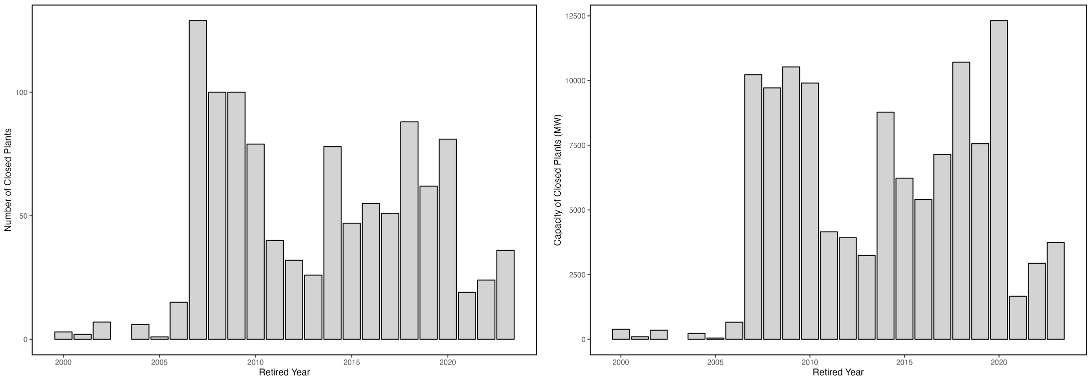
Notes: Panel A plots the number of retired coal units (left axis, blue solid line) and the number of new solar units (right axis, orange dashed line) by year from 2000 to 2023. Data combines all countries globally. Solar projects include installations of 1 MW and above. Panel B is at the country-year level 2000-2023. X axis shows the number of new solar projects, and Y axis shows the number of retired coal units in the same country and year. The dashed line indicates the linear best fit.

Figure S2: Number of closed coal units and new solar units



Panel A: Closed coal units

Panel B: New solar units



Panel C: Closed coal units by year

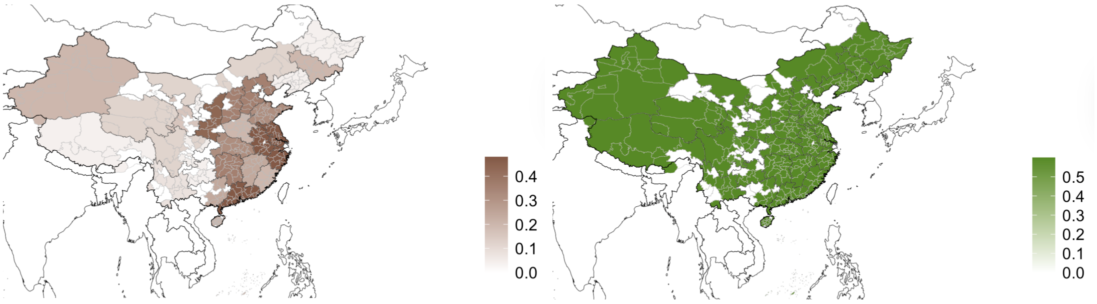
Panel D: Closed capacity by year

Notes: Panels A and B show the total number of closed coal units and new solar units in each prefecture from 2000 to 2020. The legend indicates the number of units. Panels C and D display the number and capacity of closed coal units by year from 2000 to 2023. Data are sourced from the Global Coal Plant Tracker and Global Solar Power Tracker, Global Energy Monitor.

