How Do Extreme Weather Events Impact Investment in Combined Heat and Power?

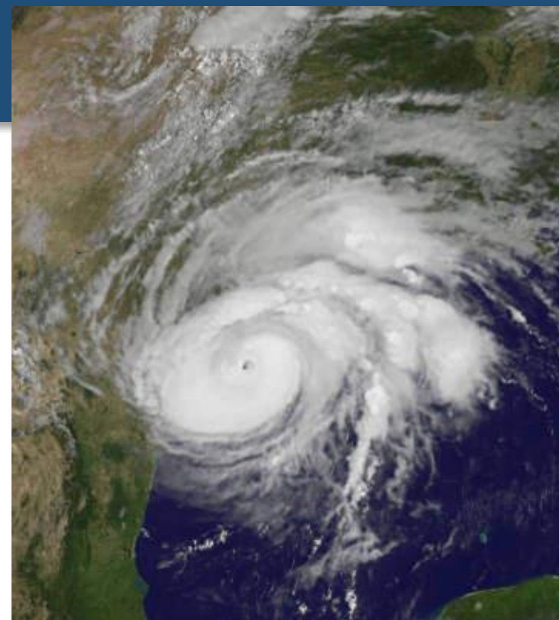
Photo Credit: 'All Eyes on Harvey' by Eric Smith

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Introduction

Since 1980 the United States has experienced 219 separate billion-dollar plus natural disaster events. The total cost of these 219 events is estimated to be $1.8 trillion dollars. This takes into account 2017, which is on record as being the most costly year for natural disasters, with a cumulative cost of over $300 billion dollars[1]. The number and intensity of these events are causing growing concern across the globe as well.

The risks faced by the public and private sector related to climate include direct physical impacts on investments, degradation of critical infrastructure, reduced availability of key inputs and resources, supply chain disruptions and changes in workforce availability and productivity[2]. The Global Risks Report 2016, finds that two of the top three concerns for business over the next 10 years are failure of climate change mitigation and a failure to adapt to potential extreme weather events. The concern indicated as most crucial is a water crises. All of these issues point to increasing likelihood of investment in more resilient infrastructure in order to limit these risks[3]. It is anticipated that these extreme weather events are likely to increase over time, particularly with the intensity of floods, droughts, and/or heat waves[4]. A similar increase in intensity is also predicted with tornadoes, hailstorms and thunderstorm winds, but there is still some uncertainty as to what extent and where. These extreme storm events are intensifying disaster risk and will continue to have a significant impact on communities and infrastructure. Recovery often requires enormous resources, which underscores the growing need for new adaptive infrastructure to make critical facilities and communities are more resilient[5].

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1 https://www.ncdc.noaa.gov/billions/
2 https://www.ametsoc.org/ams/index.cfm/publications/bulletin-of-the-american-meteorological-society-bams/explaining-extreme-events-of-2013-from-a-climate-perspective/
3 https://www.ceres.org/resources/reports/insurer-climate-risk-disclosure-survey-report-scorecard
4 https://www.globalchange.gov/nca3-downloads-materials
5 https://www.nap.edu/catalog/13457/disaster-resilience-a-national-imperative; https://www.ipcc.ch/pdf/special-reports/srex/SREX_Full_Report.pdf; https://www.globalchange.gov/nca3-downloads-materials

For this study, we explore whether the growing number and intensity of storm events has led to greater investment in more resilient power systems. A resilient power system is one that is built to lessen the likelihood of a power outage. These systems must manage and respond to power outage events to mitigate impacts, quickly recover when the power comes back on, and learn from the outage event to reduce the likelihood of future outages[6].

Our study period is from 2000 to 2016. During this timeframe, the United States experienced more than 99,000 power outages, some small and some rather large[7]. This includes ice storms that knock out power for a few thousand customers to Superstorm Sandy, which at the height of the blackout left approximately 5.7 million customers without power across New York, New Jersey and Connecticut. Further, severe weather events, including hurricanes, extreme heat and droughts between 2004 and 2013, resulted in over 25 significant power generation disruptions that led to curtailment of power generation and power outages across the US[8].

We test whether power outages as a result of natural disasters influence decisions by organizations and critical facilities to adopt methods to reduce the likelihood of potentially detrimental power disruptions. One way to test this assumption is by looking at the deployment of combined heat and power (CHP) applications across the United States. CHP is by no means the only approach to mitigate power outage risk at a site, but is one of the more likely options to be pursued[9].

Combined Heat and Power & Power Resilience

Combined heat and power (CHP) is being touted as a technology that can help with power reliability and resilience concerns[10]. CHP produces power on-site, typically using natural gas which is highly reliable. This was demonstrated during Hurricane Sandy, where CHP systems performed very well in comparison to the grid and diesel back-up generators. We have seen anecdotal evidence that CHP is coming online to improve site resilience, and a handful of states have been pushing for rules to promote resilient CHP[11]. In this study, we wanted to see if CHP is more generally being installed to improve site resilience.

What is CHP?

CHP is a type of distributed power generation that is located near or at the point of energy consumption. The system provides power and thermal energy from a single source. This single source is a prime mover, such as a reciprocating engine or turbine that powers a generator. The efficiency benefit comes from the capture of the waste heat to provide useful thermal services. The heat from the prime mover is captured by a heat exchanger and this heat can be used for cooling with an absorption or steam driven chiller or heating applications such as process steam, space heating, or domestic hot water.

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[6] https://www.nap.edu/download/24836
[7] Based on our analysis of NOAA's Storm Risk data set - http://www.spc.noaa.gov/
[8] https://energy.gov/sites/prod/files/2013/07/f2/20130710-Energy-Sector-Vulnerabilities-Report.pdf
[9] For future studies, we would like to gather additional data on other resilience system installs such as solar-battery application, as well as standard natural gas and diesel generation installations.
[10] https://betterbuildingsinitiative.energy.gov/accelerators/combined-heat-and-power-resiliency
[11] https://foresternetwork.com/distributed-energy-magazine/guest-commentary-distributed-energy-magazine/the-new-era-of-chp-2/

Currently, there are 81 GW of CHP installed across the United States, and significant potential for much more. A 2016 DOE study demonstrated that there is 340 GW more of technical potential for CHP[12]. There has been considerable effort at the federal level to push for more CHP in the near-term. Examples include the Energy Policy Act of 2005, Federal Interconnection Standards, 2008 Federal Investment Tax Credit for CHP, 2008 Accelerated Depreciation for CHP[13], boiler Maximum Achievable Control Technology (MACT) in 2011, and President Obama's Executive Order in 2012 that set a goal of 40 GW of new CHP by 2020.

There has also been considerable regulatory and financial assistance activity at the state, utility, and local level. This includes interconnection standards, as well as incentives, grants, rebates, and loans. Some of the more notable activity includes New Jersey's Energy Resilience Bank which provides grants and loans to cover 100% of costs of resilient systems, The New York State Energy Research and Development Authority (NYSERDA) CHP Incentive Program, and California's Self-Generation Incentive Program (SGIP) which funds systems of up to 3 MW. Some other state activities to promote CHP for resilience include legislation in Texas and Louisiana that requires all newly constructed state facilities or state facilities undergoing major renovation to assess opportunities for CHP[14]. Similarly, Connecticut's Microgrid Pilot Program has a central focus on the role of CHP. Missouri, Illinois, and Michigan also have various CHP-focused energy resilience planning efforts[15].

The federal and state efforts to deploy CHP appears to be working to some degree. Figure 1 indicates a steady increase in CHP installs, with a bump in the mid-1980s and again at the beginning of the 21st century.

