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Does the community choice aggregation approach advance distributed generation development? A case study of municipalities in California

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ABSTRACT

Globally, decentralized energy systems are gaining popularity due to their potential for energy accessibility, energy resilience, and sustainability benefits. Existing research on an energy system decentralization approach, community choice aggregation (CCA), shows its ability to lower energy costs and increase renewable electricity consumption for U.S. communities. Nevertheless, research on the relationship between CCA and distributed electricity generation development is lacking. This paper fills this gap by investigating if the CCA approach associates with distributed generation capacity interconnection in California municipalities. The finding shows that although the average capacity has increased for all municipalities throughout the study period, contrary to proponents' arguments, the CCA approach has insignificantly decreased the capacity interconnected for municipalities. It is unclear if the result is due to a lack of higher-level support for the full CCA implementation or substitution by community-owned distributed generation. Future research is necessary to determine the CCA effect comprehensively in California. With this understanding, the research could be expanded to explore how community energy approaches work towards distributed generation across the U.S. and the globe.

1. Introduction

Energy security and resilience gained importance after the 2000–2001 Energy Crisis in California (Reddy, 2001; Duane, 2002; Fenn, 2002). To resolve the failure of the electricity market deregulation, California State Legislator Carole Migden sponsored a bill authorizing community choice aggregation (CCA) in 2002 (Hess, 2019). The legislation, California Assembly Bill No. 117 (AB117) Chapter 838 (2002), authorizes local governments to make energy procurement decisions for small-scale customers in their jurisdictional areas, except for accounts served by publicly owned utilities (California Public Utilities Code). While CCAs are responsible for energy procurements, IOUs are obligated to offer other indispensable energy services, like transmission, distribution, and customer billing (O'Shaughnessy et al., 2019; Kennedy and Rosen, 2020). The CCA approach can be employed for either electricity or natural gas management. This study exclusively focuses on the electricity sector.

Previous studies have assessed if CCA worked to lower electricity prices and increase renewable electricity consumption (Armstrong, 2019; Deryugina et al., 2020; O'Shaughnessy et al., 2019). There is a lack of empirical scholarship on how community energy approaches like CCA work on distributed generation development, although many recent studies have discussed community energy and distributed generation (Trabish, 2019; Bakhtavar et al., 2020; Ceglia et al., 2020, 2022; Fernandez et al., 2021; Pressmair et al., 2021; Fina et al., 2022; Maldet et al., 2022; Roy et al., 2023). However, these studies have not empirically tested the effectiveness of community energy approaches on distributed generation development, let alone potential causes of the ineffectiveness of the approaches on distributed generation. This paper fills this gap. It evaluates if the approach has increased the capacity of distributed generation interconnected to the grid for municipalities.

Our finding suggests that contrary to proponents' arguments, the CCA approach has not contributed to developing small-scale distributed generation in Californian municipalities. Instead, it demonstrates that CCA is associated with an insignificant decrease in the interconnected distributed generation capacity. This research cannot attribute the result to any specific causes. A possible explanation could be a lack of legislative, financial, and informational support from higher-level governments to fully realize the CCA effect on distributed generation. Nevertheless, before enhancing the support, we recommend researching

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the root of the policy's ineffectiveness to test if it is due to insufficient higher-level support or the existence of community-owned electricity generation sources. The answer offers insight into policymaking that links CCA or similar decentralized energy management approaches and distributed generation.

2. CCA and distributed generation: the policy mechanism

2.1. Overview of the U.S. CCA approach

As shown in Fig. 1, state CCA-enabling legislation is a prerequisite for local governments to become CCAs because no national-level CCA-enabling law is available (O'Shaughnessy et al., 2019; Brooks, 2020). Ten U.S. states have adopted the CCA approach, three of which are still in the pre-implementation phase (LEAN Energy U.S., 2022). Local governments can intervene in the electricity production and consumption sectors as CCA administrators. They purchase or produce electricity based on customers' preferences (EPA, 2022). Most communities with CCAs have established the opt-out version, automatically enrolling all eligible customers in communities' jurisdiction areas to increase participation (Littlechild, 2008; Bartling, 2018; EPA, 2022). Under the opt-out CCA, customers who do not want to participate in the program must apply to quit. Conversely, customers must apply for participation under the opt-in approach. Local governments must take extra legislative steps to establish an opt-out CCA (EPA, 2022).

Proponents of the CCA approach, including scholars and policy advocates, have expressed three possible CCA benefits in their publications: energy affordability, renewable electricity consumption, and distributed generation (see Fig. 1). Scholars and advocates expect CCA to increase electricity affordability, considering CCAs get more contract negotiating power when they aggregate consumer demand loads and purchase electricity in bulk (O'Shaughnessy et al., 2019; Brooks, 2020). In 2019, Deryugina and her colleagues found that CCA in Illinois has helped municipalities lower electricity prices and increased electricity affordability. Besides the affordability benefit, scholars and advocates expect CCA to offer more competitive green electricity plans due to increasing local demand for sustainability. Armstrong (2019)'s study shows that CCA programs in California set higher renewable energy standard targets than the state target. In the meantime, O'Shaughnessy et al. (2019) found that CCA programs sold more green electricity than state requirements across U.S. states.

