Getting Dirty Before You Get Clean: Institutional Investment in Fossil Fuels and the Green Transition*

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Abstract

This paper shows that fossil fuel assets provide valuable opportunities for renewable development, and PE firms are better able to identify and realize these opportunities. Using the intensity of sunlight that falls on fossil fuel plants as an exogenous measure of solar investment opportunity and the passage of the investment tax credit that made solar generation commercially attractive, I find that PE firms are more likely to acquire fossil plants that provide higher solar investment opportunities after solar generation becomes viable. PE acquisition of fossil fuel power plants is followed by an 8% higher likelihood of solar development and a 10% increase in the number of solar plants in the same county. This increase comes from institutional investment in solar energy, specifically from the investors related to the PE owners of fossil plants. These findings contradict the notion that PE firms adversely affect the environment, and suggest that regulations prohibiting PE investment in fossil fuels may unintentionally prevent clean energy financing and impede the green transition.

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1 Introduction

Institutional investments in fossil fuel companies through private equity (PE) funds have grown significantly in the last decade, with over a trillion dollars invested since 2010.[1] Consequently, there is a growing concern that PE investment in fossil fuels delays the green transition by prolonging the lives of dirty assets.[2] This concern has led to mounting pressure on pension funds and asset managers to divest their fossil fuel holdings, not only from their public equity investments but also from private equity.[3]

Contrary to these concerns, I show that PE investments in fossil fuels may *facilitate* the green transition by allowing new, clean technologies to develop. The key insight is that old, dirty assets often provide opportunities for the development of new, clean technologies, and private equity can better realize these investment opportunities than other incumbent owners. I show in this paper that PE acquisition of fossil fuel power plants is followed by an increase in solar development in the area, especially from other institutional investors related to the PE owners of fossil plants. Moreover, PE firms are more likely to own fossil fuel plants that provide exogenously higher investment opportunities for solar development. To my knowledge, my paper is the first to establish this link between private equity investment in fossil fuels and the development of clean energy.[4]

Old, polluting assets often come with resources valuable for new, clean technologies. For example, fossil fuel power plants have access to grid infrastructure and the right to interconnect and transmit electricity. This resource is critical to the development of clean energy sources such as solar, which faces significant costs, delays, and regulatory hassles related to the

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[1] See this PE Stakeholder Project report titled 'Private Equity Propels the Climate Crisis.'

[2] See this article in The Economist titled 'Who buys the dirty energy assets public companies no longer want?' on media concerns related to PE investments in fossil fuels.

[3] New York City became one of the first cities to announce divestment of the future private equity holdings of its major pension funds from fossil fuels in April 2023. See this news report.

[4] While a growing literature studies PE investments (Andonov and Rauh, 2022; Shive and Forster, 2020; Bellon, 2020) in and corporate divestment (Duchin, Gao and Xu, 2022) from polluting assets, it has focused on their effects on the polluting assets, not on the clean energy development.

interconnection of a new plant to the grid (Rand et al., 2023).[5] Solar development also requires several agreements and concessions with power purchasers, regulators, landowners, and the local community (Jarvis, 2021).[6] A fossil plant owner has relationships with these stakeholders and can help overcome these barriers for a new solar developer. Therefore, these fossil assets provide synergies for the development of future solar power plants.

Fossil plant owners and solar developers should contract with each other to jointly realize these opportunities. However, there are contracting frictions that may prevent such partnerships from being realized. These partnerships require large up-front investments by solar developers in land and solar equipment that rely on contracts with the fossil plant owners to share the electrical infrastructure. Such relationship-specific investments that depend on these long-term contracts are prone to hold-up problems (Klein, Crawford and Alchian, 1978) as once these specific investments are made, the fossil plant owner can expropriate future rents from solar developer. Solar investors, such as pension funds, banks, and other institutional investors, may therefore underinvest in such projects that require partnering with fossil plant owners.

Private equity firms, which are increasingly important owners of fossil fuel plants (Andonov and Rauh, 2022), can alleviate these contracting frictions. PE firms have repeated interactions with other institutional investors (Demiroglu and James, 2010; Ivashina and Kovner, 2011; Malenko and Malenko, 2015) and are incentivized to maintain relationships for future fundraising purposes (Chung et al., 2012). This relationship alleviates the hold-up concerns for the institutional solar investors as PE firms' gains from holding up may be outweighed by the long-run costs of lost relationships. Therefore, PE firms can better realize these opportunities together with other investors who specialize in developing solar.

If fossil fuel assets provide solar development opportunities, and if PE firms are better able to realize these opportunities, we should expect a) solar development to increase in areas

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[5] See this NYT article: "In a Twist, Old Coal Plants Help Deliver Renewable Power. Here's How."
[6] See this NYT article: "As Demand for Green Energy Grows, Solar Farms Face Local Resistance."

with PE-owned fossil plants, and b) fossil plants that offer more investment opportunities for solar to be reallocated to private equity. These are the key hypotheses I test and find support for in this paper.

If fossil fuel assets provide solar development opportunities, and if PE firms are better able to realize these opportunities, we should expect a) fossil fuel plants that offer more investment opportunities for solar to be reallocated and owned by private equity, and b) solar development to increase in areas with PE-owned fossil plants. These are the key hypotheses I test and find support for in this paper.

Do PE firms select and acquire fossil-fuel plants that offer more solar investment opportunities? Isolating this investment opportunity motive of a PE firm behind acquiring a fossil plant is empirically challenging for two primary reasons: (i) it is difficult to measure the investment opportunity set of a new technology like solar power, and (ii) the opportunity to develop solar plants is correlated with other unobserved factors that also concurrently affect the PE's motivation to acquire the fossil fuel plant. For example, a state-wide renewable policy will affect both the potential for solar development and the generation prospects from existing fossil fuel plants.

I overcome these challenges by exploiting a unique technical feature of the solar power industry. Solar generation in a region depends on the intensity of sunlight that falls on an area, which is commonly measured as the Global Horizontal Irradiance (GHI). The National Renewable Energy Laboratory (NREL) provides hourly measures of GHI in segments of 4 km by 4 km (around 2.5 miles by 2.5 miles). I collect this data and calculate the average GHI for the segment that each fossil fuel plant is in and use this as a proxy for the investment opportunity set for future solar development in that area.

I also take advantage of the fact that the returns to solar development have changed over time for policy-related reasons. Solar generation became commercially attractive in the US only after the passage of the Energy Policy Act (EPA) of 2005. The Act created a solar Investment Tax Credit (ITC) that offered a 30% federal tax credit for investors in solar energy properties. It significantly reduced the cost of solar development and increased the value of the fossil fuel plant from a solar development perspective.

I exploit these variations in a difference-in-differences setting and compare the effect of solar radiance on the likelihood of PE ownership of fossil fuel plants before and after the passage of the investment tax credit. The identifying assumption is that solar radiance should not affect the value of a fossil fuel plant differentially before and after 2005, except for the option value of future solar development.

I find that private equity firms are more likely to buy a fossil fuel power plant in areas with higher solar radiation after solar generation becomes commercially more attractive. A one standard deviation increase in solar intensity within a state increases the likelihood of private equity firms buying a fossil fuel plant by 3.1% after 2005. This is an economically meaningful 41% increase relative to the likelihood of PE ownership of a fossil fuel plant in my sample (7.5%). This effect holds after including plant fixed effects that account for any time-invariant plant-level characteristics, such as the production quality of the power plants, and state-year fixed effects that control for time-varying state-level characteristics, such as states' renewable policies.[7] This result is also robust to the inclusion of plant-level time-varying characteristics, such as total generation and the efficiency of the plant, and county-level changes in population.

What kind of plants are more attractive from the future solar development perspective? Older plants have shorter remaining lives, and smaller plants generate less electricity. Such plants are more attractive from the solar point of view, as they offer all the benefits such as proximity to transmission lines and substations, without costing as much as large and new plants. The investment opportunity value of these assets, therefore, is much higher than the value of the assets-in-place. Consistent with this, I find that PE acquisition of fossil plants

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[7] Several states have adopted renewable policies, such as Renewable Portfolio Standards (RPS), during this period (Upton and Snyder, 2017).

depends on sunlight only for smaller and older plants, and not for larger and newer plants.

Using a staggered difference-in-differences design, I find that the PE acquisition of a fossil power plant in a county leads to an 8% increase in the likelihood of new solar development in that county in the next five years, relative to other counties with fossil-fuel power plants. This increase is economically significant as only 37% of all counties have any solar development in my sample. On an intensive margin, I also find an additional 11% increase in the number of solar plants installed in that county and a 40% increase in new solar power capacity. These results hold after controlling for fossil fuel generation in these counties and county-level population to account for any time-varying changes in the overall energy demand in the area. My results also hold after including regulated-state-by-year fixed effects that control for varying time trends in deregulated and regulated states. This suggests that the results are not driven by deregulation in the electricity market, which is a key factor behind the ownership changes in the power sector (Andonov and Rauh, 2022). The results are also robust to new staggered difference-in-differences methodologies (Sun and Abraham, 2021; Callaway and Sant'Anna, 2021).