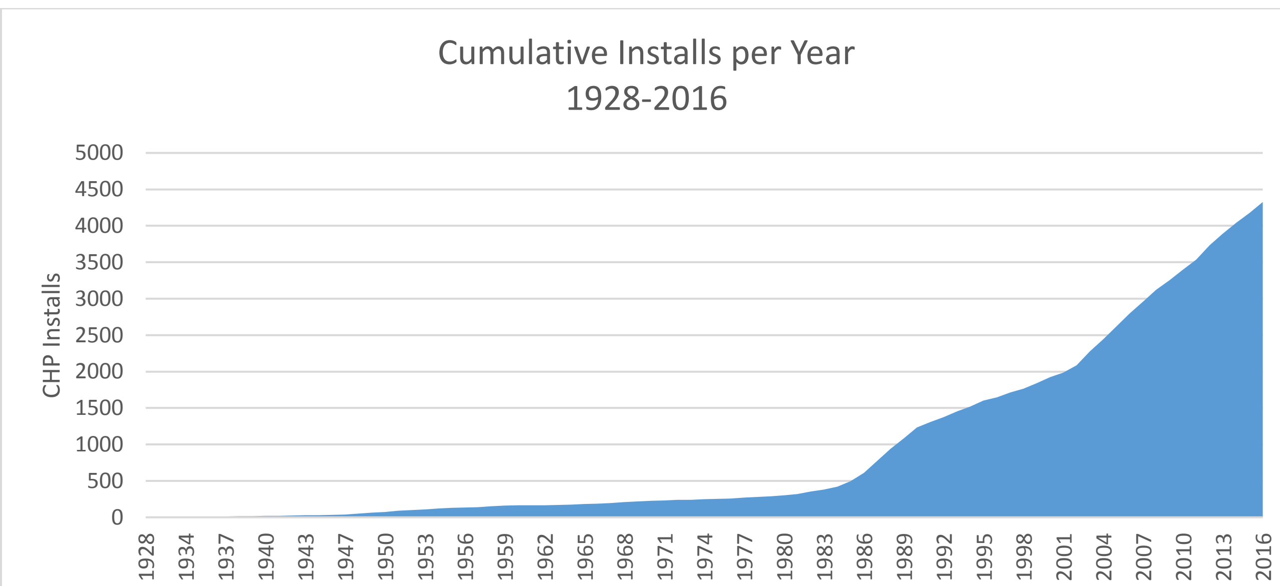

Figure 1. Cumulative Installs per Year

[12] https://energy.gov/eere/amo/downloads/new-release-us-doe-analysis-combined-heat-and-power-chp-technical-potential

[13] Modified Accelerated Cost Recovery Systems (MACRS)

[14] Texas state legislature passed HB 1831 and HB 4409 in 2009 and HB 1864 in 2013; Louisiana legislature passed a similar law (Resolution No. 171) in 2012.

[15] Missouri – Comprehensive State Energy Plan, Illinois State Energy Assurance Plan and the CHP Roadmap for Michigan.

The slight bump in the early 2000's is further defined in Figure 2. Here we see a primary reason for this bump was a marked increase in the activity in California. This could be attributed to the Self-Generation Incentive Program (SGIP). In the first part of 2000, California saw a significant increase and then an equally significant decrease starting in 2006, but maintains a relatively high number of installs compared to other states. In New York, CHP activity has remained relatively flat over the study period, with a slight bump after Super Storm Sandy. However, it has consistently maintained a higher number of installs in relation to all other states other than California (see Figure 3). Between 2002 and 2007, California accounted for almost half (46%) of the total CHP installations on a yearly basis. Throughout the entire study period New York typically averaged 20% of the total installations. Both states have been fairly aggressive in promoting CHP programs and have relatively higher energy prices which help improve system economics.

We also looked at which states had the greatest number of average installs per year. We found that only 22 of the states averaged at least 1 install per year during the study period. California (44 installs per year), New York (27) and Massachusetts (10) top the list, followed by Connecticut, New Jersey, Alaska and Pennsylvania, all with at least five per year (Figure 3). Of interest here is that the top five states in Figure 3 are also the five states with the highest spark spread. These are also the states with some of the more generous utility and state incentive and rebate programs.