2.2. The CCA approach and distributed generation development

This study focuses on the third purported benefit of the CCA approach – distributed generation development. As local government agencies, proponents expect CCAs to prioritize procuring electricity from local renewable sources to promote community economic development, environmental sustainability, and local energy control (UCLA Luskin Center for Innovation, 2017; O'Shaughnessy et al., 2019). Our study evaluates if the CCA approach in California has advanced community distributed generation development. It differs from previous studies on the relationship between CCA and renewable electricity consumption. Previous studies show that the CCA approach has helped with renewable energy consumption. However, renewable electricity can be produced elsewhere and traded with renewable energy certificates (O'Shaughnessy et al., 2019; Kennedy and Rosen, 2020).

Understanding the relationship between CCA and distributed generation helps direct future research and practices that combine community energy management, decentralized energy production, and energy security. Traditionally, retail customers and smaller utilities purchase electricity from wholesale generators that produce electricity in a centralized way (EPA, 2023). The mechanism works well when the wholesale energy supply is stable and sufficient to meet the market demand (Science Direct, 2022). However, customers take risks when there is a shortage, like during the 2000–2001 California Electricity Crisis (Fenn, 2002; Leopold, 2002). According to CCA proponents, CCA is a valuable policy tool to ensure energy security through community energy control. They deem CCA as a mechanism to realize democratic and decentralized energy production and management through promoting the development of distributed generation (San Francisco Ordinance 86-04, 2004; Burke and Stephens, 2017; UCLA Luskin Center for Innovation, 2017; van Veelen and van der Horst, 2018; Hess, 2019; Szulecki and Overland, 2020). Distributed generation has become a choice for electricity customers due to its increasing affordability, market potential, and autonomy-related benefits (van Veelen and van der Horst, 2018; Ceglia et al., 2020; Szulecki and Overland, 2020; Zhang et al., 2023). As scholars suggest, it empowers citizens to participate in

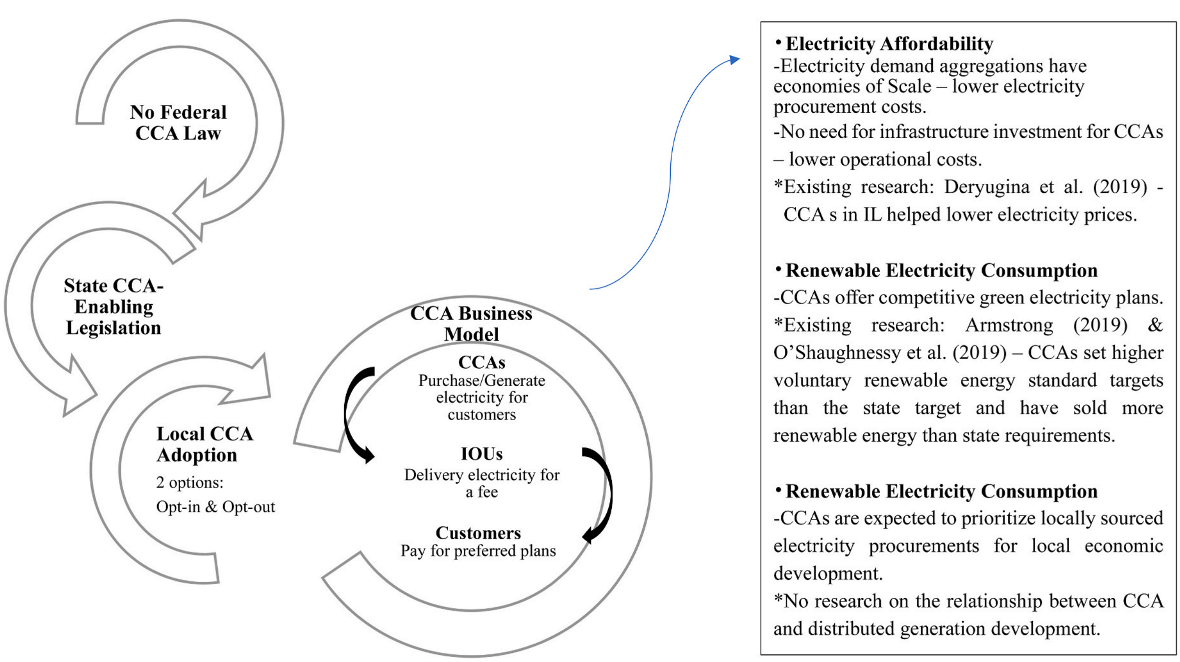

Fig. 1. CCA Business Model and Purported Benefits. This figure portrays how the CCA approach works and its purported benefits.

energy management as prosumers who consume and produce energy simultaneously, which helps them reduce or eliminate dependence on the centralized system (Ceglia et al., 2020; Fernandez et al., 2021; Pressmair et al., 2021). In other words, citizens can secure control of their electricity access and the electricity supply market through distributed generation.