Figure S3: Distribution of solar and wind subsidies

Panel A: Solar subsidies

Panel B: Wind subsidies

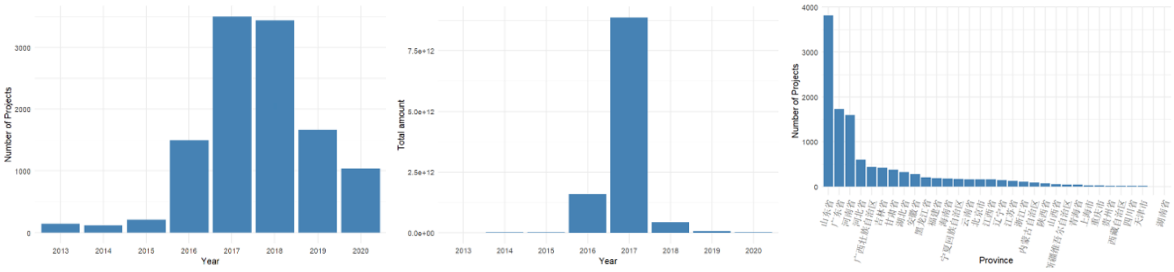


Notes: This figure displays the proportion of years between 2000 and 2020 in which each prefecture received solar (Panel A) or wind (Panel B) subsidies. The legends indicate the share of years with subsidies. Lighter shades represent fewer years, while darker shades indicate more years of subsidy presence.

Figure S4: Distribution of renewable portfolio standards

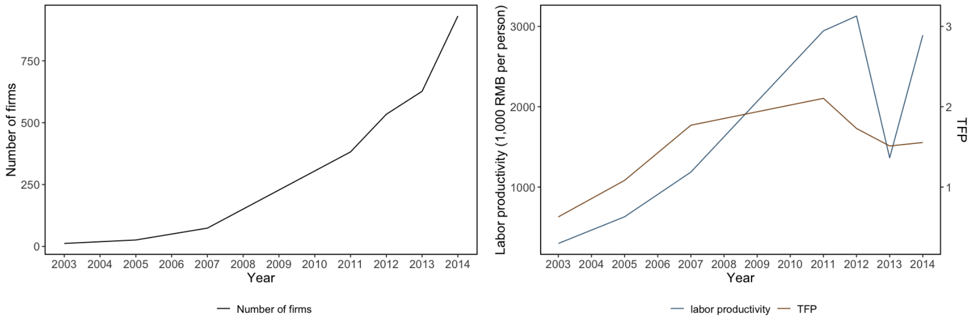
Notes: This figure displays the proportion of years between 2000 and 2020 in which each prefecture was subject to a renewable portfolio standard.

Figure S5: Public procurement over time and across provinces


Panel A: #Project by year Panel B: Total amount by year Panel C: #Project by province

Notes: Panel A shows the number of renewable energy procurement cases by year, Panel B displays the total procurement amount over time, and Panel C shows the distribution of projects across provinces.

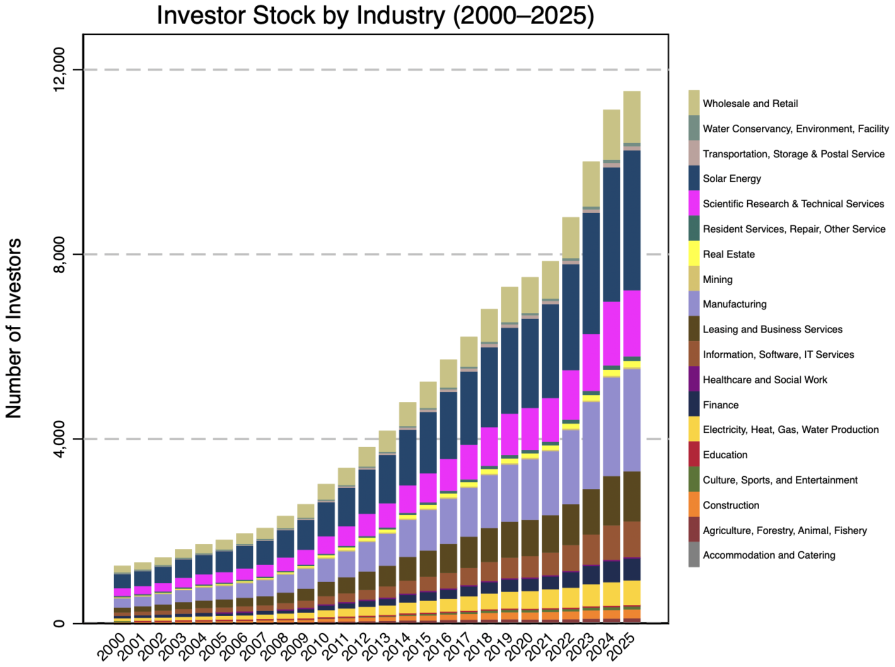
Figure S6: Firms in the Enterprise Survey over time