These results, taken together, suggest a strong relationship between PE ownership of fossil plants and solar development in the area. Next, I explore the mechanisms through which private equity facilitates solar development. PE firms have strong relationships with other institutional investors (Ivashina and Kovner, 2011; Malenko and Malenko, 2015), who are also key players in greenfield solar development (Andonov and Rauh, 2022). The repeated interaction between these investors eases the flow of information about new opportunities and makes contracting (e.g., power agreements) easier.

A simple case study illustrates this mechanism. CLECO is an electric utility that owns power plants in Louisiana. CLECO was acquired by a consortium of PE investors led by the Macquarie Group in 2016. In 2022, CLECO provided the interconnection rights of a coal power plant to the D.E. Shaw & Co. (a hedge fund) for solar development and entered into a long-term power off-take agreement with the hedge fund. While Macquarie and D.E. Shaw may seem unrelated, Macquarie had previously sold several solar plants to D.E. Shaw. The two investors, therefore, had prior relationships and expertise in solar-related agreements.

While we do not observe these agreements for all such partnerships, I provide some empirical evidence to show that this case study reflects a more general pattern. I find that the increase in solar development in PE counties (counties with PE-owned fossil plants) comes from institutional investment (such as from private equity, banks, and pension funds) in solar. Moreover, in more than half of the PE counties with institutional solar development, I find that the solar and fossil investors are either owned by the same parent company or related through prior limited partnerships. This suggests that the relationships between institutional investors may be valuable in realizing these investment opportunities.

Overall, contrary to the prevailing criticism that PE acquisition of dirty assets delays the green transition, I show that it can facilitate the transition by allowing new technologies to come up. PE firms, due to less regulatory and public scrutiny, offer institutional investors a path to entry into the energy sector that then increases their green investments in solar. My findings suggest that any future regulations prohibiting institutional investments in fossil fuels may unintentionally also reduce clean energy investments and hamper the green transition.

Literature review: My paper contributes to several strands of literature. First, it relates to the growing literature on environmental finance. One important question in this literature is the effectiveness of divestment in achieving environmental and societal goals (Heinkel, Kraus and Zechner, 2001; Duchin, Gao and Xu, 2022; Green and Vallee, 2022; Broccardo, Hart and Zingales, 2022; Berk and van Binsbergen, 2021; Edmans, Levit and Schneemeier, 2022; Sachdeva et al., 2023). Another related strand studies the environmental effects of institutional ownership of dirty assets (Shive and Forster, 2020; Bellon, 2020; Bai and Wu, 2023). Existing research primarily examines how divestments from or investments in polluting assets impact those assets themselves. In contrast, my paper highlights that in the presence of barriers to entry for new technology and synergies between old and new assets, the ownership structure of existing assets may affect the development of new technology and should be taken into account. I show that prohibiting institutional investments in dirty assets may lead to fewer investments in clean technology.

Andonov and Rauh (2022), a paper close to mine in this strand, documents that institutional investors have increased their ownership in the power sector through development of new plants, especially renewables, and find deregulation to be the key driver behind these ownership changes. My paper, on the other hand, establishes a causal link between private equity ownership of fossil fuel assets and the development of renewable plants in those areas.

Second, this paper contributes to the literature studying the stakeholder impact of private equity.[8] While a few papers have studied the impact of PE on innovation (Mollica and Zingales, 2007; Popov and Roosenboom, 2009; Lerner, Sorensen and Strömberg, 2011), the evidence on the effects of PE on new business creation is scarce, primarily due to lack of data availability on new business creation. My paper bridges this gap in the literature by showing that PE acquisition of old assets leads to creation of new businesses, creating positive externalities for the local economy and the environment.

Third, my paper is related to the energy economics literature studying decarbonization of the electricity sector. One of the key impediments to decarbonizing the power sector has been the lack of sufficient network infrastructure, such as transmission lines, and regulatory mechanisms to allocate these transmission rights (Joskow and Tirole, 2000; Gonzales, Ito and Reguant, 2022). I provide empirical evidence that existing power plants with transmission rights and local knowledge can facilitate decarbonization if the contracting frictions between the owners are reduced, e.g., through a change in the ownership structure.

A related literature in energy economics studies the determinants and the effects of the

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[8] A large literature studies the impact of PE acquisition on competitors (Chevalier, 1995a,b), industry peers (Bernstein et al., 2017; Aldatmaz and Brown, 2020), and the environment (Bellon, 2020). For a review of the literature on stakeholder impact of PE, see Sørensen and Yasuda (2022).

ongoing ownership changes in the power sector (Borenstein and Bushnell, 2015; Cicala, 2022; Andonov and Rauh, 2022). To the best of my knowledge, my paper is the first to show that the ownership of fossil plants affects clean energy development due to asset synergies and owners' varying incentives and abilities to exploit them.

2 Hypothesis Development

I hypothesize that the relationship between PE ownership of fossil fuel plants and solar development is driven by three key features: 1) synergies between fossil fuel and solar plants; 2) frictions that prevent owners from exploiting these synergies; and 3) characteristics of PE firms that make them less susceptible to these frictions. In this section, I describe these points and use them to formulate my hypotheses.

2.1 Synergies between fossil and solar plants

There are two key challenges solar developers face in the US. The first relates to siting — the process of choosing a location to install solar panels. Utility-scale solar farms require large plots of land in flat, sunny areas that are also close to the grid and transmission lines and have access to electrical infrastructure, such as substations and transformers.[9] Often, such plots of land exist near population centers, where power plants were established historically and are used for pastoral and agricultural purposes. Development on these lands faces significant objections from local communities as it adversely affects the landscape and diminishes property value (Jarvis, 2021; Gaur and Lang, 2023).[10] In addition, siting requires permits from regulators and agreements with several other stakeholders, such as power purchasers and electric utilities.

The second key impediment to solar development is related to interconnection — the

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[9] 1MW of power requires roughly five to eight acres of land (Ong et al., 2013).

[10] See these objections from https://www.clarkcoalition.com/solar.

process of connecting a new power plant to the transmission lines (see Rand et al. (2023) for an overview of interconnection issues). The interconnection process requires a new plant to undergo a series of impact studies that estimate the total costs of new transmission equipment and upgrades needed to connect the plant to the grid. The new project bears this entire cost of transmission upgrade, even though the benefits are shared by every plant connected to the grid, leading to collective action problems (Shleifer and Vishny, 1986; Grossman and Hart, 1980). These costs can be significantly high, especially for smaller projects such as solar plants, as costs associated with equipment upgrades are generally fixed.[11] Moreover, the regulatory process to approve these projects is slow. Consequently, there is a large 'interconnection queue' — a backlog of projects waiting to be approved and connected to the grid. As of February 2023, over 2000 GW of new capacity (130% of current US electricity demand) is seeking interconnection to the grid, with an average wait time of over four years. Solar capacity accounts for the largest share at 947 GW (Rand et al., 2023), highlighting a key challenge solar developers face in the US.

Existing fossil plants may help overcome these challenges. First, these plants are already wired to the power grid and have the rights to interconnect and transmit electricity through the grid, called capacity interconnection rights (CIR). The power plants can share these rights with other developers, saving significant costs, time, and regulatory hassle for a new solar developer.[12] Moreover, fossil fuel plant owners have better information about the state of the electrical infrastructure and the load on local transmission lines and, therefore, may help a solar developer plan where to request an interconnection. Fossil plant owners also have relationships with other stakeholders, such as regulators and local communities, that may help reduce information asymmetry between new solar developers and these players. The synergies between fossil and solar plants are also evident from the proximity of solar development in the US. Figure 1 (b) shows that around 85% (58%) of all solar plants are

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[11] Many new renewable projects are withdrawn due to higher-than-expected interconnection costs.

[12] Different regional transmission organizations (RTOs) have different rules regarding the sharing and transfer of CIR to other developers.

within 20 miles (10 miles) of a fossil fuel plant.

2.2 Frictions

Fossil plant owners and solar developers should contract with each other to jointly realize these opportunities. For example, a fossil fuel plant owner can contract with solar developers and share the fossil plant's interconnection and transmission rights with the solar plant. However, there are contracting frictions that may prevent such partnerships from being realized. Solar projects require large up-front investments in land and solar equipment. These investments would then rely on long-term contracts with the fossil fuel plant owners to obtain the interconnection and transmission infrastructure. Such relationship-specific investments that depend on these long-term contracts are prone to hold-up problems (Klein, Crawford and Alchian, 1978) as once these specific investments are made, the fossil plant owner can expropriate future rents from the solar developer.

This hold-up problem is more acute for institutional investors, such as PE funds, pension funds, and hedge funds, who do not have direct relationships with fossil plant managers. These investors may therefore underinvest in such projects that require partnering with fossil plant owners.

2.3 Role of private equity

Private equity firms, which are increasingly important owners of fossil fuel plants (Andonov and Rauh, 2022), can alleviate these contracting frictions. PE firms have repeated interactions with other institutional investors (Demiroglu and James, 2010; Ivashina and Kovner, 2011; Malenko and Malenko, 2015) and are incentivized to maintain relationships for future fundraising purposes (Chung et al., 2012). This relationship alleviates the hold-up concerns for the institutional solar investors as PE firms' gains from holding up may be outweighed by the long-run costs of lost relationships. Therefore, PE firms can better realize these opportunities together with other investors who specialize in developing solar.