2.3. The CCA approach in California

California passed the *Electric Utility Industry Restructuring Act* for electricity market deregulation in 1996 (Weare, 2003; Brooks, 2020). It separated the electricity generation and delivery systems to increase electricity supply competition and allow customer energy choices (Morain, 1996; Weare, 2003). However, the deregulation failed due to the centralized electricity production model, wholesale generators' manipulations, and individual customers' inability to negotiate with suppliers (Leopold, 2002; Weare, 2003).

Electricity price rises were accompanied by frequent large-scale blackouts and IOUs' financial difficulties during the well-known 2000–2001 California Electricity Crisis (Duane, 2002; Sweeney, 2002). The energy crisis taught Californians the importance of energy security and local energy control (Reddy, 2001; Fenn, 2002). In 2002, California passed AB117 into the California Public Utilities Code to authorize local governments to adopt the CCA approach, which aimed at various goals, including market competition, local autonomy, and decentralized energy production and management (Lingbloom, 2002; Fenn, 2002; UCLA Luskin Center for Innovation, 2017; Hess, 2019; Hsu, 2022). The first CCA program, Marin Clean Energy, was established in 2010 to serve customers in Marin County (LEAN Energy U.S., 2022).

2.4. Ways CCA in California could advance distributed generation

CCA programs in California offer two major incentives to encourage customers to install and interconnect distributed generation systems. First, CCA customers are given more confidence that the market for distributed generation is sustainable than IOU customers. Most IOUs own power plants, so customers may expect them to purchase less electricity from distributed generation (Science Direct, 2022). On the other hand, CCAs rely on energy purchases and frequently express their interest in prioritizing locally generated electricity in their energy procurement plans (San Francisco Ordinance 86-04, 2004; Burke et al., 2005; Lydersen, 2012; Burke and Stephens, 2017; UCLA Luskin Center for Innovation, 2017; O'Shaughnessy et al., 2019; The Climate Reality Project, 2020).

The second incentive is categorized as financial savings and returns. According to previous research, financial returns and tax incentives influence customers' decision-making on solar system installation (Crago and Koegler, 2018; Zander, 2021; Trabish, 2019; Bernardes et al., 2022). Our research on CCAs' official websites found that some CCAs offered extra subsidies and rebates to their customers on top of federal and state financial incentives. In 2021, nine of 22 (about 41%) California CCA programs offer additional subsidies to customers who install solar systems. Once a customer has installed a distributed generation system, the customer can interconnect the system to the grid to participate in net-energy-metering (NEM) programs[1] getting credits from the load-serving entity, which can be either a CCA or IOU. Our CCA website research also discovered that CCA customers generally got more long-term financial returns than IOU customers. As of 2021, twenty of 22 (about 91%) California CCA programs pay higher NEM rates for electricity sent to the grid than IOUs.

After reviewing how the CCA approach works in California, we came up with the following research question:

> **Research Question**: Keep other things equal, has the CCA approach advanced distributed generation development for municipalities in California?

3. Methods

3.1. Variables and data sources

This study uses a longitudinal dataset to assess CCA's effect on distributed generation development. The dataset includes 443 municipalities across 16 years. The study period begins in 2005, five years before the first CCA in California was established in 2010. This allows us to distinguish the CCA implementation effects on distributed generation based on data sufficient for comparison, considering the CCA could not affect the outcomes so many years before its first established program. In this way, we could assess if there had already been a trend difference between the treated and controlled groups before the treatment was adopted. The study period ends in 2020, the latest year for which sufficient annual interconnection data was available. We obtained the list of municipalities from the California Community Choice Interactive Map, which shows all cities in California (Clean Power Exchange, 2020). The dataset includes none of the municipalities served by publicly owned electric utilities as the state legislation does not allow them to adopt CCA (California Public Utilities Code).

We examine how the CCA approach has contributed to distributed generation development in California. The explained variable is the annual distributed generation capacity interconnected to the grid. We use the data published by the California Distributed Generation Statistics website. The dataset is the Distributed Generation Interconnection Program Data, created and maintained by the non-profit Energy Solutions in cooperation with the California Public Utilities Commission (CPUC) and California's three major IOUs. It contains details of each distributed generation system interconnected by the IOUs.[2] These IOUs are responsible for the interconnection services within their service territories, regardless of whether the system owner is served by a CCA or IOU (see CCA official websites; CPUC, 2021c). We use the information on the city, date of interconnection application received, and system size in direct current (DC) to generate the explained variable. We distinguish the annual capacity interconnection made by residential customers from the general class of customers to assess if participation in CCA has made a difference in the outcome. As a result, we include the annual residential distributed generation capacity interconnection and the annual total distributed generation capacity interconnection as the explained variables of this study.