Panel A: #Firm by year Panel B: Productivity by year

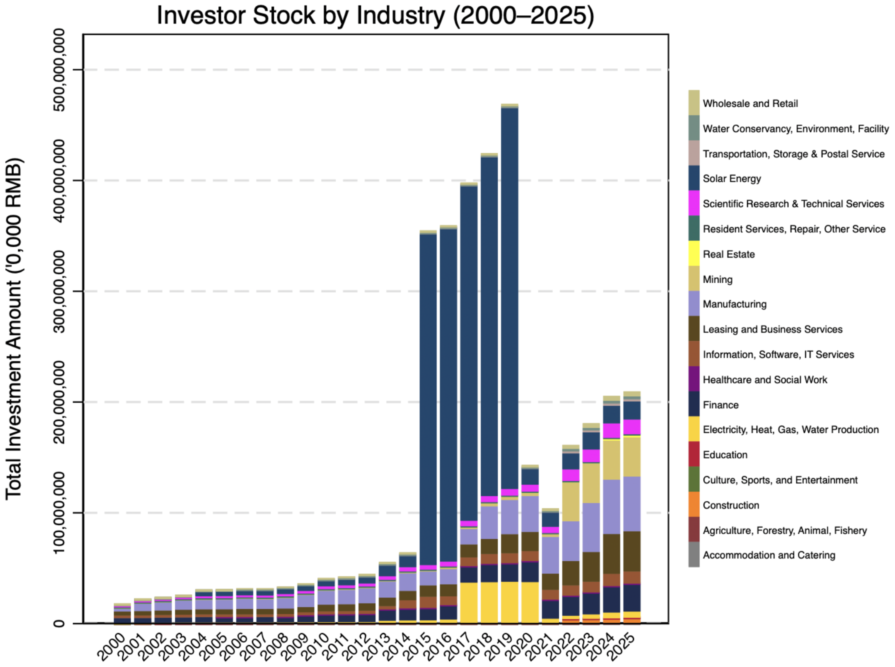
Notes: Panel A shows the number of renewable energy firms in the Enterprise Survey by year, Panel B displays the labor productivity (1,000 RMB per person) and total factor productivity over time.

Figure S7: Investors Dynamics in the Solar Sector

Panel A: #Investors by year



Panel B: Investment Amount by year



Notes: Panel A presents the number of investors in renewable energy firms surveyed in the Enterprise Survey by year, while Panel B shows the investment amounts in these firms over time.

C Additional tables

Table S1: Effects of distance to capacity threshold on coal plant closure

	New closure dummy		Already retired dummy	
RD Estimate	-0.0074**	-0.0080***	-0.0537***	-0.0767***
	(0.0030)	(0.0019)	(0.0028)	(0.0047)
Bandwidth	500	1000	500	1000

Notes: Each column reports an RD estimate using local linear regression with triangular kernel and bandwidths of 500 MW or 1000 MW. The running variable is the distance to the policy capacity threshold. Standard errors are based on nearest-neighbor (NN) robust variance estimation. Significance level: * p<0.1, ** p<0.05, *** p<0.01.