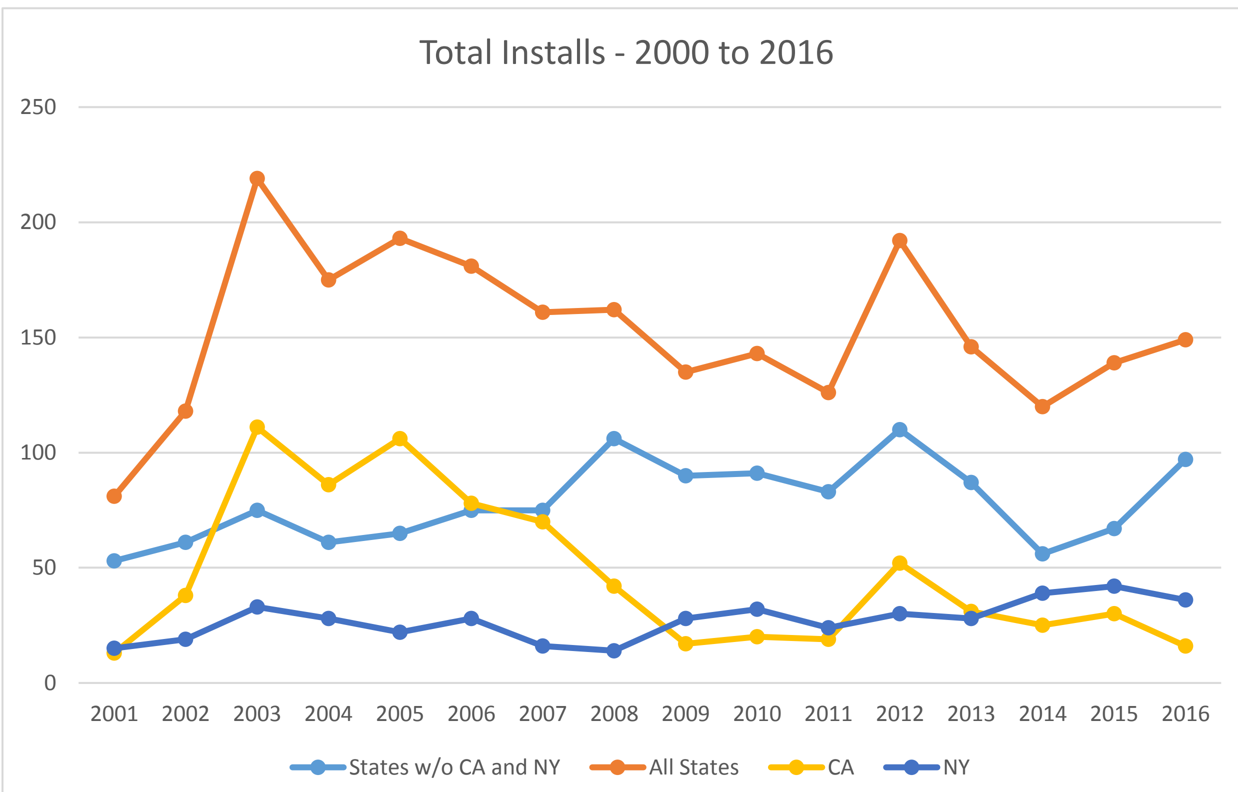

Figure 2. Total CHP Installs – 2000 to 2016

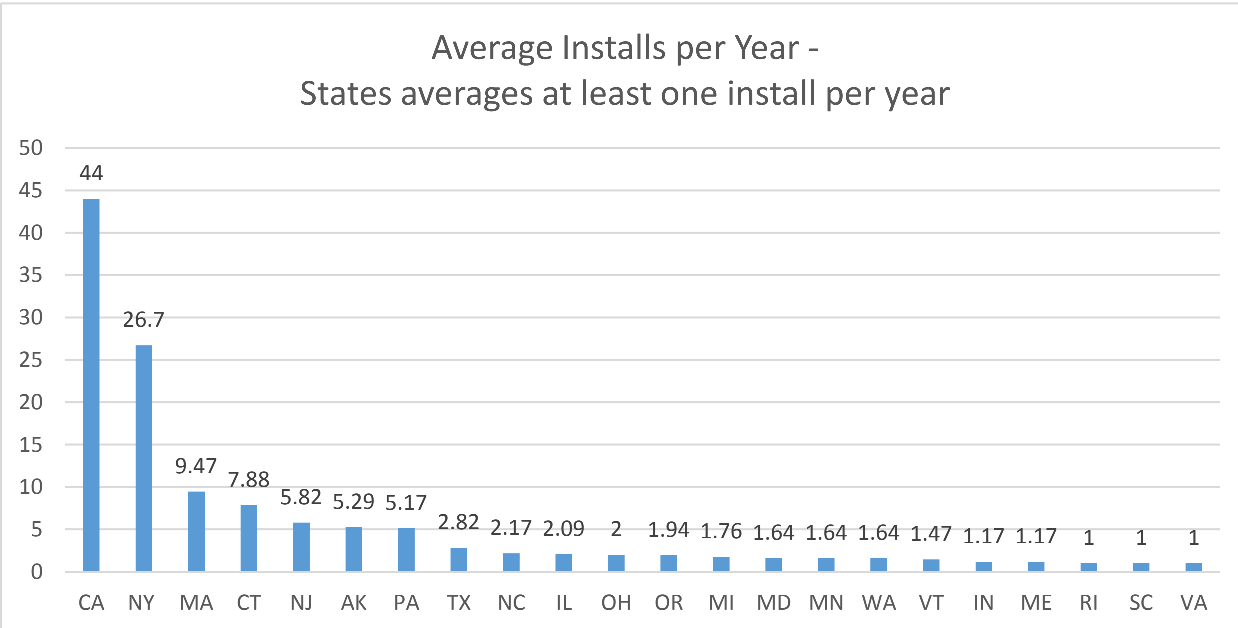

Figure 3. Average Installs per Year

We also consider total installs per year since the first recorded CHP installation in 1928. From 1928 to 2000, the number of installs per year averaged out at 27. From 1991 to 2000, the average was 69 installs per year. In 2002, the number of installs dramatically increased to 100 per year and to 193 per year in 2003. Since 2003, the number of installs per year has averaged 153 per year. In Figure 4, we see two large spikes. The first increase in the early 1980's through the 1990's can be attributed to Public Utilities Regulatory Policy Act of 1978 (PURPA), as well as greater federal efforts led by the EPA to promote the development of CHP[16]. The second increase can be attributed primarily to incentive activities by California, as well as other utility CHP incentives, improved, more flexible CHP technologies, such as packaged CHP systems, and favorable energy prices on the east and west coast.

[16] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3332257/

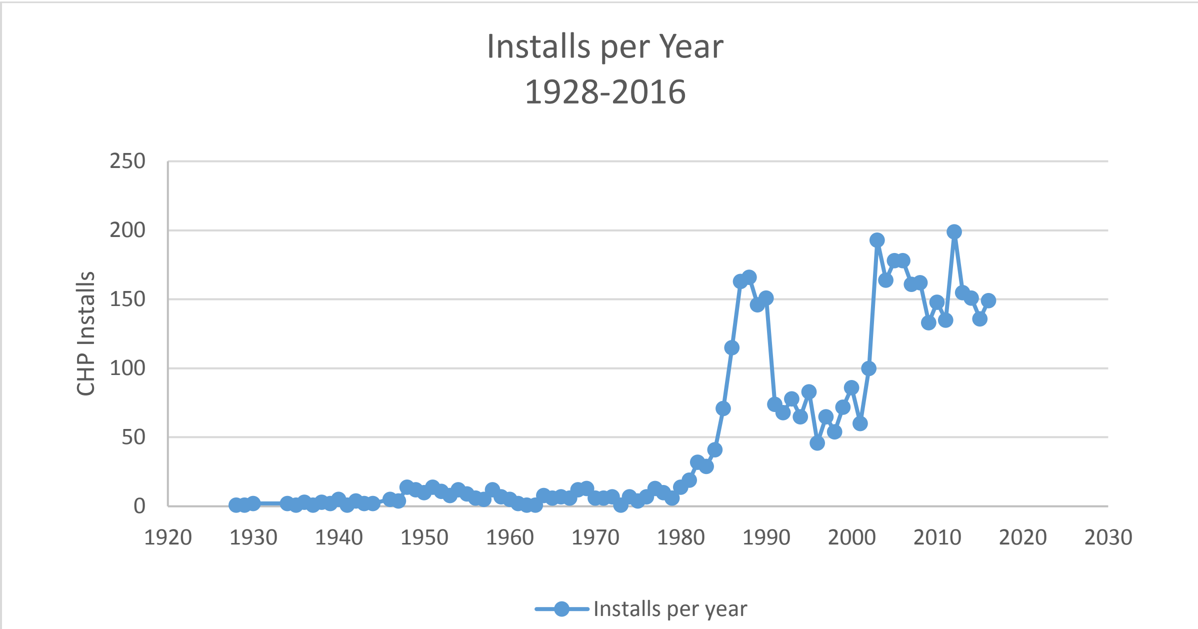

Figure 4. Installs per Year

We see in Figure 5, that although the frequency of installs have increased and remained higher than the historical average, the size capacity of these systems has decreased significantly. During the 1990's, the average size per CHP system averaged around 37 MW. In contrast, from 2000 to 2016, the average size of installs each year was 12 MW per year, with 89% of the installs were under 10 MW. More striking is that from 2005 to 2016, the average install size decreased to 3 MW. The industry has seen a significant increase in installs, but an equally significant decrease in system capacity. There are a variety of factors contributing to this including power market deregulation, more volatile natural gas prices and a change in PURPA in the 2000s that provided less incentive to install these larger CHP plants[17]. Further, we see the introduction of utility incentives that have been made available to support smaller CHP system size, such as California's self-generation incentive program, as well as changes in technology that allow for much smaller systems to be economically installed than in the past.

[17] https://www4.eere.energy.gov/seeaction/system/files/documents/publications/chapters/see_action_chp_policies_guide_appendix_b.pdf