The explanatory variable is a dummy variable that indicates whether or not a municipality operates a CCA in that year. A "0" means no, and a "1" means yes. The information is from the Clean Power Exchange website, a non-profit organization that traces the dissemination of CCA across California. Besides collecting the information from Clean Power Exchange, we also check CCAs' implementation plans to determine when CCA starts operating in each municipality. For municipalities that have adopted CCA but have not started operating it, we code the explanatory variable as a "0".

[1] Between 2016 and 2017, PE&G, SCE, and SDG&E switched to Net Energy Net-metering (NEM) 2.0 program (CPUC, 2021b). The program removes the renewable energy interconnection cap set by NEM 1.0 program and mandates a time-of-use rate schedule. However, NEM 2.0 offers lower financial incentives as it charges a surcharge based on the consumption volume but not credit it to customers when they sell electricity (Hyder, 2022). This change would impact both CCA and IOU customers.

[2] The dataset contains distributed generation systems with small sizes. Under the NEM 1.0 program, the size was capped to be under 1 MW (MW). Under the NEM 2.0 program, the size limit was lifted to some extent, but we did not find interconnected systems with a size as large as community-level distributed generation (CalCCA, 2023).

We control for several potential confounders. We control for factors related to distributed generation system installation and CCA adoption based on previous studies (Gil and Joos, 2008; Bartling, 2018; Armstrong, 2019; Barbose et al., 2021). They include population, percentage of voters who affiliated with more environmentalist parties, the median age of the population, percentage of households using electric heating, and socioeconomic status. We calculate the socioeconomic status score using several factors. The score represents the overall socioeconomic status of the population in a municipality. Table 1 shows the variables included in the study and their data sources.

3.2. Statistical model

According to Goodman-Bacon (2021), analysis using datasets with variations in adoption timing and treatment content cause bias when using the traditional difference-in-differences (DID) model. The traditional DID estimation compares later adopters to earlier adopters while considering the earlier adopters as controlled units. Considering municipalities in our dataset adopted the CCA approach in different years, and the policy goals could be heterogeneous across municipalities and time, we use the dynamic Average Treatment Effect on the Treated (ATT) method introduced by Callaway and Sant'Anna (2021). This method builds on the traditional model. Unlike the traditional DID model, it takes the variations into account.

The dynamic ATT method examines ATTs as relative-time differences in the outcome between the treated and controlled groups before and after the treatment adoption. The estimation also gives a simple ATT, which is the difference in the outcome between all treated and controlled units for the post-treatment period compared to the pre-treatment period. The method uses the doubly robust estimation procedure to reduce potential biases[3]. Table 2 elaborates on the descriptive statistics of the variables included.

Table 1
Data sources for study variables.

Variable	Description	Source
Residential Capacity	Annual interconnected residential distributed generation capacity in a municipality	Distributed Generation Interconnection Program Data
Total Capacity	Annual interconnected total distributed generation capacity in a municipality	Distributed Generation Interconnection Program Data
CCA	If a municipality operates CCA (0 = No; 1 = Yes)	California Community Choice Interactive Map & CCA implementation plans
Population	The population of a municipality	US Census Bureau City and Town Population Totals 2005–2020
%Democratic & Green & Peace and Freedom Party Voters	Percentage of registered voters who are affiliated with the Democratic, Green, and Peace & Freedom Parties	Voter Registration Statistics from the California Secretary of State website
%High School & Higher*	Percentage of population over age 25 who attained a high school or higher degree	American Community Survey (ACS) database 2005–2020
%Bachelor & Higher*	Percentage of population over age 25 who attained a bachelors' or higher degree	ACS database 2005–2020
Household Median Income*	The median income of households	ACS database 2005–2020
Unemployment Rate*	Percentage of population over age 16 who are unemployed	ACS database 2005–2020
Poverty Rate*	Percentage of families whose incomes are below the poverty line	ACS database 2005–2020
%Occupation in MBSA*	Percentage of employed population with an occupation in management, business, science, and arts	ACS database 2005–2020
Median Age	Median age of population	ACS database 2005–2020
%Electric Heating	Percentage of occupied houses that use electricity for heating	ACS database 2005–2020

*We use the variables to calculate the socioeconomic status (SES) score. The method for the calculation is the factor analysis provided by Stata (Torres-Reyna, 2008). Table A1 shows the factor analysis result in Appendix A.

Table 2
Descriptive statistics.[41]

Variable	Obs.	Mean	Std. Dev.	Min	Max
Annual Residential Capacity	7068	750.34	2195.10	0	48674.65
Annual Total Capacity	7068	1176.15	3180.56	0	75600
CCA	7068	.09	.29	0	1
%Democratic & Green & Peace and Freedom Party Voters	7068	.44	.12	.06	.79
Population	7068	68117.28	210703.80	184	3982885
%Electric Heating	5597	.24	.1	0	.94
Median Age	6074	37.37	7.26	19.40	78.20
SES Score	5864[5]	0	.99	−3.33	2.50

4. Results

4.1. Parallel trend

To analyze if the CCA approach has affected the installation and interconnection of distributed generation capacity, we first test the parallel trend assumption (The World Bank, 2022; Cheng and Li, 2022). Supposing the pre-treatment trends of the treated and controlled groups are parallel, we assume that municipalities in the two groups do not behave differently before adopting CCA. Alternatively, if the assumption does not hold, it would be difficult to conclude that any post-treatment differences between the two groups are due to CCA. We utilized both calendar time trend and relative time trend analyses to test the assumption. As shown by Figs. 2 and 3, the annual capacity interconnection was always higher for the treated group before the first CCA program launched in California, regardless of the customer class. The direction and magnitude of the differences are constant and relatively stable, which indicates that the parallel assumption holds.