Table S2: First stage: effect of coal stock being below capacity on coal closur

	Coal closure	
Operating unit below threshold	0.0705***	
	(0.0195)	
Operating capacity below threshold		0.0546***
		(0.0144)
Observations	5940	5940
R-square	0.191	0.129
Y-mean	0.168	18.726
Y-sd	0.815	102.021
Prefecture FEs	Y	Y
Year FEs	Y	Y

Notes: The analysis is at the prefecture-year level, 2001-2020. Dependent variable in Column (1) is the number of coal units closed; in Column (2), it is the capacity of coal closed. Standard errors are clustered at the prefecture level.

Table S3: Coal closure at the province-year level

	Panel A: #New unit			
	OLS	IV	OLS	IV
Coal closure	0.0286	0.4296***	0.0002	0.0038**
	(0.0286)	(0.1433)	(0.0003)	(0.0015)
Observations	6740	6740	6740	6740
R-square	0.296	0.276	0.296	0.273
F-stat		273.125		105.651
Y-mean	1.315	1.315	1.315	1.315
Y-sd	6.154	6.154	6.154	6.154
	Panel B: New capacity			
	OLS	IV	OLS	IV
Coal closure	0.1104	3.9466**	-0.0021	0.0528**
	(0.5489)	(1.8396)	(0.0057)	(0.0238)
Observations	6740	6740	6740	6740
R-square	0.263	0.258	0.263	0.247
F-stat		273.125		105.651
Y-mean	26.197	26.197	26.197	26.197
Y-sd	113.681	113.681	113.681	113.681
	Panel C: #Active unit			
	OLS	IV	OLS	IV
Coal closure	0.2623***	1.3845***	0.0018**	0.0130***
	(0.0929)	(0.3203)	(0.0009)	(0.0040)
Observations	6740	6740	6740	6740
R-square	0.426	0.412	0.426	0.404
F-stat		273.125		105.651
Y-mean	5.646	5.646	5.646	5.646
Y-sd	19.859	19.859	19.859	19.859
	Panel D: Active capacity			
	OLS	IV	OLS	IV
Coal closure	3.3870*	16.5238**	0.0119	0.2265**
	(2.0358)	(6.6359)	(0.0166)	(0.0904)
Observations	6740	6740	6740	6740
R-square	0.424	0.419	0.424	0.404
F-stat		273.125		105.651
Y-mean	105.273	105.273	105.273	105.273
Y-sd	398.284	398.284	398.284	398.284
IV		#Coal unit below threshold		Coal capacity below threshold
Prefecture FEs	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y

Notes: The analysis is at the prefecture-year level, 2001-2020. Endogenous regressors in Columns (1) and (2) are the number of coal units closed; in Columns (3) and (4), the capacity of coal closed. Standard errors are clustered at the prefecture level.

Table S4: Robustness: control for solar subsidy

		Panel A: #New unit		
	OLS	IV	OLS	IV
Coal closure	0.0175	2.1371**	0.0003	0.0203**
	(0.0531)	(0.9739)	(0.0008)	(0.0103)
Solar subsidy	2.0284***	1.9748***	2.0285***	2.0021***
	(0.3592)	(0.3608)	(0.3591)	(0.3736)
Observations	5940	5940	5940	5940
R-square	0.317	0.257	0.317	0.229
F-stat		12.508		13.902
Y-mean	1.435	1.435	1.435	1.435
Y-sd	6.515	6.515	6.515	6.515
		Panel B: New capacity		
	OLS	IV	OLS	IV
Coal closure	1.7924	51.4608*	0.0060	0.5908*
	(1.7755)	(29.0959)	(0.0165)	(0.3060)
Solar subsidy	7.2969	6.0399	7.3344	6.5623
	(9.9342)	(9.9052)	(9.9384)	(10.3263)
Observations	5940	5940	5940	5940
R-square	0.268	0.158	0.268	0.019
F-stat		12.508		13.902
Y-mean	27.559	27.559	27.559	27.559
Y-sd	112.838	112.838	112.838	112.838
		Panel C: #Active unit		
	OLS	IV	OLS	IV
Coal closure	0.7422	9.7427**	0.0033	0.0867**
	(0.4663)	(4.3851)	(0.0029)	(0.0433)
Solar subsidy	6.1970**	5.9692**	6.2114**	6.1013**
	(2.4147)	(2.3918)	(2.4159)	(2.4439)
Observations	5940	5940	5940	5940
R-square	0.444	0.338	0.443	0.295
F-stat		12.508		13.902
Y-mean	6.136	6.136	6.136	6.136
Y-sd	20.905	20.905	20.905	20.905
		Panel D: Active capacity		
	OLS	IV	OLS	IV
Coal closure	11.3337	219.9179*	0.0495	2.5160*
	(7.1774)	(127.0500)	(0.0548)	(1.3442)
Solar subsidy	4.6656	-0.6135	4.8871	1.6309
	(46.2616)	(45.3041)	(46.3204)	(47.3781)
Observations	5940	5940	5940	5940
R-square	0.437	0.279	0.437	0.077
F-stat		12.508		13.902
Y-mean	110.344	110.344	110.344	110.344
Y-sd	396.152	396.152	396.152	396.152