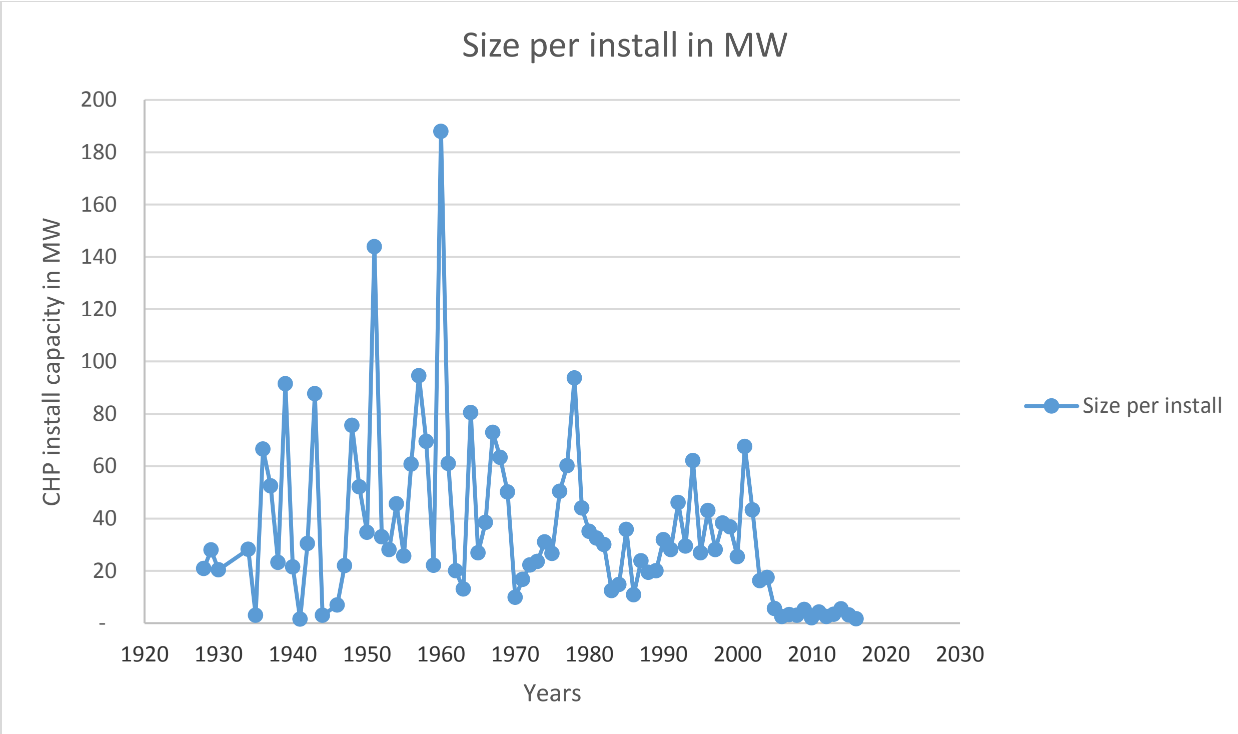

Figure 5. CHP Capacity per Install

Do Power Outages Increase Likelihood of CHP Investment?

There is ample evidence that federal and state level activity has had some impact on the CHP market[18],[19]. For this study, we wanted to better understand to what degree demand for resilience may impact the installation of CHP systems. Historically CHP investment has been seen as a system that can decrease costs of operation through improved energy efficiency, and through this greater efficiency reduce greenhouse gas emissions. Gaining greater attention in the last few years is the additional benefit that CHP can provide resilience benefits. CHP has demonstrated multiple times that it is able to keep the lights on during major storm events[20]. We were curious to better understand whether number and intensity of power outages have any significant impact on CHP installation across the US. Does threat of storms and power outages change the calculation made to invest in power resilience and particularly CHP? Taking into account the economic drivers promoting CHP, are severe weather events and power outages considered in the investment decision for CHP?

[18] https://www4.eere.energy.gov/seeaction/system/files/documents/publications/chapters/see_action_chp_policies_guide_appendix_b.pdf
[19] https://foresternetwork.com/distributed-energy-magazine/guest-commentary-distributed-energy-magazine/the-new-era-of-chp-2/
[20] https://energy.gov/eere/amo/downloads/chp-enabling-resilient-energy-infrastructure-critical-facilities-report-march

It has been argued that as the number severe weather events increase, future perceptions of risk will adjust as it becomes more apparent that there is growing near-term and future risks. Expectations that negative consequences are likely to happen to self or others, and improved knowledge of the causes of such problems, can lead to more adaptation efforts[21]. Further, it is anticipated that geographical proximity to climate risk, physical conditions, and experiences may change the perception of what once were potential perceived risks to a sense of actual, plausible risks. This shift will influence the level of physical vulnerability driving adaptation activity[22]. Therefore, in the case of natural disaster events related to power losses, if these events are more frequent, commonly occurring and of mid to high magnitude, we would anticipate the likelihood of CHP installations to be higher in states experiencing a significant number of power outages in comparison to states not experiencing similar outage event scenarios.

Hypothesis 1 States with a greater number of power outages will have greater investment in CHP relative to states with a lower number of power outages over time.

Hypothesis 2 States with a greater severity of power outages will have greater investment in CHP relative to states in which outages are less severe over time.

Capability is another potential driver to influence the adoption of climate adaptation efforts. The resources must be available, including financial, technological and human capital resources. This would require that climate adaptation be considered a priority where resources would be allocated to the effort of adaptation.[23]

Hypothesis 3 The availability of state, local and utility incentives, rebates, and/or loans will increase investment in CHP.

Hypothesis 4 States with interconnection standards will see more CHP installs relative to states without interconnection standards.

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[21] O'Connor, R.E., Bord, R.J. & Fisher, A. Risk Anal (1999) 19: 461. https://doi.org/10.1023/A:1007004813446; Weber, E. U. (1997). Perception and expectation of climate change: Precondition for economic and technological adaptation. In M. H. Bazerman, D. M. Messick, A. E. Tenbrunsel, & K. A. Wade-Benzoni (Eds.), *The New Lexington Press management series and the New Lexington Press social and behavioral science series. Environment, ethics, and behavior: The psychology of environmental valuation and degradation* (pp. 314-341). San Francisco, CA, US: The New Lexington Press/Jossey-Bass Publishers.

[22] Stedman, R. C. (2004), Risk and Climate Change: Perceptions of Key Policy Actors in Canada. Risk Analysis, 24: 1395–1406. doi:10.1111/j.0272-4332.2004.00534.x; Samuel D. Brody, Sammy Zahran, Himanshu Grover, Arnold Vedlitz. (2008) A spatial analysis of local climate change policy in the United States: Risk, stress, and opportunity. *Landscape and Urban Planning*87:1, pages 33-41; Zahran, Sammy & Brody, Samuel & Grover, Himanshu & Vedlitz, Arnold. (2006). Climate Change Vulnerability and Policy Support. Society and Natural Resources. 19. 771-789. 10.1080/08941920600835528.

[23] Lubell, M., Zahran, S. & Vedlitz, A. Polit Behav (2007) 29: 391. https://doi.org/10.1007/s11109-006-9025-2; Lubell, M., Vedlitz, A., Zahran, S., & Alston, L. (2006). Collective action, environmental activism, and air quality policy. *Political Research Quarterly, 59*(1), 149–160.

Research Design

For this study, we looked at CHP installation activity from 2000 to 2016. This 17 year study period provides a significant window into CHP installation trends and allows for the testing of a variety of factors. We have two key areas of interest; first, the degree to which spark spread[24] matters in the installation of CHP and second, the influence of weather event power outages on the adoption of CHP.

Methodology

To conduct this study, we developed a panel data set to build a Time Series Cross Sectional (TSCS) model. The TSCS approach allows us to assess how state-specific variables and time influence the adoption of CHP within each state. The data set includes data for all 50 states over the entire study period. For each year and each state, we assess an array of variables including: number of CHP installs, spark spread, number of power outage events, state and local incentives and rebates, federal policies and interconnection rules.

Variables

Our dependent variable for this study is number of installs per year, per state. For each state, we calculated the number of installs for each year of the study period using the DOE CHP Database.

We tested six variables against the dependent variable.

Spark Spread: Economics of the project are likely to be a key factor for the adoption of CHP. Spark spread is not the only factor, however it does provide a good indicator as to project viability. Simply put, the spark spread is the price difference between electric power and natural gas. Typically, the larger the difference, the higher the likelihood that the project will be economically feasible. We calculated the spark spread variable for each state over the study period using the yearly DOE Energy Information Administration (EIA) average price by state electricity and natural gas data sets.

Power Outages: CHP is seen as technology that can significantly reduce the likelihood of power outages. It is anticipated that increasing storm intensity and states with high rates of power outages per year will see higher rates of CHP deployment over time than states with lower intensity and fewer outages. To determine the relationship between power outages and CHP adoption, we use the National Oceanic and Atmospheric Administration (NOAA) Storm Risk Data from 2000 to 2016. The NOAA data contains the number of power outage events for all recorded storms during this time period. With this data we are able to track power outage episodes per state for each year. There were a total of 99,000 recorded power outage episodes during this time period, with a significant range across states from 70 outage episodes to 7,114 during the study period.

[24] Spark spread is the difference between the price received by a generator for electricity produced and the cost of the natural gas needed to produce that electricity. https://www.eia.gov/todayinenergy/detail.php?id=9911

CHP does take time to install and we would anticipate at least a one year lag between the outage event and the installation of CHP. We anticipate that power outages in year one will not directly influence installation within the same year. To account for this delay, we lag the power outage data. The lags are for two, three or four years. This allows us to account for CHP installations that may be influenced by power outages in the preceding two, three or four years.