2.4 Hypotheses

In the presence of asset-side synergies and contracting frictions, I formulate the following hypotheses:

H1: Solar development increases more in areas with PE-owned fossil plants.

If synergies between fossil and solar plants exist, and if private equity firms can better exploit the synergies than traditional owners due to financial frictions, we should expect solar development to increase in counties where PE owns fossil plants.

H2: Fossil plants that offer more synergies for solar development should be more likely to be owned by private equity.

In equilibrium, assets should be reallocated to their most efficient user. If PE firms are better able to manage the synergies, the plants that offer more synergies should have higher value for a PE firm than other firms. Therefore, in equilibrium, they should be more likely to own plants that are valuable from a solar development point of view.

3 Data and Descriptive Statistics

Power plant-level characteristics: I obtain plant characteristics from the Energy Information Administration (EIA). EIA Form 860 provides generator-level information such as fuel type, technology type, and installed capacity for electric power plants with 1 MW or greater nameplate capacity. EIA Form 923 provides annual information on electricity generation and fuel consumption at the power plant-prime mover level for plants greater than 1MW capacity. I aggregate information from these forms for all solar plants and fossil-fuel plants that run on coal, natural gas, or oil from 2000-2022.

Panel A of Table 1 reports the summary statistics of plant-year-level information for fossil and solar power plants in my sample. An average fossil fuel plant in my sample is 28 years old, has a capacity of 272MW, and generates 1026GWh of energy per year. In contrast, an average solar plant is younger and smaller in capacity, with an average age of 3 years, capacity of 11MW, and generation of 31GWh per year.

Ownership data: I collect plant-ownership data for fossil-fuel and solar plants from S&P Capital IQ, which compiles asset-level ownership data for power plants in the US, and supplement this with hand-collected data from news articles, PR newswire, and homepages of private equity firms. I classify the owner of a power plant as an institutional investor if more than 25% of the plant is owned by private equity funds, asset managers, banks, or pension funds (through direct investments). All other owners are classified as energy companies, which include publicly traded electric utilities, private independent power producers, and other oil and gas companies. Around 10% of fossil plants and 17% of solar plants have an institutional owner for at least one year of the sample. Similar to Andonov and Rauh (2022), I find greater ownership of renewable plants by private equity and institutional investors compared to fossil plants.

Private equity data: I collect data on private equity investors and their limited partners and co-investors from Pitchbook. Pitchbook provides separate files with information on relationships between private equity funds and their limited partners and investors and their co-investors. I use these files to compile a relationship database of all private equity firms and institutional investors invested in fossil-fuel plants and solar plants and every investor they are affiliated with through limited partnerships or co-investments.

Solar radiation: There are three most common measurements of solar radiation: global horizontal irradiance (GHI), direct normal irradiance (DNI), and diffuse horizontal irradiance (DHI). Global horizontal irradiance (GHI) captures total solar radiation incident on a horizontal surface. It comprises both the DHI and the component of DNI that falls on the surface.[13] GHI is also used to estimate the capacity of total solar power that can be generated from an area and is, therefore, an important and highly relevant measure of solar investment opportunity from an area. While a few other papers in the energy literature, such as Sexton et al. (2021), have used irradiance as a proxy for solar development from the location of a solar power plant, mine is the first paper, to the best of my knowledge, that uses solar irradiance at a fossil-fuel plant location as a measure of investment opportunity for solar development.

I obtain this measure of solar radiation from the National Solar Radiation Database (NSRDB). NSRDB provides hourly values of the GHI at a spatial resolution of 4×4 km (around 2.5×2.5 miles). I collect this data for every fossil-fuel power plant location in the US for five years, from 2010 to 2014, and calculate the average daily GHI (in kWh/m^2) by adding hourly GHI for every day and taking an average over five years. While there is a significant temporal variation within a year, the average daily GHI at a location does not vary significantly across years.

There is a significant spatial variation in the GHI both across states and within-state. Figure 1 shows this variation. Panel A plots the Global Horizontal Irradiance (GHI) of all fossil-fuel power plants (with a capacity greater than 10MW). The size of the circle represents the plant's capacity, and the color shows the irradiance. The darker the red color, the more sunlight the area receives. On average, GHI varies from $5.83 kWh/m^2$ in Arizona, the state with the most sunlight in my sample, to $3.34 kWh/m^2$ in Washington, the state with the least sunlight on its power plants. Across states in the US, the standard deviation of solar radiation is 0.59 W/M2, roughly 13% of the average solar radiation ($4.57 kWh/m^2$). There is also a significant within-state variation in solar radiation. Panel B plots the within-state variations for four states: California, Texas, New York, and Michigan. This within-state variation allows me to tease out the effect of solar radiance on outcomes after controlling for

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[13] GHI is calculated as DNI * Cos(Z) + DHI, where Z is the solar zenith angle

state-level changes in policies.

County-level aggregated sample: For the overall analysis of the impact of PE acquisition of fossil plants on solar development, I need to define an area close enough to a power plant that the solar plant benefits from the transmission synergies. I use the administrative county of the fossil-fuel power plant as the area of interest around it. I start with all the US counties with a utility-scale fossil-fuel power plant.[14] Next, I create county-year-level panel data of these counties from 2001-2020 and aggregate information such as the total number of generators, total capacity, and total generation from fossil fuel plants and solar plants in these counties.

I define a county to be PE county in a given year if at least one fossil plant in the county is owned by a private equity firm in the year. As counties with power plants differ in quality and potential for future power development from those without, I keep a county in my dataset if it has at least one fossil power plant in the year 2000. This allows me to compare solar development in counties with PE-owned fossil plants with those that have a fossil plant but is not PE-owned.

Panel B of Table 1 reports county-year-level summary statistics grouped by PE ownership in the county. PE counties have more number and capacity of fossil plants than non-PE counties. On average, a PE county has around 5.7 power plants in the county, with a total capacity of 1600MW. In contrast, a non-PE county has around two power plants and a capacity of 481MW. An average PE county also has more number (1.9 plants) and capacity (20.5MW) of solar plants in my sample than an average non-PE county at 0.33 plants and 4.8MW capacity.

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[14] Utility-scale power plants are plants with at least 1 megawatt of total electric generating capacity.

4 PE Incentives to Acquire Fossil Fuel Plants

In this section, I establish a direct link between PE ownership of fossil fuel plants and solar development. More specifically, I test my second hypothesis. If private equity firms are better at realizing the investment opportunities that fossil assets provide for solar development, we should expect the assets that offer more opportunities to be reallocated to their more efficient user, in this case, private equity (Maksimovic and Phillips, 1998). Specifically, PE firms should be more likely to own fossil plants that offer more investment opportunities for solar development.

4.1 Empirical design

Studying whether PE firms acquire and own a fossil plant that offers more investment opportunities for solar development is empirically challenging. First, it is difficult to measure the investment opportunity set around a fossil plant for the development of solar power. Second, the opportunity to develop solar plants may be correlated with other unobserved factors that also simultaneously affect the PE's motivation to acquire the fossil fuel plant. For example, if an area implements a new renewable policy, it will affect not only the likelihood of new solar development but also the generation prospects from existing plants. Therefore, it is empirically challenging to isolate the variations in the solar investment opportunity that leave other factors unchanged.

I isolate this effect using the interaction of a spatial variation in the ability to generate solar power and a time-series variation in the costs of solar development. First, I use the intensity of the sunlight, measured in solar irradiance, that falls on a fossil-fuel power plant as a measure of future solar generation capacity from the area. A comprehensive measure of total solar irradiance on a surface is the Global Horizontal Irradiance (GHI). I collect this measure of solar intensity for an area of roughly 2.5 miles by 2.5 miles (4 km by 4 km) around the geographical coordinates of each fossil fuel power plant in the US over five years from 2010-2014 and calculate the average GHI. I use this average GHI as a proxy for the investment opportunity set for future solar development in that area.

Using the intensity of sunlight as a measure of the solar investment opportunity set has several advantages. First, there is a significant spatial variation in the intensity of solar radiation in the US, both across states and within a state. Second, the variation in solar irradiance is relevant for solar development, i.e., the sunlight that falls on an area strongly predicts the likelihood of solar development (Law et al., 2014; Sexton et al., 2021).

While solar radiation is plausibly exogenous to the quality of fossil-fuel plants in the area, there may be unobservable characteristics of fossil plants that are correlated with sunlight intensity, which might affect the likelihood of PE acquisition of these plants. Therefore, I use an additional time-series variation in the costs of solar development to strengthen my exogeneity claim. I use the passage of the Energy Policy Act (EPA), 2005, which introduced a 30% solar Investment Tax Credit (ITC) for residential, commercial, and utility investors in solar. This ITC substantially reduced the costs of solar development and made it commercially viable for the first time in the US. It has been one of the most significant federal policies to support the growth in solar generation in the US.[15]

I exploit these variations — the solar radiance of an area and the passage of the ITC — to achieve a plausibly exogenous change in the PE's incentive to acquire fossil plants for future solar investment opportunities. Specifically, I use a difference-in-differences model with continuous treatment and compare the effects of solar radiance on the likelihood of PE ownership of fossil plants before and after 2005. I estimate the following equation:

$$PE\ Owned_{i,t} = Plant_i + State \times Year_{s,t} + \beta \times Solar\ Radiance_i \times Post\ 2005_t + \epsilon_{i,t} \quad (1)$$

The dependent variable, $PE\ Owned_{i,t}$, is a dummy that takes one if a fossil-fuel plant i is

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[15] See Stokes and Breetz (2018) for an overview of significant energy policies in the US.

owned by a PE firm in year t. $Solar\ Radiance_i$ is the average GHI (solar irradiance) around the area of the power plant i, standardized to have a mean of 0 and standard deviation (s.d.) of 1. $Post\ 2005_t$ is a dummy that takes one in the years starting 2005, and zero before. The model includes plant fixed effects to account for any time-invariant plant-level characteristics, such as production quality, and state-by-year fixed effects to soak away any time-varying state-level characteristics, such as changing state-level renewable policies and incentives. In additional specifications, I include plant-level controls for the plant's net generation and energy efficiency to account for any time-varying changes in the quality of the plant and annual county-level population to control for time-varying changes in the demographics of each county. Therefore, my model allows me to estimate the differential effects of the solar intensity of the PE likelihood of fossil fuel before and after 2005 within each plant after taking into account state-year-level changes, changes in plant quality, and county-level changes in demographics.