IV		#Coal unit below threshold		Coal capacity below threshold
Prefecture FEs	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y

Notes: The analysis is at the prefecture-year level, 2001-2020. Endogenous regressors in Columns (1) and (2) are the number of coal units closed; in Columns (3) and (4), the capacity of coal closed. Standard errors are clustered at the prefecture level.

Table S5: Effects on future years' solar expansion

			#New unit		
	same year	lead1	lead2	lead3	lead4
Coal closure	2.0961**	1.9546**	1.8675**	2.0536**	2.4906**
	(0.9725)	(0.8848)	(0.8084)	(0.9179)	(0.9887)
Observations	5940	5940	5926	5912	5615
R-square	0.253	0.261	0.260	0.256	0.244
F-stat	12.444	12.444	12.420	12.223	19.573
Y-mean	1.435	1.479	1.544	1.630	1.716
Y-sd	6.515	6.519	6.530	6.554	6.714
			#New unit		
	lead5	lead6	lead7	lead8	lead9
Coal closure	2.5936***	2.5112**	1.6535**	1.3585**	0.7678
	(0.9950)	(1.0863)	(0.7563)	(0.6425)	(0.6915)
Observations	5318	5021	4724	4427	4130
R-square	0.250	0.256	0.298	0.316	0.333
F-stat	20.269	14.556	13.765	27.134	24.171
Y-mean	1.812	1.919	2.040	2.176	2.332
Y-sd	6.886	7.072	7.274	7.495	7.736
Prefecture FEs	Y	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y	Y

Notes: The analysis is at the prefecture-year level, 2001-2020. Endogenous regressors in all columns are the number of coal units closed. IVs in all columns are the number of coal units below capacity thresholds. Standard errors are clustered at the prefecture level.

Table S6: Coal closure at the prefecture-year level using synthetic difference-in-differences

	#New unit (1)	New capacity (2)	#Active unit (3)	Active capacity (4)
Coal closure	0.793***	7.600	3.001**	30.057
	(0.298)	(7.107)	(1.268)	(28.341)
Observations	7414	7414	7414	7414
Y-mean	1.196	23.816	5.132	95.703
Y-sd	5.880	108.651	19.005	380.951
Prefecture FEs	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y

Notes: The analysis is conducted at the prefecture-year level for 2001-2020. Coal closure is defined as a binary variable equal to 1 if at least one coal power unit was closed in a given prefecture-year. The effect of coal closure is estimated using a synthetic difference-in-differences approach [Arkhangelsky et al., 2021], with standard errors clustered at the prefecture level.