We also anticipate the intensity of the event will impact the likelihood of investing in CHP[25]. The NOAA Storm Risk data provides the dollar cost of each power outage event. We use a similar lag for the storm intensity variable as we do for the number of power outages variable.

Incentives and Rebates: Also important to the economics of a CHP project[26] is the availability of incentives, tax credits and rebates during this time period from state and local governments, as well as utilities. We have been able to identify these incentives through the Database of State Incentives for Renewables & Efficiency (DSIRE) database, and the EPA CHP Policies and Incentives Database and the American Council for an Energy-Efficient Economy (ACEEE) State Energy Efficiency Scorecards. We created a set of three dichotomous variables that independently measures whether an incentive, rebate or grant was available during each year of the analysis for each state.

Federal Policies: The Federal policies that we focus on are the federal investment tax credit and the federal accelerated depreciation, Modified Accelerated Cost Recovery System (**MACRS**). Both were passed in 2008. Attributing a federal policy to individual CHP action per state, per year is not the most concise measure of impact on CHP, however, we are able to at least account for its occurrence in the model and determine its impact.

Interconnection: A final factor we considered was a state's interconnection standard[27]. The expectation is that states with interconnection standards may have a higher likelihood of more CHP installs per year than those states without such a standard. We used the DSIRE database, the EPA CHP Policies and Incentives Database and ACEEE's State Energy Efficiency Scorecards to identify those standards. Interconnection is treated as a dichotomous variable that measures whether a state had an interconnection standard in a particular year or not.

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[25] We were not able to get clear picture of the duration of the power outage event, so had to use number and dollar cost to determine intensity.
[26] We had considered the cost of CHP systems over time. We anticipated a lowering of cost overtime. However, an analysis by ICF and the EPA's CHP Catalog suggests that CHP system cost has remained static over this time period.
[27] Interconnection standard is the standard used by a utility and/or independent system operator that governs how a CHP system is connected to the electric power grid. The Federal Energy Regulatory Commission (FERC) also has a standard for smaller systems, 20 MW or smaller.

Results

Power Outages and CHP Installation

Using time series cross-sectional regression analysis, our first test was whether power outages influence the installation of CHP systems. During the study period, there were around 99,000 power outages. The average number of outages per year, per state was approximately 116. These outages varied from a few thousand customers without power to several million. Iowa, New York and Wisconsin saw the highest number of outage events. The top twenty states can be found in Figure 6[28].

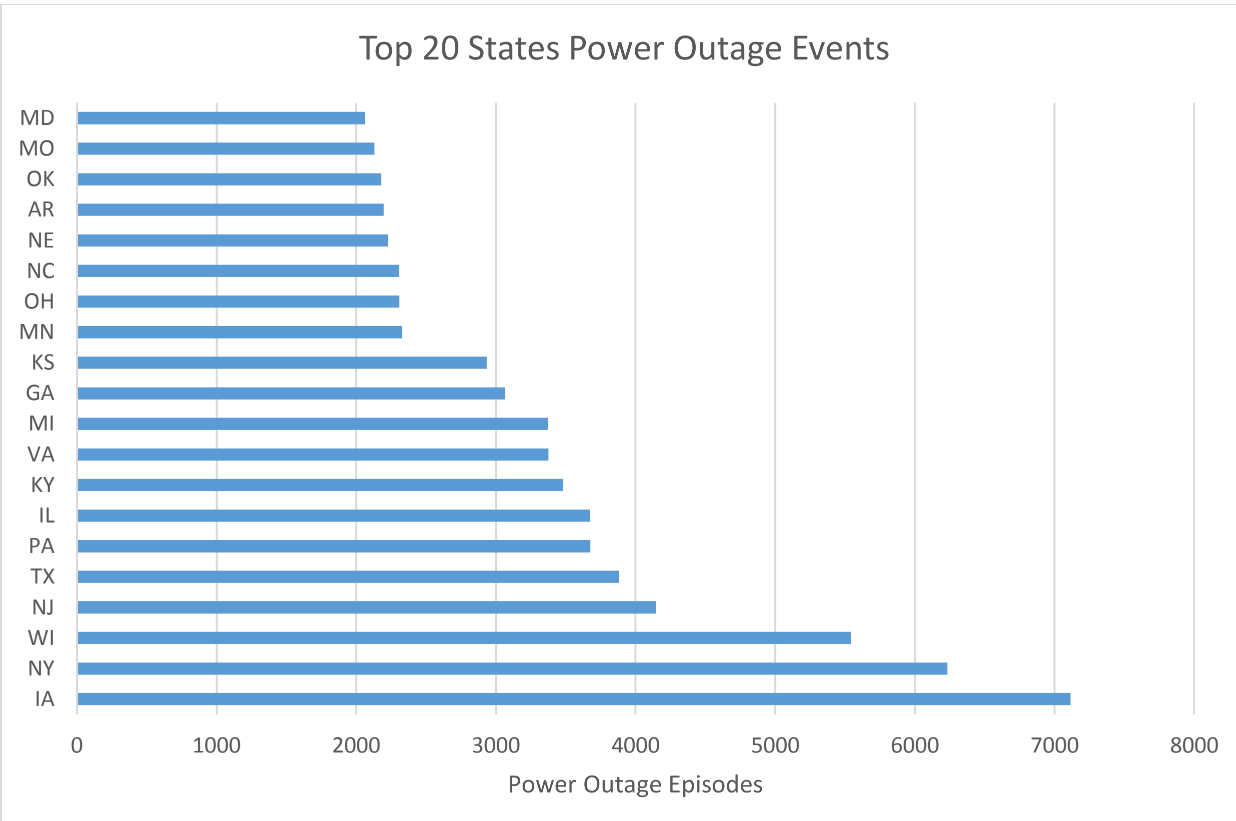

Figure 6. Top 20 States Power Outage

In the time series regression model, we assess whether number of power outages has an effect on CHP installs. We control for incentives, grants, rebates, federal policies and inteconnection regulations. Based on this analysis, we find that power outages do not have a significant impact on CHP installs during the study period. Figure 7 demonstrates this lack of relationship. The outlier is California with over 700 installs during the study period and New York at a little over 400 installs. New York does demonstrate what we expected to occur as power outages increase, CHP installs are likely to increase.

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[28] In future studies we would like to gather data on total customer outages. That may provide us greater insight into total impact and severity of outage.