The time trends in Figs. 2 and 3, however, only show the stable difference between the two groups before the first CCA program adoption. Municipalities in California adopted CCA in different years, so we cannot assume the parallel trend affirmatively. Thus, we also do the event study analysis to test the parallel trend assumption across relative time periods (Cunningham, 2021; Cheng and Li, 2022). The analysis demonstrates differences in outcomes between the treated and

[3] According to Callaway and Sant'Anna (2021), the procedure includes a generalized propensity score estimation and an outcome regression. A generalized propensity score indicates the probability that a unit is first treated at a specific time. The score is estimated using pre-treatment observed confounders. The procedure helps reduce the estimation bias caused by self-selection to the treatment. An outcome regression, on the other hand, generates the treatment effect while controlling for observed confounders. It helps reduce bias related to the situation that the same treatment has different effects on units in different subgroups.

[5] As of the time of completing data analysis, municipal-level ACS datasets for 2020, except for population, were not published by the U.S. Census Bureau. There are also missing values in the published datasets for certain municipalities in specific years.

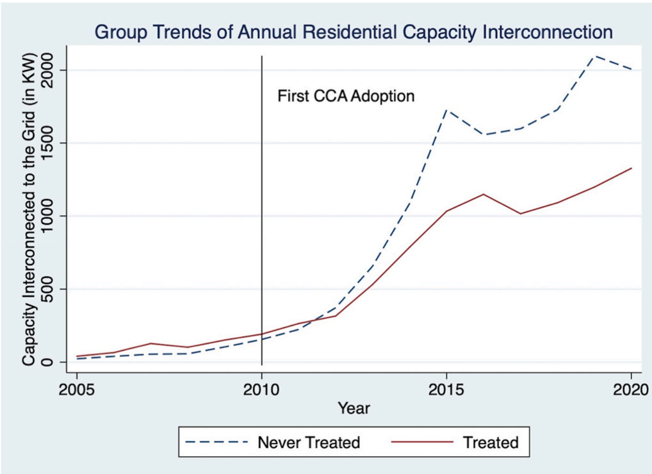

Fig. 2. Time trend for residential capacity.

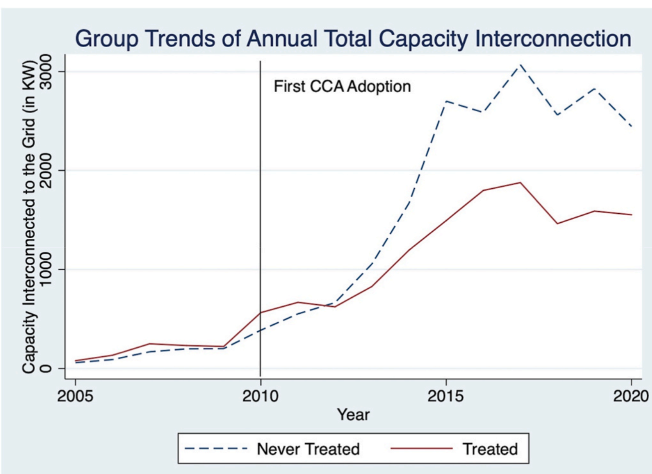

Fig. 3. Time trend for total capacity.

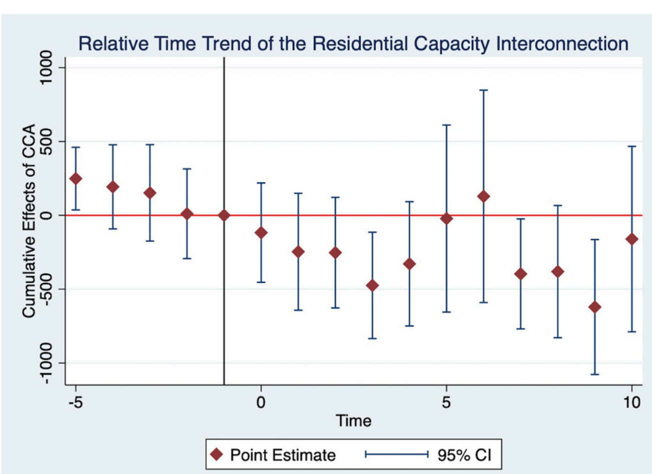

Fig. 4. Relative time trend for residential capacity.