Table S7: Effects of coal closure on investment on solar firms

	ln(New investment)	
Coal closure	0.4965**	0.0069**
	(0.2399)	(0.0032)
Observations	2616	2616
R-square	0.440	0.426
F-stat	63.127	16.185
Y-mean	5.438	5.438
Y-sd	8.148	8.148
IV	#Coal unit below threshold	Coal capacity below threshold
Prefecture FEs	Y	Y
Year FEs	Y	Y

Notes: The analysis is at the prefecture-year level, 2001-2020. Endogenous regressor in Columns (1) is the number of coal units closed; in Column (2), the capacity of coal closed. Standard errors are clustered at the prefecture level.

Table S8: Effects of coal closure on coal and solar power

	#New coal unit	#New solar unit	New coal capacity	New solar capacity
Coal closure count	0.1932	2.0961**		
	(0.3546)	(0.9725)		
Coal closure capacity			2.6214*	0.5866*
			(1.3921)	(0.3058)
Observations	5940	5940	5940	5940
R-square	0.259	0.253	-0.115	0.022
F-stat	12.444	12.444	13.581	13.581
Y-mean	0.470	1.435	162.575	27.559
Y-sd	1.146	6.515	444.259	112.838
IV	#Coal unit below threshold	#Coal unit below threshold	Coal capacity below threshold	Coal capacity below threshold
Prefecture FEs	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y

Notes: The analysis is at the prefecture-year level, 2001-2020. Standard errors are clustered at the prefecture level.

Table S9: Effects on firm productivity

	Labor productivity (1,000 RMB per person)		TFP	
	(1)	(2)	(3)	(4)
Coal closure	108.509	0.287	0.098**	0.001*
	(334.120)	(3.927)	(0.038)	(0.001)
Age	476.323	478.065	0.013	0.011
	(531.791)	(536.830)	(0.017)	(0.017)
Observations	2,561	2,561	2,561	2,561
R-square	0.033	0.033	0.076	0.075

	Output (1,000 RMB)		Exports (1,000 RMB)	
	(5)	(6)	(7)	(8)
Coal closure	52,969.530*	518.774*	25,687.060**	233.954**
	(31,648.930)	(313.040)	(11,542.590)	(97.088)
	(297,448.100)	(295,899.600)	(90,011.390)	(87,095.090)
Age	67,006.590**	66,352.390**	37,310.630***	37,275.990***
	(30,225.260)	(30,432.390)	(12,663.080)	(12,686.740)
Observations	2,561	2,561	1,782	1,782
R-square	0.062	0.065	0.102	0.104

	Capital (1,000 RMB)		Number of employees	
	(9)	(10)	(11)	(12)
Coal closure	11,941.730	6.085	5.501	0.008
	(45,391.180)	(551.502)	(21.819)	(0.261)
Age	96,074.020**	96,366.840**	58.356**	58.470**
	(41,245.070)	(41,824.640)	(24.926)	(25.171)
Observations	2,561	2,561	2,561	2,561
R-square	0.062	0.063	0.108	0.108
IV	#Coal unit below threshold	Coal capacity below threshold	#Coal unit below threshold	Coal capacity below threshold
4-digit sector FEs	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y
Solar subsidies	Y	Y	Y	Y

Notes: The analysis is at the firm-year level, 2003-2014 using the variation at province-year level. Labor productivity is measured in 1,000 RMB per employee and exports are measured in 1,000 RMB. Endogenous regressors are the number of coal units closed for column (1), (3), (5), (7), (9), (11), and coal capacity closed for column (2), (4), (6), (8), (10), (12). IVs in are the number/capacity of coal units below capacity thresholds. Standard errors are clustered at the province level.