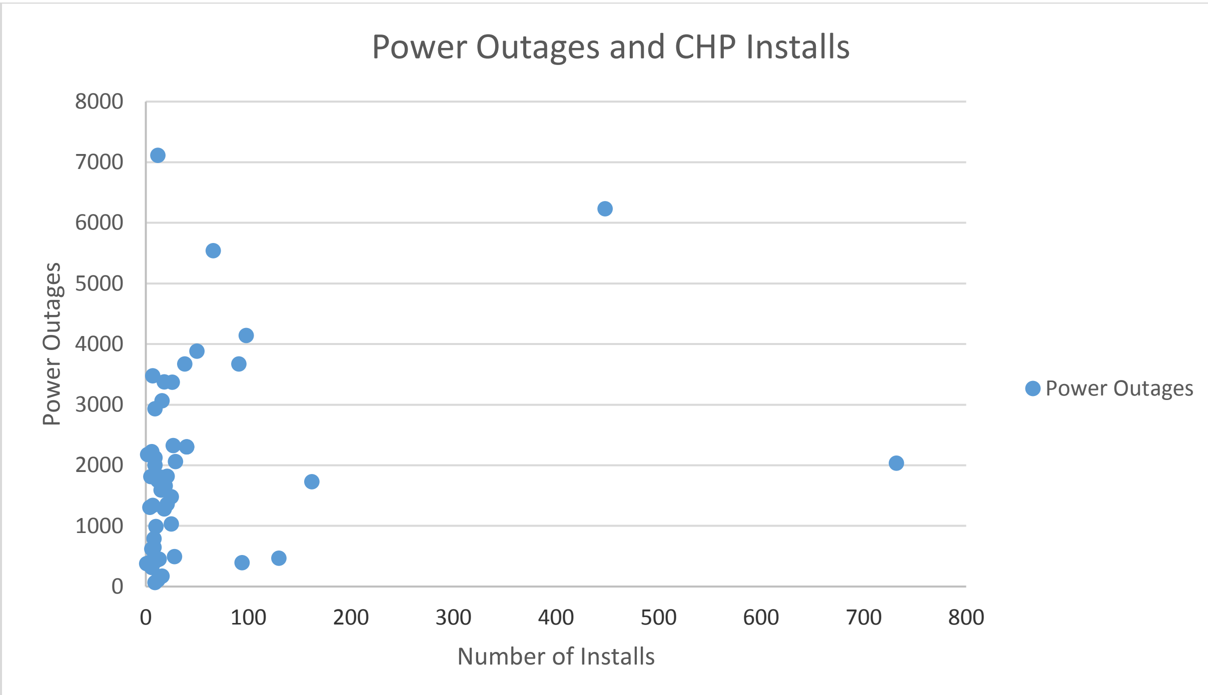

Figure 7. Power Outages and Number of Installs

We also test whether number of outages and intensity of storm events causing the outages has an impact on CHP installs during the study period. Again, we find that nationwide there is not a significant impact. The Figure 8 bubble chart below shows the number of power outages, the dollar costs of damage and the number of installs. The size of bubble indicates the magnitude of damage costs. The y-axis is number of power outages and the x-axis number of installs.

Figure 8 indicates again that the outlier is California, with the largest number of installs but a relatively low number of power outages and damage costs. New York, with about 450 installs and around 6,000 power outages, appears to be an outlier but fits our expectation that higher losses result in a higher number of installs. We want to point out that although the model does not indicate any significant relationships across the US, it does not mean that there were not some individual state effects on CHP installations.

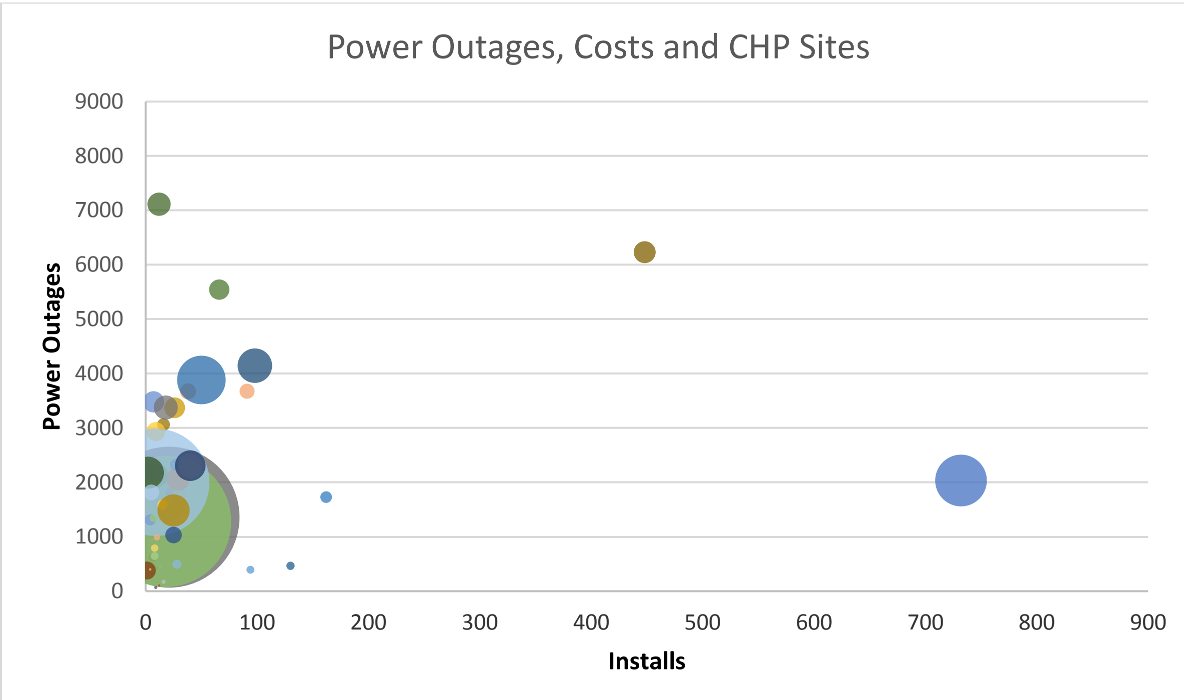

Figure 8. Power Outages, Damage Costs and CHP

We were curious whether the higher profile, larger storms such as Superstorm Sandy, Hurricanes Ike, Rita, Katrina and the multiple hurricanes that hit Florida in 2004 and 2005 influenced any CHP activity. In many of these storms, multiple customers were without power for weeks. Even with significant distruption across these storms, we find that the only storm that resulted in any significant change in CHP installations was Superstorm Sandy.

We considered the impact of the 2012 Superstorm Sandy on the number of CHP installs in New York, New Jersey, Connecticut, Massachusetts and Pennsylvania. Each of these states realized some significant power outages due to Sandy. We do find in each state that there was a slight bump in CHP installs during the two years following the 2012 storm. The Superstorm Sandy Install Trends shown in Figure 9 indicate that New Jersey and Massachusetts saw this *Sandy bump* and the trajectory of the number of installs continues to increase. For the other three states, the bump appears to be more short lived and number of installs have started to decrease or level out annually from the initial increase.

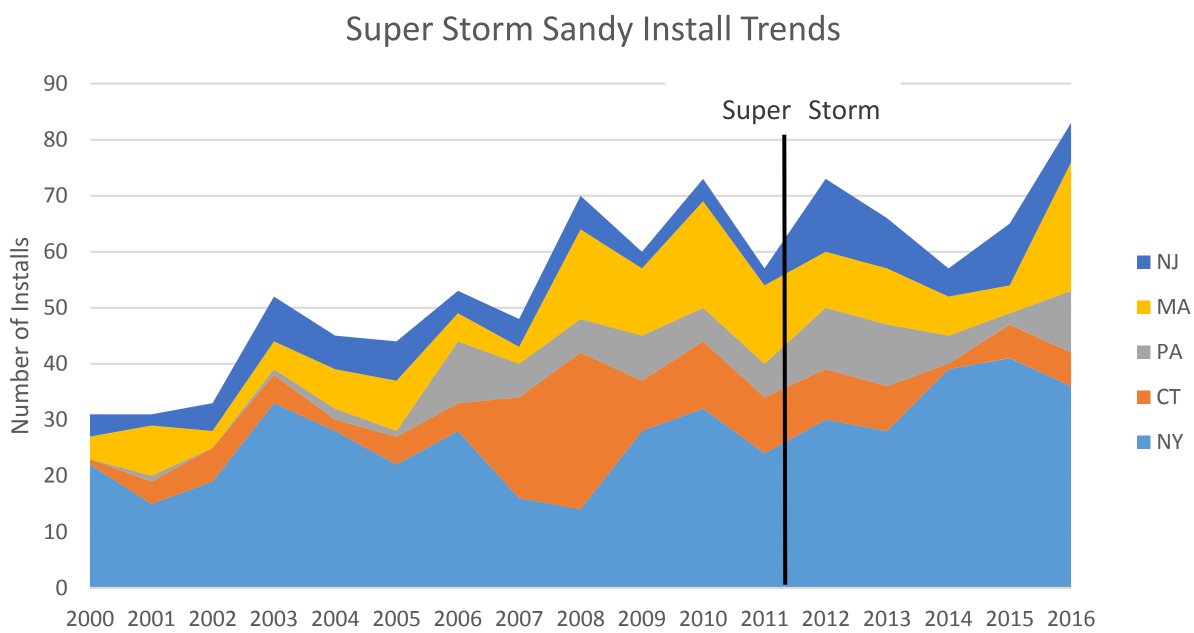

Figure 9. Super Storm Sandy Install Trends

The study also looks at the average number of installs per year prior to Sandy (2000 to 2012) and post Sandy (2013 to 2016). Figure 10 indicates that other than Connecticut, each state realizes an increase in the average number of installs per year after Sandy. New York shows the greatest magnitude of change, going from an average of 23 to 38 per year post-Sandy. This can be attributed to the early steps taken by New York Governor Cuomo and New York City to provide funding for more CHP post-Sandy, as well as the development of an energy resilience plan by New York City[29]. New Jersey, Massachusetts and Pennsylvania see bumps, as well. New Jersey sees a 60% in number of installs and appears to be sustaining this level over time. Much of that may likely be attributed to the significant financial support for CHP and the development of the Energy Resilience Bank.