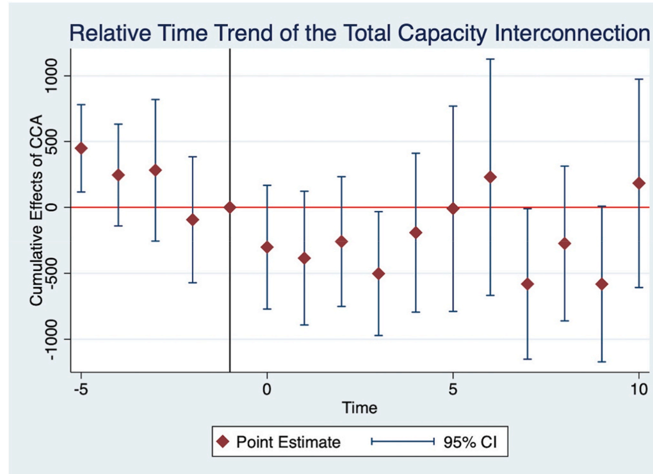

Fig. 5. Relative time trend for total capacity.

controlled units relative to the adoption year. As shown in Figs. 4 and 5, the comparison period includes five years before and ten years after each CCA establishment. While controlling for the confounding factors, the results show no significant difference in the outcomes between the treated and controlled units for the four pre-treatment years. The results support the parallel trend assumption.

*To simplify the analysis of the pre-treatment trend, only five years before CCA adoption were included in the event study. The five-year pre-treatment trend should be sufficient to test the parallel trend assumption. The insignificant coefficients for the four years before adopting the approach indicate that municipalities in the treated and controlled groups had not significant difference in the outcome while controlling for covariates. The specification applies to both Figs. 4 and 5.

4.2. *Results of the dynamic ATT method*[6]

Figs. 6 and 7 present the dynamic ATT estimation results. They demonstrate the differences in the residential distributed generational capacity interconnection between the treated and controlled groups in different periods relative to the treatment adoption, keeping other things equal. Fig. 6 shows the comparison between the treated and never-treated units. The blue points are the pre-treatment ATT estimates, and the red ones are the post-treatment estimates. The blue point estimates approximate zero, and their 95% confidence intervals contain zero. The results indicate that the differences between the treated and controlled units were close to zero before the treatment adoption. For units in the treated group, the trend of ATTs becomes negative. However, the ATTs are statistically insignificant, as the bars in red show that the 95% confidence intervals always contain the zero value. In the meantime, the Simple ATT and the t-value corroborate that the overall difference between the post- and pre-treatment ATTs is negative but statistically insignificant. The Simple ATT represents the general post-treatment difference in the outcome between the treated and controlled units relative to the pre-treatment period.

Like Fig. 6, Fig. 7 examines how the treatment correlates with annual

[4] Based on the rule of thumb, there is no concern over the multicollinearity issue, as all Variance Inflation Factor (VIF) values are smaller than 4 (Pennsylvania State The Pennsylvania University, 2018).

[6] Besides the dynamic ATT method, we also utilize a similar method introduced by Sun and Abraham (2021) for the robustness check. Their Cohort-specific Average Treatment Effect on the Treated (CATT) method follows the same logic as Callaway and Sant'Anna's method, but there are nuances in the calculation. The CATT method assigns cohorts of the treated units based on how long they have been with the treatment in a specific year. Then, the method calculates a specific ATT for each cohort, which is the difference in the outcome between the treated units in that specific cohort and the controlled units. We attach the results of the CATT analysis in Appendix B.

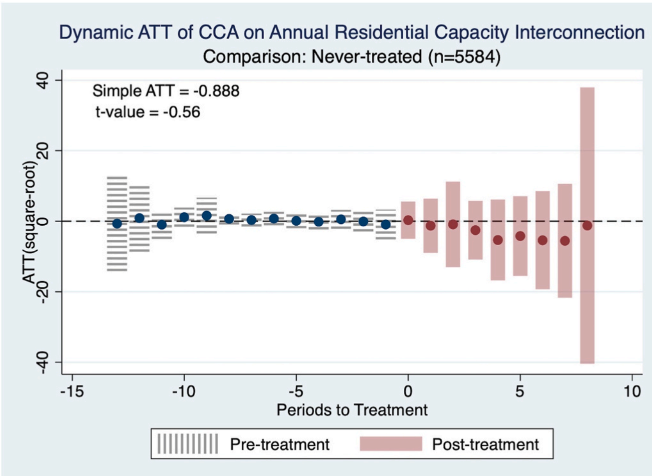

Fig. 6. Dynamic ATT of CCA on annual residential distributed generation capacity interconnection, compared to never-treated units.

* We transformed the capacity using the square-root function as the distribution of the original values was seriously right-skewed.
* The dynamic ATT function gives the Simple ATT in Stata.
* Above specifications also apply to Figs. 7, 8, and 9.