4.2 Results

I begin my analysis by showing how the effects of the radiance on the PE likelihood evolved by estimating the following event study-type regression model:

$$PE\ Owned_{i,t} = Plant_i + State \times Year_{s,t} + \sum_{\tau} (year = \tau) \times \beta_\tau \times Solar\ Radiance_i + \epsilon_{i,t} \quad (2)$$

The dependent variable $PE\ Owned$ takes 1 if plant i is owned by private equity in the year t. I use 2004, the year before the passage of the investment tax credits, as the reference year. Therefore, I compare the effect of solar radiance on the likelihood of PE ownership of fossil plants relative to 2004. Figure 3 presents the coefficient estimates and the 95% confidence intervals from this model. The figure suggests a parallel pre-trend and shows that prior to 2004, solar radiance had no significant effect on the likelihood of PE ownership of fossil plants. After 2004, however, there is a sharp increase in the effects, which persists in magnitude for the rest of my sample.

Table 2 presents the results of the regression model in Equation (1). Column (1) shows results for the baseline specification with no controls. It shows that a one standard deviation (s.d.) increase in the solar intensity of the plant location increases the likelihood of PE acquisition of the power plant by 3.1% after 2005 relative to before. This is an economically significant increase of 40% relative to the unconditional mean of PE ownership in my sample of 7.5%. Column (2) includes the time-varying plant-level controls for the net generation and the efficiency of the power plant. Column (3) adds further control for the county-level population to account for any time-varying changes in demographics across the counties. The results are robust to the inclusion of these controls. After including these controls, a one s.d. increase in the solar intensity of the plant location increases the likelihood of PE acquisition of the power plant by 3.3% after 2005 relative to before.

Next, I explore the cross-sectional variations in the characteristics of the plants that PE acquires with future solar investment motives. The value of a fossil fuel plant for its owner comes from the future cash flows it generates from the existing assets in place and the value it provides for future solar development. Therefore, the solar development value should be relatively more important for plants that have a lower present value of future cash flows from the existing assets. Older plants close to retirement and plants with smaller capacities that generate less electricity have lower future earnings than newer and larger plants. However, the options value of these plants, which comes from the infrastructure, such as access to transmission lines and relationships with stakeholders, are similar to larger, newer power plants. Therefore, such smaller and older plants should be more attractive from a solar development point of view. To test this, I split my sample of plants based on their installation year and capacity and estimate Equation (1) separately for these sub-samples. I classify plants built before the start of my sample in 2000 as old. Plants with less than 100MW of power are classified as small and others as large.

Table 3 presents the results. Columns (1) and (2) split the sample based on age and (3) and (4) on size. Columns (1) and (3) show that there is no significant relationship between solar intensity and PE acquisition for new and large plants respectively. On the other hand, columns (2) and (4) show that the likelihood of PE ownership of old and small plants significantly depends on the solar radiance post-2005 relative to before. A one s.d. increase in solar intensity increases the likelihood of PE acquisition post-2005 by 4.4% for old plants and 6.1% for small plants. These effects are also economically large in magnitude, given that the likelihood of PE ownership of an old plant (small plant) is only 5.9% (6.3%).

Overall, these results suggest that power plants that offer more synergies and higher investment opportunities for solar development are more likely to be owned by PE firms. This is consistent with my hypothesis that PE firms are better able to exploit these synergies. In equilibrium, assets are reallocated to reflect that.

5 PE Ownership of Fossil Fuel Plants and Solar Development

In this section, I investigate the effects of Private equity acquisition of fossil fuel power plants on solar development in the area. For this analysis, I aggregate fossil and solar plant information at the county-year level. I start with all the counties that has a fossil-fuel power plant at the start of my sample. I ask whether solar development increases in a county after the PE acquisition of a fossil plant in that county.

5.1 Empirical design

To study this, I start with the traditional difference-in-differences equation with two-way fixed effects (TWFE) that estimates the following model:

$$y_{c,t} = County_c + Year_t + \beta \times Post\,PE_{c,t} + Controls_{c,t} + \epsilon_{c,t} \tag{3}$$

where $County_c$ and $Year_t$ are county and year fixed effects, $Post\,PE_{c,t} = 1$ if there is a PE-acquired fossil plant in county c and year t and zero otherwise. The main dependent variable, $y_{c,t}$ takes 1 if there is a solar power plant in the county c in year t and zero otherwise. I cluster standard errors at the county level for this analysis. Under the parallel trends assumption and in the presence of homogenous treatment effects, β represents the effect of PE acquisition on the likelihood of solar development in the county.

Recent developments in econometrics suggest that this TWFE estimator may be biased when treatment is staggered and treatment effects heterogenous.[16] To address these concerns, I first balance the panel data by restricting my treated sample to have 5 years of data before and after the treatment.[17] Next, I follow the methodology proposed by Sun and Abraham (2021) that alleviates the concerns related to TWFE. This method uses "interaction-weighted" (IW) estimators that are formed by first estimating an average treatment effect with a regression that is saturated in the cohort and relative period indicators, and then averaging estimates across each cohort at a given period. More specifically, Sun and Abraham (2021) estimate an equation of the following form:

$$y_{c,t} = County_c + Year_t + \sum_{g} \sum_{k \neq -1} \beta_{g,k} (1\{G_g = g\} \cdot D^k_{c,t}) + Controls_{c,t} + \epsilon_{c,t} \tag{4}$$

where $County_c$ and $Year_t$ are county and year fixed effects, $1\{G_g = g\}$ is the cohort-indicator

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[16] For an overview of the problems with TWFE and alternative estimators as solutions, see Baker, Larcker and Wang (2022).

[17] My results are robust to choosing other choices of pre- and post-treated periods.

representing each treatment cohort g, $D^k_{c,t}$ is the relative period k from PE-acquisition of a fossil plant in county c and year t. $\beta_{g,k}$ represents the cohort-specific average treatment effect on the treated (CATT). The average treatment effect on the treated (ATT) is then the weighted average of these cohort-specific estimates, with weights equal to each cohort's respective sample share. I report this ATT as the main effect in this paper. My results are robust to alternative specifications, for example, as suggested in Callaway and Sant'Anna (2021).

5.2 Results

Figure 4 plots the dynamic effects of PE acquisition of fossil plants on the likelihood of solar development in the county and presents two key evidence in support of my empirical results. First, it shows that solar development in treated and control counties followed a parallel trend before the PE acquisition of a fossil plant. The parallel pre-trend alleviates the concerns that the treated and control counties had different pre-trends in their solar development. Second, the likelihood of solar development gradually increases over the next five years, with the increase in years 4 and 5 statistically significant at 5%. This suggests that the increase in solar development comes a few years after PE acquisition and is consistent with the average of 2-3 years it takes to plan and develop solar plants during my period (Rand et al., 2023).

Table 4 reports the estimates from the staggered differences-in-differences models in Equations (3) and 4. In columns (1)-(4), the dependent variable is $solar\ dummy_{c.t}$, a dummy that takes the value of 1 if there is a solar development in county c and year t, and zero otherwise. Columns (1) and (3) present the baseline results estimating Equations (3) and (4) respectively. The likelihood of solar development in the county increases by around 8.1% (10.1% using TWFE), after the PE-acquisition of a fossil fuel plant in that county relative to control counties.

While county and year fixed effects in my analysis take care of time-invariant county-specific characteristics and time-varying macro trends, they do not address unobservable time-varying county-level characteristics such as higher demand for electricity due to increasing population or higher supply due to more number of power plants being developed in the area. While I cannot rule out these possibilities altogether, I control for changes in electricity demand by including controls for the number, capacity, and total generation of fossil fuel plants in the county each year and the county-year level population. The results are robust to the inclusion of these controls, as shown in columns (2) and (4).