[29] https://www.epa.gov/sites/production/files/2015-07/documents/guide_to_using_combined_heat_and_power_for_enhancing_reliability_and_resiliency_in_buildings.pdf

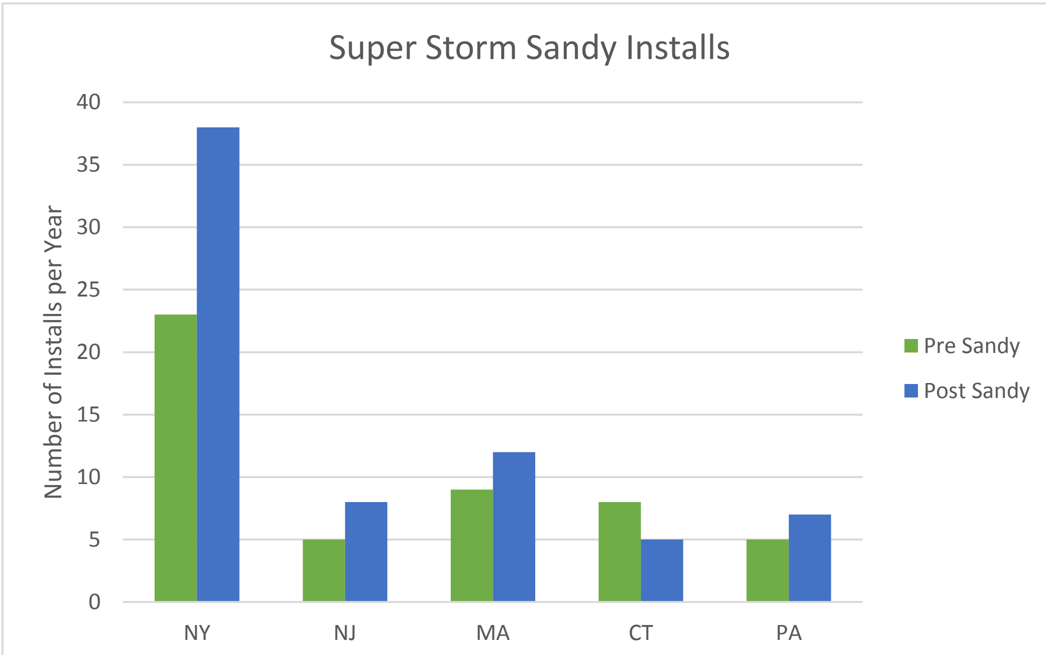

Figure 10. Super Storm Sandy Install Trends

We can conclude that power outages generally do not appear to significantly influence the adoption of CHP. In the last seventeen years, Super Storm Sandy appears to be the only major power outage event that had an impact on the adoption of CHP. We did not see any significant change in CHP adoption patterns in other states that have experienced major power outage events due to hurricanes or other natural disasters. This includes the numerous hurricanes that hit the southeastern United States, particularly Florida, and the Gulf Coast states.

Spark Spread and CHP

We now consider the adoption of CHP through an economic lens. The size of the spark spread is believed to have a significant impact on the likelihood of choosing to install CHP. The larger the spark spread, the more likely the CHP system will be economically viable. We use a time series cross-sectional regression model to determine to what degree spark spread matters in this decision process. We then develop predicted values based on different spark spread and incentive scenarios.

Prior to running the regression model, we plot the spark spread and number of installs in the aggregate. During this study period, depending on state and year, the spark spread ranges from $0.12 to -$0.04. In Figure 11, we find that there appears to be a threshold of economic viability at $0.05. As a state approaches and moves beyond the $0.05 spark spread, the likelihood of CHP installs appears to increase significantly. As mentioned above, the top five install states, were also the states with the highest spark spreads.

We now run the regression model looking at the relationship between spark spread and the number of CHP installs per year[30]. In the model, we control for incentives, rebates, grants, federal policies and interconnection regulations.

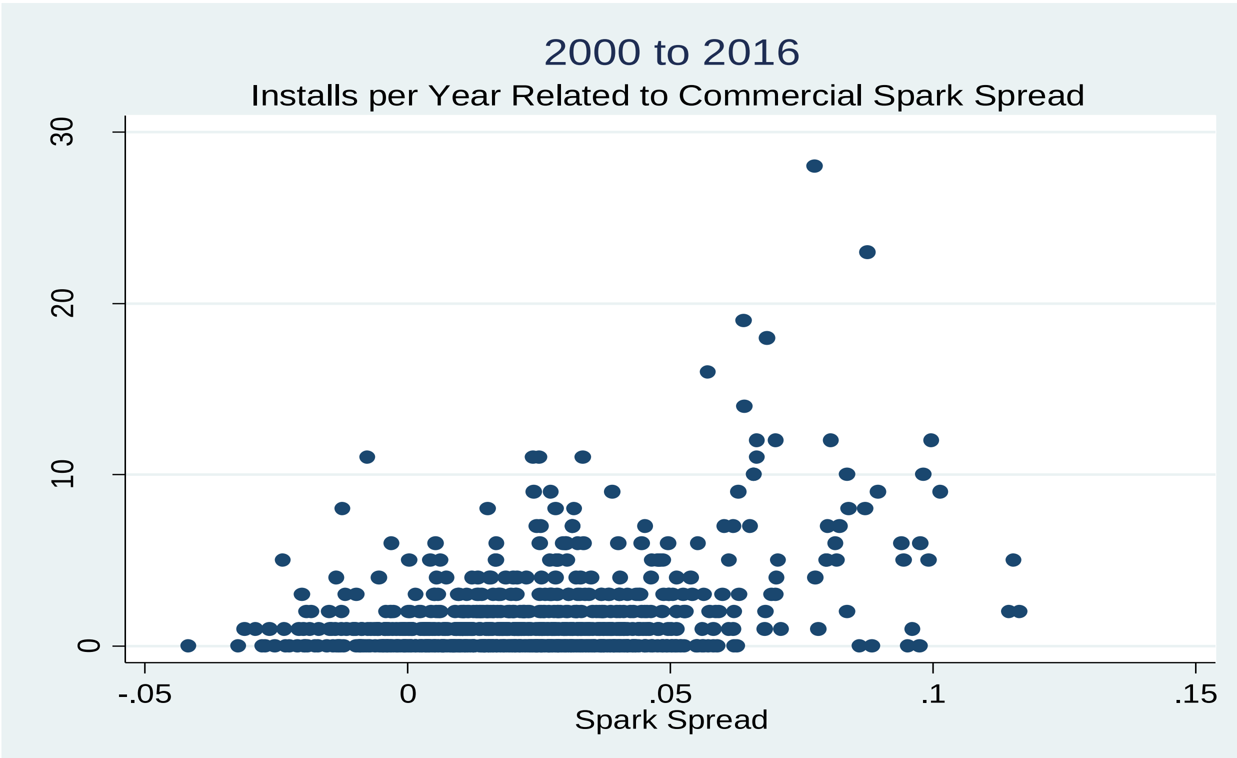

Figure 11. Installs per Year and Spark Spread

The study considers a variety of spark spread and incentive/grant scenarios. Table 1 provides a breakdown for spark spread and installs per year. For spark spreads, the median across the study period is $0.02, with a maximum spark spread of $0.12. For installs per year, the average number of installs was 1.6, with a maximum of 28 installs per year[31]. The relatively wide range of installs per year, but relatively low mean is due to 33 states averaging one or fewer installs per year.