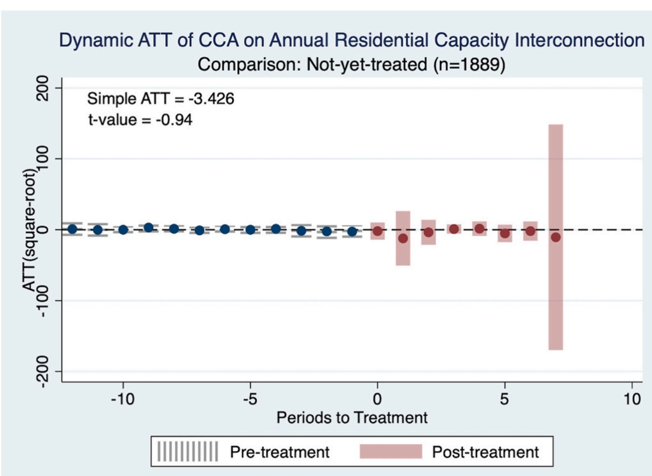

Fig. 7. Dynamic ATT of CCA on annual residential distributed generation capacity interconnection, compared to not-yet-treated units.

residential capacity interconnection. The difference is that the controlled group in Fig. 7 comprises the not-yet-treated units while excluding the never-treated ones. A municipality is recognized as a controlled unit for the period before 2015 if it adopted CCA in 2015. The results are similar to that in Fig. 6: post-treatment differences between the treated and not-yet-treated units are negative but statistically insignificant. Also, as the Simple ATT and t-value show, the overall post-treatment difference in the outcome between the treated and not-yet-treated units relative to the pre-treatment period is also negative and statistically insignificant.

Figs. 8 and 9 display ATTs of CCA on the annual interconnection of total distributed generation capacity. As shown by the figures, the ATTs are averagely negative for post-treatment than pre-treatment periods. Nevertheless, the differences are not statistically different from zero, as the 95% confidence intervals contain the zero value. The Simple ATTs and the t-values indicate that the overall ATT is negative but not statistically different from zero, regardless the controlled group comprises never-treated or not-yet-treated units.

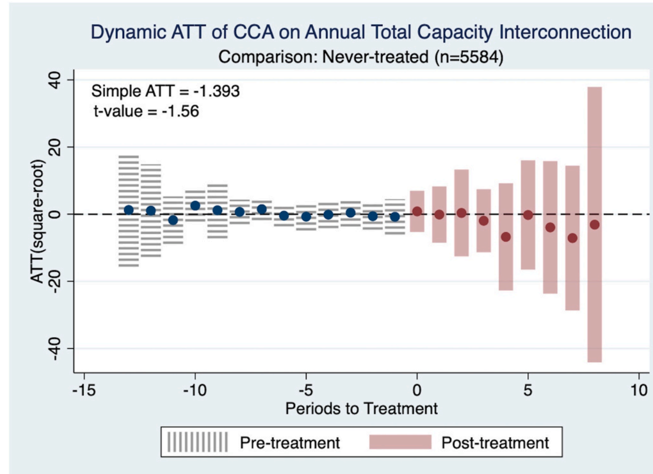

Fig. 8. Dynamic ATT of CCA on annual total distributed generation capacity interconnection, compared to never-treated units.

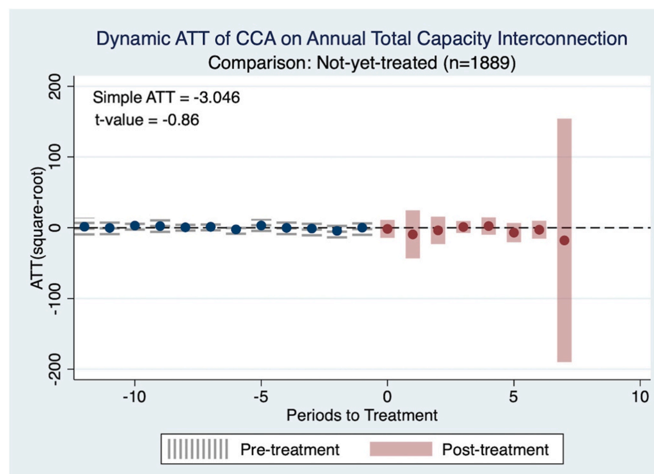

Fig. 9. Dynamic ATT of CCA on annual total distributed generation capacity interconnection, compared to not-yet-treated units.

In sum, according to the analyses of trends and ATTs, the outcomes for the treated units are smaller than for the controlled units for both customer classes. However, since the 95% confidence intervals always contain the zero value and the absolute t-values of the Simple ATTs are always smaller than 1.96, we do not conclude that the treatment has made the treated units behave differently than the controlled units. In other words, the treatment does not significantly affect the outcomes.

5. Discussion

The results demonstrate that contrary to CCA advocates' arguments, the approach has not advanced the development of distributed generation for municipalities in California while controlling for potential confounders. Instead, the results suggest that CCA has insignificantly decreased California municipalities' distributed generation capacity interconnection.