Another possible concern is that the deregulation in the electricity markets in several states may be driving my results (Borenstein and Bushnell, 2015; Mansur and White, 2012). Several states have reformed their transmission access to ensure independent oversight and control of the transmission networks. Instead of an electric utility company managing transmission networks, these states have an Independent Systems Operator (ISO) as a balancing authority.[18] Andonov and Rauh (2022) find that states with deregulated electricity wholesale markets (states with ISOs) have higher ownership by private equity, and these states also have more renewable development. While much of the deregulation happened in the late 1990s, before the start of my sample, states with deregulated electricity markets may have different trends in ownership and power generation mix over the last two decades. To address this concern, I first add a Regulated state dummy-by-year fixed effects in column (5) to account for varying time trends in deregulated and regulated states separately. My results hold after including these fixed effects. I also restrict my sample to only deregulated states and estimate Equations (3) and (4) on the restricted sample and find the results to be the same as the full sample. Overall, across specifications, there is approximately a 9% increase in the likelihood of solar development in PE counties relative to non-PE counties. This increase is economically significant given that only 37% of all counties have any solar development in my sample.

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[18] See Borenstein and Bushnell (2015) for an overview of electricity restructuring in the US.

In addition to the extensive margin, I also test whether, on an intensive margin, there is an increase in the number, capacity, and generation from solar plants in counties that would have had solar development without the treatment. To study this, I follow the methodology suggested in Chen and Roth (2022) that shuts off the extensive margin channel. Specifically, I transform Y into $m(Y) = log(Y/Y_{min})$ for all $Y > 0$, and $m(Y) = 0$ for all $Y = 0$, where Y_{min} is the minimum non-zero value of the variable Y. This sets the zero values of the variable equal to the minimum non-zero value of that variable, shutting off the extensive margin.

I use this transformed log variable of the number of solar plants, the capacity of solar plants, and generation from solar plants as my dependent variable in columns (6)-(8), respectively. These columns also use the control variables and Regulated -by-year fixed effects as in column (5). The number of solar plants increases by around 11%, solar capacity by 40%, and total generation from solar by 80% in PE counties relative to non-PE counties. These effects are statistically significant at 1%. This set of results suggests that PE acquisition of fossil plants also leads to an increase in solar development on an intensive margin (i.e., the amount of solar power increases in counties that would have had solar development anyway).

6 Mechanisms

6.1 Relationship between owners of fossil plants and solar plants

PE firms have strong relationships with other institutional investors due to repeated interactions (Ivashina and Kovner, 2011; Malenko and Malenko, 2015). PE firms are also incentivized to maintain strong relationships with these capital providers for future fundraising purposes (Chung et al., 2012). These institutional investors are also key investors in greenfield solar development in the US (Andonov and Rauh, 2022). The repeated interaction between these investors eases the flow of information about new opportunities and makes contracting (e.g., power agreements) easier.

A simple case study, as shown in Figure 5, illustrates this mechanism. CLECO is an electric utility that owns power plants in Louisiana. CLECO was acquired by a consortium of PE investors led by the Macquarie Group (together with British Columbia Investment Management Corporation, John Hancock Financial, and other infrastructure investors) in 2016. In 2022, CLECO provided the interconnection rights of a coal power plant to the D.E. Shaw & Co. (a hedge fund) for solar development and entered into a long-term power off-take agreement with the hedge fund. While Macquarie and D.E. Shaw may seem unrelated, Macquarie and D.E. Shaw have prior interaction in the renewable energy space. For example, in 2013, Macquarie Group sold five solar farms in California to D.E. Shaw & Co. The two investors, therefore, have prior relationships and expertise in solar-related agreements.

While we do not observe these agreements for all such partnerships, I provide some empirical evidence to show that this case study reflects a more general pattern. If PE firms jointly realize these investment opportunities with other institutional investors, we should expect the solar development in PE counties to come from institutional investments in solar. To test for this, I classify the owners of the solar plants into two broad categories: (a) traditional energy companies, which include investor-owned utilities (IOUs), independent power producers, and energy companies, and (b) institutional investors, such as private equity, banks, asset managers, and pension funds.[19] Next, I define a county with solar development to be *institutional* solar if it has any institutional owner of a solar plant, and *non-institutional* otherwise.

I begin my analysis by showing some descriptive statistics in Table 5. Column 2 of the Table shows that solar development increased more in counties with PE-owned fossil plants (treated counties) than in counties without PE-owned fossil plants (control counties). It shows that around 34% of all control counties have solar development by the end of my sample, whereas this fraction is 59% in treated counties. Next, I divide the counties

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[19] There are also government-owned and other non-profit owners, such as cooperatives, that are not included in my sample. (see Andonov and Rauh (2022) for different types of owners).

with solar development into those with institutional investment in solar and those without. This breakdown is shown in the 3rd and 4th columns. Counties with no institutional solar development have a similar share of solar across treated and control counties — 18% of all control counties and 22% of treated counties have solar development only by energy companies. On the other hand, there is a significant increase in institutional investment in solar in treated counties relative to control counties. Around 16% of the control counties have any institutional investment in solar, whereas around 37% of the treated counties have at least one institutionally owned solar. This shows that the increase in solar development in PE-owned counties mostly comes from institutional investment in these counties.

I more formally test this in Table 6. I classify a county with solar development as an institutional solar county if it has any institutional investment in solar and a non-institutional solar county with no institutional investment in solar. I then separately test whether the solar development in treated counties comes from institutional solar counties or non-institutional. More specifically, I estimate Equation (4) with two separate dependent variables, $institutional\ solar_{c,t}$ taking 1 if a county c has solar development by any institutional investors in year t, and zero otherwise (columns (1) and (2)), and $non\ institutional\ solar_{c,t}$ taking 1 if a county c has solar development in year t, but not by institutional investors (columns (3) and (4)). The likelihood of solar development increases in counties where institutional investors invested in solar by around 7%. This increase is statistically insignificant for counties with no institutional investor, suggesting that the PE acquisition of fossil plants helps institutional investors reduce their barriers to entry and develop solar.

I form fossil-solar institutional investor pairs that invest in the same county and classify them as *same investor* if the institutional investors investing in solar and fossil have the same parent company (e.g., Blackstone group), and *related investor* if they are related through prior limited partnerships (either one is a limited partner in another or they both share the same limited partners). Out of all the treated counties, 14% have the same investor investing in solar and fossil, and another 38% have a related investor. In total, more than half of all treated counties with solar development have a related institutional investor investing in solar. This suggests that relationships between the PE firms and the institutional investors are important for them to exploit the synergies together.

7 Robustness Tests

7.1 Matched difference-in-differences

In the previous section, I show that fossil plants that offer more investment opportunities for solar development are more likely to be reallocated and owned by private equity firms. Does the solar development increase post-PE acquisition solely due to the fact that PE acquires fossil plants in sunnier counties? This is not true, as I argue below. First, the relationship between solar radiance and the likelihood of PE acquisition that I find is within-state. Across the country, the difference between average solar radiance in counties with PE-acquired fossil plants and the others is statistically insignificant.

However, to further alleviate the concern that the treated counties are different from control counties in their radiance measure, I match every PE-acquired fossil fuel county with another county that has similar average radiation using a 1:1 nearest matching algorithm. I then use a matched difference-in-differences strategy by estimating Equations (3) and (4) on this set of matched sample. Table 7 presents results from this matched difference-in-differences strategy. Columns (1) and (2) show results from the TWFE estimation, and (3) and (4) from Sun and Abraham (2021). Across all of the specifications, the results are robust and similar to the baseline specifications.

7.2 PE acquisition and future growth potential of the area

My results so far point out that PE acquisition leads to more solar development, and PE acquires fossil fuel plants with more opportunities for solar generation. Do PE firms acquire fossil plants in areas with more solar generation potential or more economic potential and higher future energy demand? In this part, I rule out this alternative explanation. First, I include county-level population controls in all of my analyses, and the results do not change after the inclusion of these controls. This suggests that the population changes do not play a key role in driving my results. To further strengthen my claim, I test whether PE acquisition of a fossil fuel plant is followed by a growth in the population in the county. More specifically, I estimate Equations (3) and (4) with population change in the county as the dependent variable. Table 8 presents the results. Columns (1) and (2) show results from the TWFE estimation and (3) and (4) from Sun and Abraham (2021). Across all of the specifications, I find no evidence that PE counties have a higher population growth relative to non-PE counties.

8 Conclusion

There is a growing concern among media, policymakers, and scholars that private equity investment in fossil fuel adversely affects environmental outcomes and delays the clean energy transition. Contrary to this prevailing notion, I provide evidence that PE acquisition of fossil fuel *facilitates* the green transition by allowing cleaner technologies to develop. I first show that PE acquisition of fossil plants leads to higher solar generation in the county. The increase in solar development in PE-owned fossil area comes from institutional investors, specifically the ones that are related to the PE owner of fossil plants. I show that PE firms are more likely to own fossil fuel plants that offer higher investment opportunities for solar development.

My results have important policy implications. As cities and states consider prohibiting their pension funds from investing in fossil fuels through private equity, it is important to consider the unintended consequences of such restrictions on the development of clean technology. My paper suggests that regulations prohibiting PE investment in fossil fuel may prevent financing of clean energy and impede the green transition.