Table S10: Effects on firm productivity: Coal closure vs. solar subsidies

	Labor productivity (1,000 RMB per person)		TFP	
	(1)	(2)	(3)	(4)
Coal closure	210.031	0.296	0.207**	0.001*
	(698.712)	(5.780)	(0.098)	(0.001)
Coal closure × Solar subsidies	−305.253	−2.128	−0.134	−0.001
	(408.189)	(2.344)	(0.093)	(0.001)
Age	474.944	479.924	0.011	0.010
	(534.375)	(539.814)	(0.018)	(0.017)
Observations	2,561	2,561	2,561	2,561
R-square	0.031	0.030	0.076	0.075

	Output (1,000 RMB)		Exports (1,000 RMB)	
	(5)	(6)	(7)	(8)
Coal closure	105,063.400**	621.037	68,393.520***	452.328***
	(52,440.170)	(429.020)	(17,979.750)	(122.787)
Coal closure × Solar subsidies	−71,613.330	−269.332	−53,694.590***	−311.897***
	(45,649.700)	(342.539)	(15,011.720)	(98.291)
Age	66,385.350**	66,338.840**	36,627.690***	36,712.490***
	(30,291.410)	(30,452.930)	(12,707.920)	(12,643.720)
Observations	2,561	2,561	1,782	1,782
R-square	0.063	0.065	0.104	0.106

	Capital (1,000 RMB)		Number of employees	
	(9)	(10)	(11)	(12)
Coal closure	40,903.120	101.990	33.100	0.143
	(73,924.960)	(670.420)	(34.456)	(0.303)
Coal closure × Solar subsidies	−50,440.820	−310.971	−29.118	−0.137
	(45,771.620)	(334.804)	(26.094)	(0.202)
Age	95,717.850**	96,405.760**	58.036**	58.260**
	(41,436.220)	(41,922.220)	(24.981)	(25.158)
Observations	2,561	2,561	2,561	2,561
R-square	0.061	0.061	0.108	0.108
IV	#Coal unit below threshold	Coal capacity below threshold	#Coal unit below threshold	Coal capacity below threshold
4-digit sector FEs	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y
Solar subsidies	Y	Y	Y	Y

Notes: The analysis is at the firm-year level, 2003-2014 using the variation at province-year level. Labor productivity is measured in 1,000 RMB per employee and exports are measured in 1,000 RMB. Endogenous regressors are the number of coal units closed for column (1), (3), (5), (7), (9), (11), and coal capacity closed for column (2), (4), (6), (8), (10), (12). IVs in are the number/capacity of coal units below capacity thresholds. Standard errors are clustered at the province level.

Table S11: Effects of coal closure on solar export value

	Export value (10^6RMB)				
	same year	lead1	lead2	lead3	lead4
Coal closure unit	12.9044**	20.4050***	32.7519***	35.7660***	50.5843***
	(5.3330)	(5.1365)	(7.4000)	(9.4087)	(12.6195)
Observations	3600	3506	3326	3146	2486
R-square	0.453	0.467	0.475	0.483	0.497
F-stat	56.987	54.445	71.666	66.440	49.472
Y-mean	180.655	187.510	196.977	207.557	219.811
Y-sd	663.041	669.471	686.299	704.767	725.808

	Export value (10^6RMB)				
	same year	lead1	lead2	lead3	lead4
Coal closure capacity	-0.0551	0.0652	0.2535**	0.3530**	0.7325***
	(0.0713)	(0.0673)	(0.1177)	(0.1384)	(0.2648)
Observations	3600	3506	3326	3146	2486
R-square	0.449	0.470	0.477	0.477	0.455
F-stat	18.495	17.361	24.312	25.158	20.581
Y-mean	180.655	187.510	196.977	207.557	219.811
Y-sd	663.041	669.471	686.299	704.767	725.808
Province FEs	Y	Y	Y	Y	Y
Year-Product FEs	Y	Y	Y	Y	Y

Notes: The analysis is at the province-HS6product-year level, 2001-2020. Endogenous regressors in Panel A are the number of coal units closed. IVs in Panel A are the number of coal units below capacity thresholds. Endogenous regressors in Panel B are the capacity of coal closed. IVs in Panel B are the capacity of coal units below thresholds. Standard errors are clustered at the product-year level.