Several possible factors could help explain the apparent ineffectiveness of CCA in distributed generation development in California. First, informational and financial costs could prevent citizens from installing and interconnecting distributed generation systems. As Allan et al. (2015) suggest, potential users of distributed generation systems may not easily access and understand information about distributed generation and related assistance programs, which could hinder the penetration of distributed generation. Also, as Christensen et al. (2019) discuss, people face burdens in learning program information and complying with various requirements for public service participation. They also propose that the costs could be more significant for citizens who are already disadvantaged but in need of assistance.

The other possible factor that impeded citizens from installing and interconnecting distributed generation systems could be the unavoidable interconnection costs. There is variation among states, IOUs, locations, and even distributed generation systems in interconnection procedures and costs (Horowitz et al., 2019; Seel et al., 2023). It takes effort and money for customers to understand the requirements and apply to interconnect their installed generation systems to the grid to get NEM credits, which allows customers to recover their facility investments in the long run (Horowitz et al., 2019; CPUC, 2021c). Crago and Koegler (2018) state that potential financial return significantly impacts customer decision-making on installing distributed generation systems. However, as Schelly et al. (2017) state, the complicated and inconsistent interconnection policies could confuse potential users about their potential gains, discouraging them from installing and interconnecting distributed generation systems. Therefore, higher-level standardized interconnection policies may be necessary for advancing distributed generation development. Moreover, Schelly et al. (2017) describe distributed generation-related monthly surcharges as a penalty to distributed generation customers that reduces their long-term financial return expectations and desires for distributed generation. Due to the informational and financial costs, many CCA customers might not know what assistance they could get and not adopt distributed generation systems.

According to Energy Sage (2021), CCA's apparent ineffectiveness in distributed generation development could also be due to the tradeoff between community- and household-owned distributed generation. Because CCA customers in California enjoy more competitive renewable electricity plans than IOU customers, either through buying renewable electricity from local sources or generating from CCA-invested distributed generation systems (O'Shaughnessy et al., 2019; CPUC, 2021a; MCE, 2022). As CalCCA (2023)'s map shows, CCAs in California have signed long-term power purchase agreements with local renewable electricity projects for more than 11,000 Megawatts and built their own community projects too. These projects are located close to customers, which makes community-level renewable electricity generation visible to customers. The visibility might lead customers served by CCAs to be less incentivized to invest in distributed generation, although they could get assistance and long-term financial return for distributed generation investment. Caplan (2023) found that people decide on community-versus household-level electricity generation by analyzing potential benefits and costs. The competitiveness of CCA renewable electricity plans, visibility of CCA-invested community solar and wind farms, and potential informational and financial costs related to household-level distributed generation installation and interconnection tend to make CCA customers prefer community-owned distributed generation.

6. Conclusions, limitations, and recommendations for future research

The research question investigated in this study is whether the CCA approach has contributed to the development of distributed generation in California. As far as we know, ours is the first study to investigate this research question. Our finding is that CCA has not led to an increase in the interconnected capacity of distributed generation for municipalities in California. Conversely, the CCA approach has decreased capacity, though the negative effect was statistically insignificant. The interesting finding suggests deeper exploration, considering the CCA approach was expected to achieve a positive effect by its proponents.

We propose a few future research recommendations to address the limitations of this study. First, only municipalities in California are included in this study. The CCA approach in California encourages distributed generation more than that in other states. Also, the CCA approach varies in design and implementation between California and the other states. Thus, our finding may not be generalizable to municipalities in other states. Further research that includes information collected on municipalities in other states could provide evidence on if the finding of this study is generalizable to a broader context. Beyond municipalities in U.S. states, research exploring the relationship between community energy approaches and distributed generation could also be expanded to communities in other countries. Local-level electricity security is the foundation for electricity system transformations at higher levels, including national and global levels. Furthermore, the improving data availability could allow long-term observation of CCA's effect on distributed generation, which can address the limitation that the policy effect might be lagged as CCA programs have started emphasizing distributed generation in recent years.

Second, this study's dataset only includes distributed generation systems interconnected to the grid. There might be installed systems not interconnected to the grid, which are missing from the dataset. However, the difference between the interconnected and installed capacities should be insignificant. The financial return is a significant driver of distributed energy system installations, and customers have to interconnect their systems to receive net metering benefits. Nevertheless, future research utilizing distributed generation system installation datasets could be useful to test if the CCA approach has advanced distributed generation capacity installation.

Finally, this study aimed to test whether the CCA approach has contributed to the development of household-level distributed generation in California. As noted above, it found that CCA has not led to an increase in the interconnected capacity of distributed generation for municipalities in California. We have discussed possible explanations for the apparent ineffectiveness of CCA on distributed generation development, which could be a lack of broader informational and financial support and the tradeoff between community-versus household-owned distributed generation systems. Nevertheless, as this study has yet to test if they were the causes, we recommend further research to explore them.

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Disclaimer

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CRediT authorship contribution statement

Jun Deng: Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing – original draft, Visualization, Project administration. **Robin Rotman:** Supervision, Writing – review & editing.

Declaration of competing interest

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

Data availability

The data will be made available in the open-access Harvard Dataverse data repository upon article publication.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2023.137451.

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