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[30] In this analysis we find that spark spreads, incentives and grants are all significant in the model. We also find that the model accounts for only 27% of the total variability of CHP installs. This indicates that the decision to install CHP is fairly complex and we only capture some portion of the decision making variables. Further study may allow us to identify additional factors that further explain the adoption of CHP.

[31] For the TSCS model we ran the model without CA and NY, thus a lower installs per year. Both states are significant outliers.

	Spark Spreads	Installs per Year
Mean	$0.02	1.6
Standard Deviation	$0.024	2.7
Minimum	-$0.04	0
Maximum	$0.12	28

Table 1. Descriptive Statistics from Spark Spreads and Installs

Based on the model, we determined predicted values for a financial support scenario[32] and one with no financial support[33] (Figure 12). We begin with the financial support scenario. If we start with the spark spreads at the mean of $0.02, with financial support available, the predicted number of installs per year is a little more than 3 per year. This doubles the 1.6 average number of installs per year recorded during the study period. If we double the spark spread, moving up one standard deviation ($0.04), the increase in the number of installs is negligible. If we consider the highest spark spreads of $0.12 during this time period, the number of installs increases by 1.5 more installs to almost 4.5 installs per year.

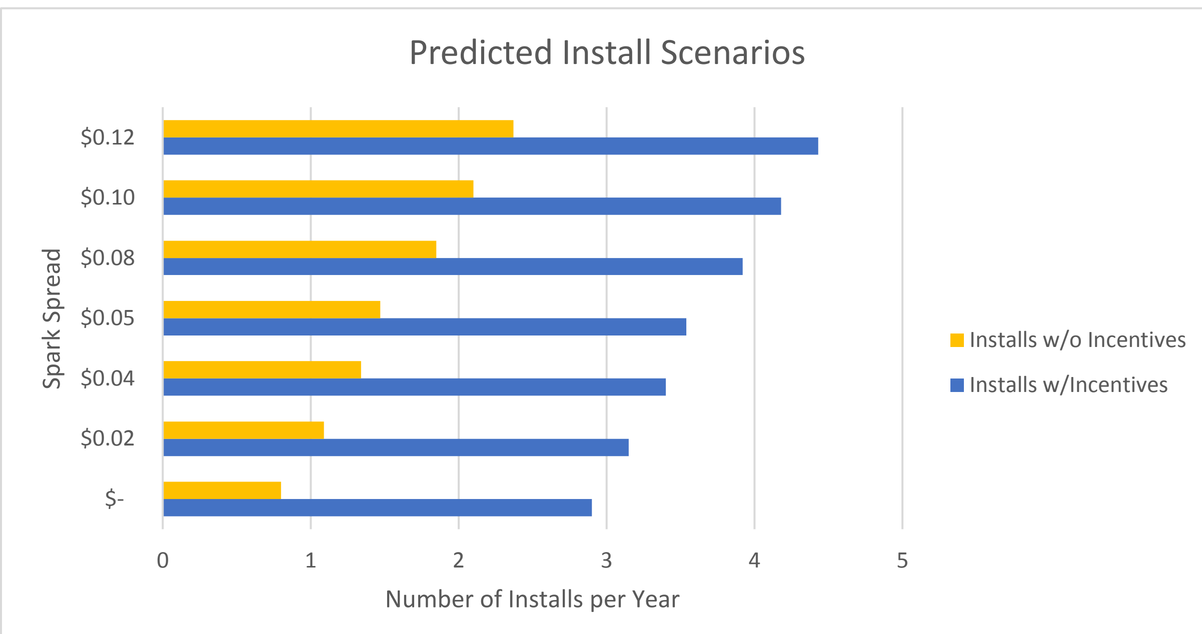

Figure 12. Predicted Install Scenarios

[32] The presence of rebates, grants and incentives for CHP.
[33] Twenty-two states during the study period did not have incentives, rebates or grants that would directly support CHP installs.

In Figure 12, we find that states without financial support have fewer installs than states with financial support. In the same time frame, if we consider states with the mean spark spread of $0.02, but without incentives or grants, the predicted number of installs decreases to 1.1 per year, a third of the installs than states with financial support. As we increase spark spread in states without financial support, we see the number of installs reach 2.4 installs per year. States without financial support appear to need a spark spread around $0.08 to meet the 1.6 mean installs seen across the study group. All scenarios without financial support have lower predicted installs per year than states with financial support and an almost zero spark spread.

Conclusions

Spark spread and financial support from state, local and utility programs are the key factors in the installation of CHP across the US. Weather events, if not coupled with some sort of financial support, do not yield any significant change in the number of CHP installs. We find in Florida, Texas and Louisiana, each of which faced significant damage and disruption from hurricanes, tropical storms and other natural disasters, had no significant change in the number of CHP installs post-storm. We can largely attribute this to a low spark spread which makes the economics of the system difficult to make work. The average spark spread across these states is $.02. Texas has the highest average spark spread of $0.03 of this group, and Florida has the lowest at $0.012. As indicated in the results, it appears that $0.05 spark spread appears to be a trigger for an increase in CHP installs, separate from other influences. Further, there are no significant CHP incentives, rebates or grants in any of these states, nor did the power outage events significantly change any state or local financial support.

It was anticipated that an increasing number and intensity of power outages could drive installation of CHP to some degree. However, from this analysis, it appears that the risk of future power outages and disruption caused by imminent power disruptions have not been determined to be significant enough to warrant consideration in the decision making process of most organizations.

A possible explanation is that due to uncertainty of the occurrence and intensity of future extreme weather events and related power outages. It is difficult for organizations to quantify the risk to their business or quantify the long-term benefit that more resilient power systems may provide.

It is also important to point out that some states and communities have been able to come to terms and quantify future risks of extreme weather events to their power systems and to their communities. Some of the states directly impacted by Superstorm Sandy have taken momentous steps to facilitate the development of more resilient power system with the development of energy resilience banks, CHP-specific grants and microgrid pilots.

A recommendation for improving cost/benefit analysis of resilient power systems is to start to take into account future weather-related power outages in financial models. An option to be considered is the use of down-scaled regional climate models. These models are now better able to measure both the likelihood and intensity of future extreme weather risks. Down-scaled models have been introduced over the last few years as effective tools to help guide infrastructure decisions. The insurance industry increasingly uses these models to better identify future climate risks of insured assets.

From this analysis, we find that power outages due to extreme weather events do not significantly influence the installation of CHP systems across the US. It can be argued that many organizations have yet to be able to properly quantify the future risk of extreme weather events on operations. The future costs are unknown which makes it very difficult to justify higher upfront investment costs to manage long-term disruption cost uncertainties. Because of the inability to appropriately quantify long-term costs due to extreme weather events and the benefits of more resilient power systems, significant financial support is required for investment. In the absence of financial support, particularly in areas with low spark spread, states may continue to see sub-optimal investment to increase the resilience of their power systems.

In this study, we do not consider additional resilience efforts taken by utilities and government to harden power infrastructure. There have been efforts by these organizations to further harden the transmission and distribution systems against storm-related power outage events[34]. The focus of our study is on the installation of CHP and other power systems to mitigate power outage risk at a site. Future studies will consider the relationship of utility grid hardening efforts and the installation of CHP systems. One could anticipate the hardening activities by utilities may lessen the sense of risk by site and reduce need to invest in onsite power systems.

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[34] . https://fas.org/sgp/crs/misc/IN10781.pdf