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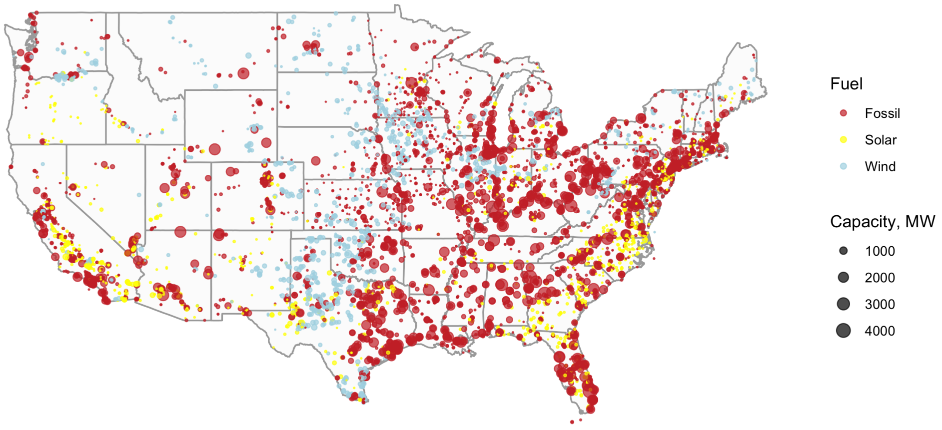
Figure 1: Proximity between solar and fossil plants

Subfigure (a) of Figure 1 plots the location of fossil fuel, solar, and wind power plants in the US. The size of the circle represents the capacity of the power plant, and the color represents fuel type. The figure shows that solar development is more evenly distributed across the U.S., and are closer to the fossil-fuel power plants, relative to wind plants. Subfigure (b) plots the frequency of solar plants at different distance from a fossil-fuel plant. The figure shows that around 85% (58%) of all solar plants are within 20 miles (10 miles) of a fossil fuel plant.

(a): Location of power plants in the US



(b) Distance of solar plants from existing fossil plants

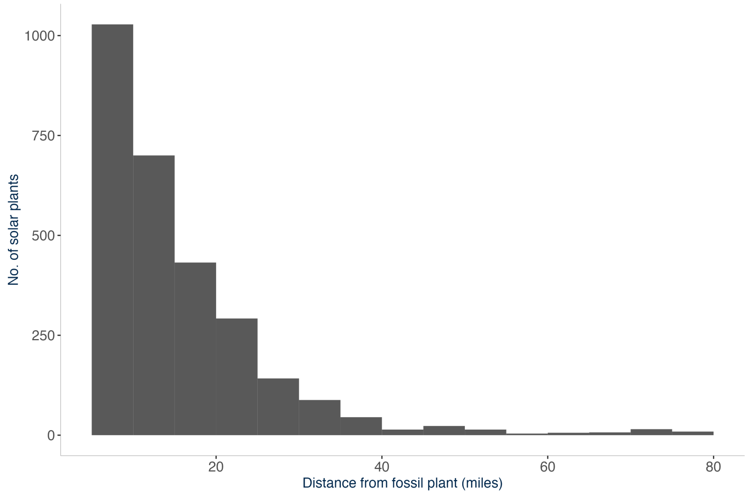
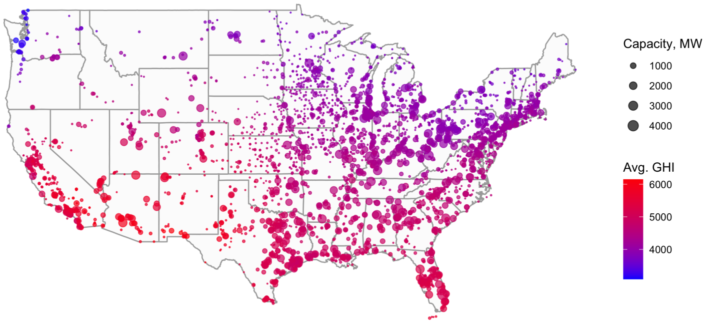


Figure 2: Sunlight intensity on fossil fuel plants

Figure 2 plots fossil fuel power plants in the US and presents spatial variation in the intensity of the sunlight (measured in GHI) that falls on the power plants. The size of the circle represents the capacity of the power plant, and the color represents the GHI. The darker red color represents areas with greater sunlight. Subfigure (a) of Figure 2 shows the variations in GHI across all states in the US. Subfigure (b) shows within-state variations in the GHI for 4 states: Texas, California, New York, and Michigan.

(a) Across-state variations in GHI around fossil-fuel plants



(b) Within-state variations in GHI around fossil-fuel plants

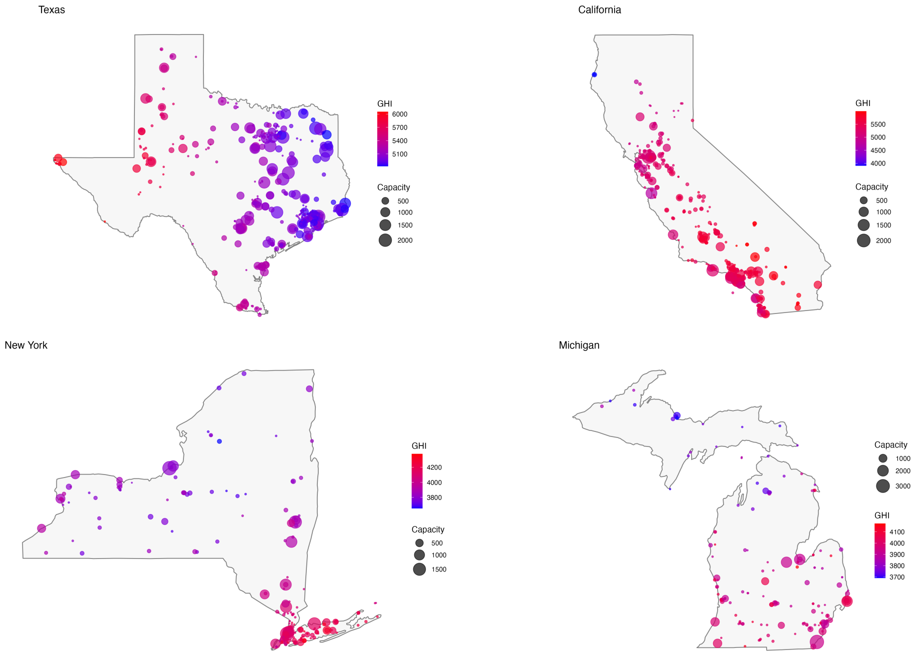


Figure 3: Solar radiance and PE acquisition of fossil plants

Figure 3 reports the dynamic difference-in-differences estimates of the effect of the solar radiance on the likelihood of PE ownership of fossil fuel plant. Specifically, the figure plots the estimates and the 95% confidence intervals of β_τ from the following equation:

$$PE\ Owned_{i,t} = Plant_i + StateYear_{s,t} + \sum_{\tau}(year = \tau) \times \beta_\tau \times GHI_i + \epsilon_{i,t}$$

where the dependent variable $PE\ Owned$ takes 1 if plant i is owned by a private equity in the year t. Standard errors are clustered at the plant level and confidence intervals at the 5% level are reported.

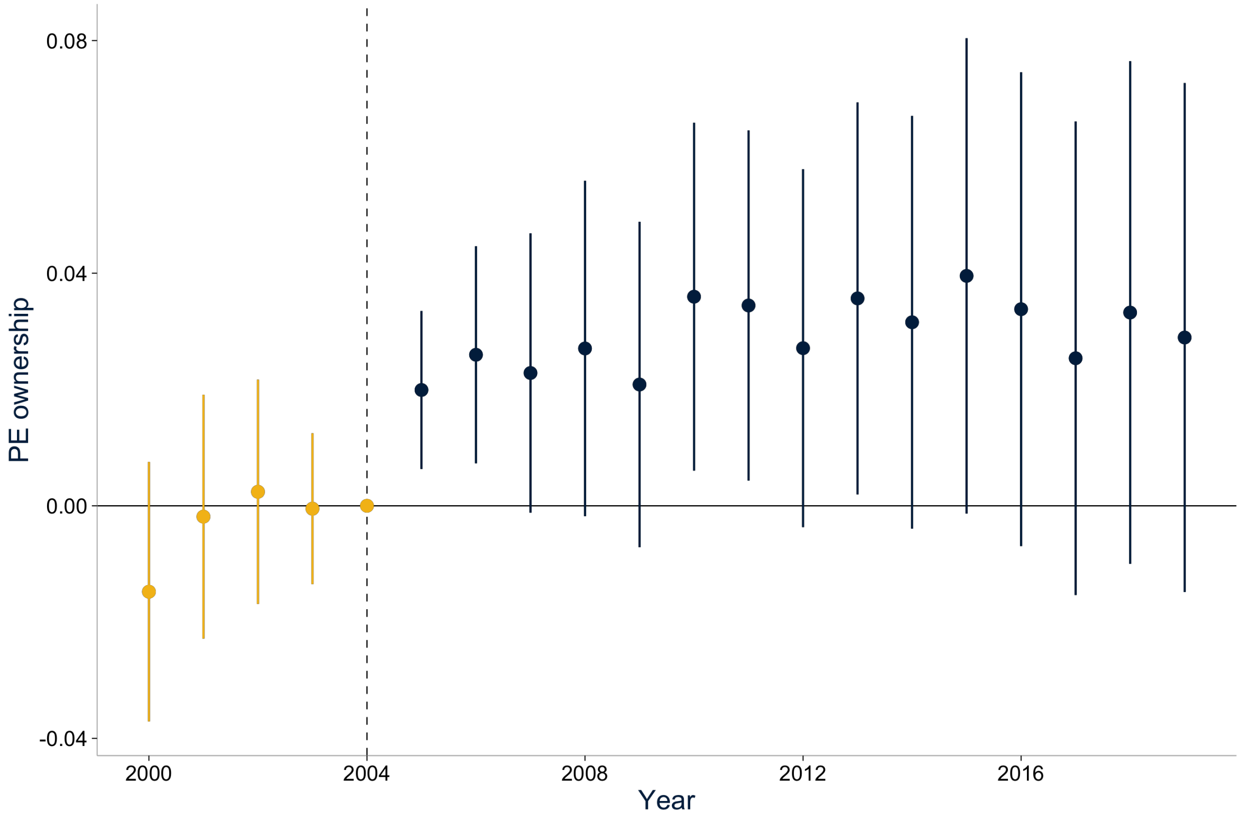


Figure 4: PE acquisition of fossil plants and solar development

Figure 4 reports the dynamic difference-in-differences estimates of the effect of the PE acquisition of fossil fuel plant on solar development following Sun and Abraham (2021) methodology.

The figure plots the $(\sum_g \beta_{g,k})_{k=-5,-4,\ldots,4,5}$ from the following equation:

$$y_{c,t} = County_c + Year_t + \sum_g \sum_{k \neq -1} \beta_{g,k}(1\{G_g = g\} \cdot D_{it}^k) + \epsilon_{i,t}$$

where $1\{G_g = g\}$ is the cohort-indicator and $D_{c,t}^k$ is the relative period k from PE-acquisition of a fossil plant. The dependent variable $y_{c,t}$ takes 1 if there is a solar plant in county c in year t. Standard errors are clustered at the county level and confidence intervals at the 5% level are reported.

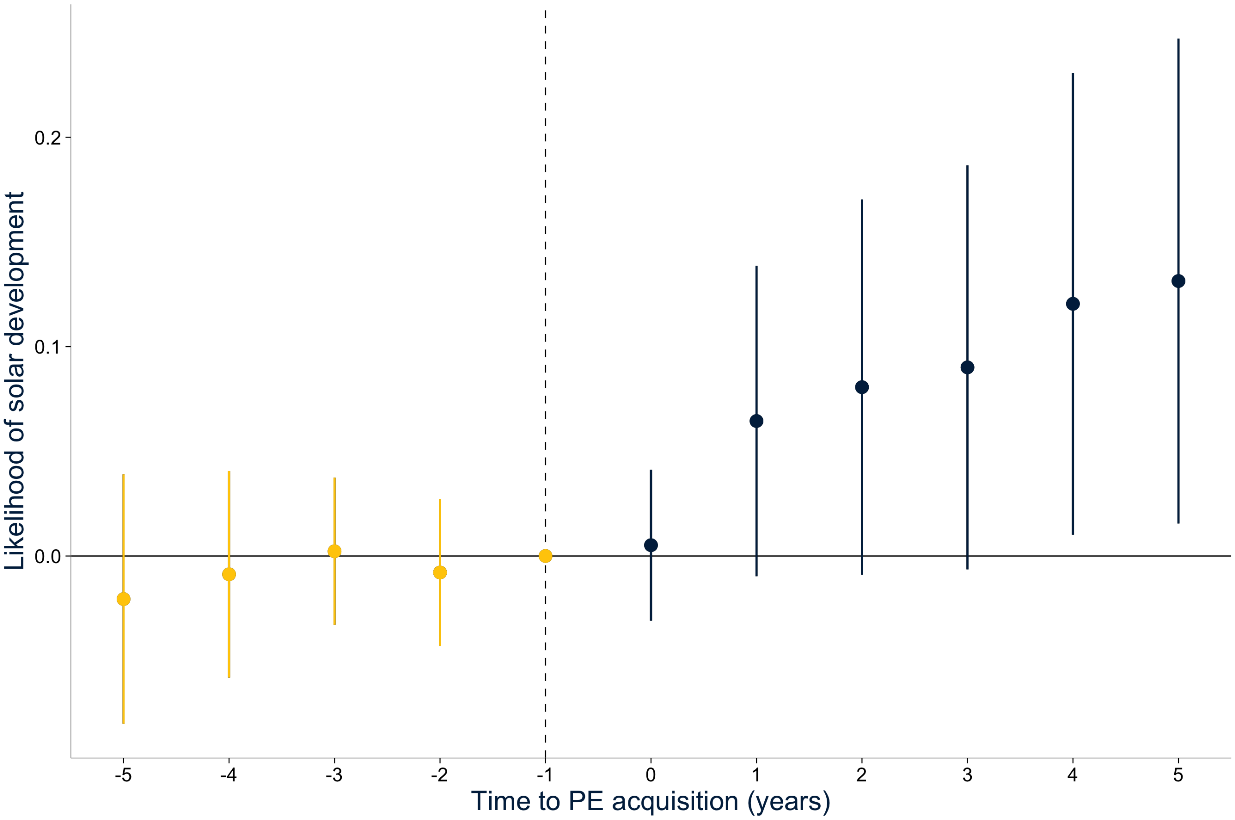


Figure 5: Contractual relationship between a coal plant and a solar plant

Figure 5 illustrates a contractual relationship between a coal plant owned by a private equity firm and a solar plant developed by an institutional investor.

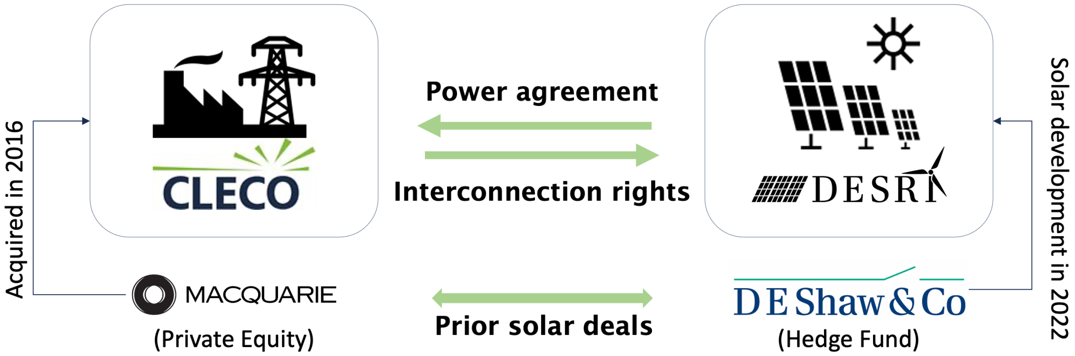


Table 1: Summary statistics

Table 1 reports the descriptive statistics of the variables used in this paper. Panel A presents characteristics at the power plant-year level. This data comes from the U.S. Energy Information Administration (EIA). Panel B presents aggregate data on county-year level grouped by observations that have PE-owned fossil plant in that county-year.

Panel A: Plant characteristics

Variable	N	Mean	SD	P25	Median	P75
Fossil-fuel:						
Age	55,894	27.51	21.38	8.00	24.000	45.00
Capacity (MW)	55,894	272.15	467.42	12.60	55.800	324.00
Generation (GWh)	50,312	1,026.23	2,471.81	2.36	49.880	654.71
Efficiency (MWh/MMBTU)	50,312	0.29	25.28	0.07	0.091	0.11
Fuel Type	55,894					
... Coal	8,485					
... Gas	29,629					
... Oil	12,135					
Solar:						
Age	15,552	2.83	3.37	1.00	2.000	4.00
Capacity (MW)	15,552	10.70	31.89	1.50	3.000	5.00
Generation (GWh)	13,835	30.86	291.07	1.95	4.020	9.66

Panel B: County-Level

	Non-PE counties			PE counties		
Variable	N	Mean	SD	N	Mean	SD
Fossil-fuel:						
No. of plants	26,040	2.06	2.03	3,560	5.74	7.20
Total Capacity (MW)	26,040	472.76	834.05	3,560	1,251.61	1,654.34
Total Generation (GWh)	26,040	1,510.77	3,478.75	3,560	3,625.53	5,674.16
Solar:						
No. of plants	26,040	0.33	1.90	3,560	1.86	7.82
Total Capacity (MW)	26,040	2.89	33.22	3,560	20.54	144.88
Total Generation (GWh)	26,040	4.78	70.88	3,560	36.63	309.47

Table 2: Solar radiance and PE ownership of fossil-plants

Table 2 reports estimates from the following equation:

$$PE\ Owned_{i,t} = Plant_i + State \times Year_{s,t} + \beta \times Solar\ Radiance_i \times Post\ 2005_t + \epsilon_{i,t}$$

where $PE\ Owned_{i,t} = 1$, if a fossil-fuel plant i is owned by institutional investors through private equity in year t, and 0 otherwise. $Solar\ Radiance_i$ is the average GHI around the area of the plant i, standardized to have a mean of 0 and standard deviation (s.d.) of 1. $Post\ 2005_t = 1$ if $year \geq 2005$ and zero otherwise. $Plant_i$ are the plant fixed-effects and $State \times Year_{s,t}$ are the state-by-year fixed effects. Column (1) shows baseline results with no controls. Column (2) controls for log of net generation (MWh) and the efficiency of power plants (kWh/BTU). Column (3) adds further control for the county-level population. Standard errors are clustered at the power plant level; t-stats are shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

	PE Owned		
	(1)	(2)	(3)
Solar Radiance × Post 2005	0.0311**	0.0332**	0.0328**
	(2.534)	(2.531)	(2.495)
Log net generation (MWh)		0.0006	0.0006
		(0.8426)	(0.8896)
Efficiency (kWh/BTU)		0.0060	0.0062
		(0.8162)	(0.8380)
Log population			0.0058
			(0.1155)
Plant FEs	✓	✓	✓
State-Year FEs	✓	✓	✓
Observations	53,488	48,002	47,288
R^2	0.61	0.61	0.61
Outcome mean	0.0754	0.0754	0.0754

Table 3: Solar radiance and PE ownership of fossil-plants

Table 3 presents cross-sectional variation in the likelihood of PE acquisition. Specifically, it reports estimates from the following equation:

$$PE\ Owned_{i,t} = Plant_i + StateYear_{s,t} + \beta \times Solar\ Radiance_i \times Post\ 2005_t + Controls_i + \epsilon_{i,t}$$

where $PE\ Owned_{i,t} = 1$, if a fossil-fuel plant i is owned by institutional investors through private equity in year t, and 0 otherwise. $Solar\ Radiance_i$ is the average GHI around the area of the plant i, standardized to have a mean of 0 and standard deviation (s.d.) of 1. $Post\ 2005_t = 1$ if $year \geq 2005$ and zero otherwise. $\alpha_{s,t}$ is the state-year fixed effects. Columns (1) and (2) report estimates from the sub-sample of plants that were built before and after 2000 respectively. Columns (3) and (4) present results from the sub-sample of plants that have a total capacity of over 100MW and under 100MW respectively. Standard errors are clustered at the power plant level; t-stats are shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

	PE Owned			
	Age		Size	
	New	Old	Large	Small
	(1)	(2)	(3)	(4)
Solar Radiance × Post 2005	0.0011	0.0439***	0.0117	0.0608***
	(0.0323)	(3.040)	(0.6630)	(3.194)
Controls	✓	✓	✓	✓
Plant FEs	✓	✓	✓	✓
State-Year FEs	✓	✓	✓	✓
Observations	11,961	35,327	23,984	23,304
R^2	0.67	0.59	0.61	0.63
Outcome mean	0.126	0.059	0.101	0.052

Table 4: PE acquisition and solar development

Table 4 reports the staggered differences-in-differences estimates of the effect of PE acquisition of fossil fuel on solar development. Columns (1) and (2) report estimates from the following two-way fixed effects estimation:

$$y_{c,t} = County_c + Year_t + \beta \times Post\ PE_{c,t} + \epsilon_{c,t}$$

where $County_c$ and $Year_t$ are county and year fixed effects. $Post\,PE_{c,t} = 1$ if there is a PE-acquired fossil plant in county c and year t and zero otherwise. Columns(3) to (8) follow Sun and Abraham (2021) methodology that estimates Equation (4) as described in Section 5.1. Columns (1) to (5) have *solar dummy* as the dependent variable that takes one if there is a solar development in county c and year t. Columns (6), (7), and (8) use no. of solar plants, log (solar capacity), and log(solar net generation) as the dependent variables. Columns (2) and (4) to (8) include controls for the number of fossil plants, total capacity of fossil plants, total generation from fossil plants, and the population of the county. Columns (5) to (8) also include a more stringent Regulated-state-by-year fixed effects. Standard errors are clustered at the county level; t-stats are shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Model	TWFE		Sun and Abraham (2021)					
			Solar Dummy			Log (plants)	Log (cap)	Log (gen)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post PE	0.1009**	0.0993**	0.0809**	0.0803**	0.0820**	0.1128***	0.4034***	0.7989***
	(2.136)	(2.057)	(2.140)	(2.095)	(2.129)	(2.714)	(2.777)	(2.726)
Controls		✓		✓	✓	✓	✓	✓
County FEs	✓	✓	✓	✓	✓	✓	✓	✓
Year FEs	✓	✓	✓	✓				
Regulated State-Year FEs					✓	✓	✓	✓
Observations	20,712	20,367	20,712	20,367	20,367	20,367	20,367	20,367
R^2	0.54	0.55	0.54	0.55	0.55	0.51	0.54	0.48

Table 5: Relationship between institutional investment in fossil and solar

Table 5 describes the number of counties with institutional investment in solar grouped by counties with PE-owned fossil plants and counties with no PE-owned fossil plants.

Institutional solar refers to counties that have at least one solar development by an institutional investor. Non-institutional solar are counties with no institutional investor in solar. Each cell repsresent number of distinct counties. Numbers in parentheses represent percentage of total counties in that row.

	Total	Solar	Non-institutional solar (% of total)	Institutional solar (% of total)
Non-PE Fossil	1060	362	212 (20%)	150 (14%)
PE Fossil	174	103	42 (24%)	61 (35%)
Total	1234	465	254 (21%)	211 (17%)

Table 6: PE acquisition of fossil plants and solar development by PE

Table 6 reports the effects of PE acquisition of fossil plant on solar development in counties with institutional investment in solar and counties with no institutional investment. Columns (1) and (3) show TWFE estimates from the Equation (3). Columns (2) and (4) table follows Sun and Abraham (2021) method and estimates Equation (4). Columns (1) and (2) present results for solar development in *Any institutional* counties, and (3) and (4) in *No institutional* counties. Standard errors are clustered at the county level; t-stats are shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

	Institutional Solar		Non-Institutional Solar	
	TWFE (1)	SA2021 (2)	TWFE (3)	SA2021 (4)
Post PE	0.0759** (2.041)	0.0665** (2.326)	0.0249 (0.7355)	0.0145 (0.5733)
County FEs	✓	✓	✓	✓
Year FEs	✓	✓	✓	✓
Observations	20,712	20,712	20,712	20,712
R^2	0.54	0.54	0.49	0.49

Table 7: PE acquisition and solar development

Table 7 reports the staggered differences-in-differences effects of PE acquisition of fossil plant on solar development after matching treated counties with a control county that has similar radiance. Columns (1) and (2) present results from TWFE estimation based on Equation (3). Columns (3) and (4) follow Sun and Abraham (2021) method and present estimates from Equation (4). Columns (1) and (3) have *solar dummy* as the dependent variable that takes one if there is a solar development in county c and year t. Columns (2) and (4) have log of solar capacity as the dependent variable. Standard errors are clustered at the county level; t-stats are shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Model	TWFE		Sun and Abraham (2021)	
	Development (1)	Log (cap) (2)	Development (3)	Log (cap) (4)
Post PE	0.1137**	0.2907***	0.0908**	0.1935***
	(2.372)	(3.195)	(2.319)	(3.118)
County FEs	✓	✓	✓	✓
Year FEs	✓	✓	✓	✓
Observations	3,878	3,878	3,878	3,878
R^2	0.62	0.54	0.63	0.55

Table 8: PE acquisition and changes in demographics

Table 8 reports the staggered differences-in-differences effects of PE acquisition of fossil plant on changes in the population. Columns (1) and (2) present results from TWFE estimation based on Equation (3). Columns (3) and (4) follow Sun and Abraham (2021) method and present estimates from Equation (4). Columns (1) and (3) have no controls. Columns (2) and (4) include controls for the number of fossil plants and total capacity of fossil plants in the county. The dependent variable is the change in population of a county from the previous year (in%). Standard errors are clustered at the county level; t-stats are shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

	Population change (in %)			
Model	TWFE		Sun and Abraham (2021)	
	(1)	(2)	(3)	(4)
Post PE	-0.0281	-0.0281	0.0068	0.0068
	(-0.2835)	(-0.2828)	(0.0771)	(0.0768)
Controls		✓		✓
County FEs	✓	✓	✓	✓
Year FEs	✓	✓	✓	✓
Observations	19,273	19,273	19,273	19,273
R^2	0.43	0.43	0.43	0.43

Appendices

A Additional Tables

Table A1: PE acquisition and solar development

This table reports the staggered differences-in-differences estimates of the effect of PE acquisition of fossil fuel on solar development for a sub-sample of states that have deregulated electricity wholesale market. The table follows Sun and Abraham (2021) method as described in Section 5.1. Column (1) has *solar dummy* as the dependent variable that takes one if there is a solar development in county c and year t. Columns (2), (3), and (4) use no. of solar plants, solar capacity, and solar net generation as the dependent variables. Each of these columns includes controls for the number of fossil plants, total capacity of fossil plants, total generation from fossil plants, and the population of the county. Standard errors are clustered at the county level; t-stats are shown in parentheses. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

	Solar Dummy (1)	Log (plants) (2)	Log (cap) (3)	Log (gen) (4)
Post PE	0.1100***	0.1370***	0.5452***	0.9853***
	(2.601)	(2.800)	(3.409)	(2.899)
No. of fossil plants	-0.0117	0.0094	0.0068	-0.0652
	(-0.9761)	(0.4442)	(0.1063)	(-0.6088)
Controls	✓	✓	✓	✓
County FEs	✓	✓	✓	✓
Year FEs	✓	✓	✓	✓
Observations	15,825	15,825	15,825	15,825
R^2	0.54	0.49	0.52	0.45