Retiring the Diablo Canyon Power Plant: California's regulatory responses to energy shortages

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ABSTRACT

This study investigated if California's regulatory plan to replace the Diablo Canyon Power Plant (DCPP) sufficiently addresses concerns about potential increases in carbon emissions and natural gas use. I examined past nuclear plant closures and found that natural gas emissions and natural gas imports increase in the 12-month period after a nuclear plant closure. I then explored California's regulatory response to past energy crises, focusing on the 2000-2001 energy crisis, the 2020 rolling blackouts, and the 2021 State of Emergency. My findings revealed repeated instances of reliance on natural gas to combat energy shortages. This pattern might threaten California's ability to replace DCPP's energy with entirely clean resources. This reliance raises concern for California's future energy sector and suggests that careful planning is needed to achieve the state's bold SB 32 and SB 100 goals, especially when a large source of zero-carbon electricity will no longer be available. Lastly, I proposed policy suggestions to address California's ongoing challenges of grid reliability and resource adequacy. Demand response programs have the potential to increase grid flexibility, maintain grid stability, and deliver economic benefits to customers by effectively managing peak loads. Furthering stakeholder involvement can bolster California's efforts in achieving greater energy efficiency while ensuring the representation of communities most impacted by future policies.

KEYWORDS

energy transition, natural gas, nuclear energy retirement, stakeholder engagement, clean energy

INTRODUCTION

As the repercussions of climate change intensify, developing resilience and transitioning to clean energy has become a necessity for a livable world. IPCC's most recent report highlights that even an immediate and sharp reduction in greenhouse gas emissions will be unable to prevent a global temperature rise of 1.5 degrees Celsius by 2040 (Masson-Delmotte et al. 2021). The process of phasing out fossil fuels and phasing in renewable energy takes time that we can no longer afford. In the United States, the Biden administration's goal is to achieve net-zero emissions by 2050, by which the climate will have already seen irreversible damage due to global temperature rise (Biden 2021, Masson-Delmotte et al. 2021). The urgent need for a radical transition calls for a large-scale and long-term investment in clean energy. Decarbonizing the electricity grid is a commitment for an increasing number of countries (Loftus et al. 2014, Ahman et al. 2017, Mathy et al. 2018). As regulators strive for an unprecedented energy portfolio, they must address potential issues of grid reliability and energy adequacy while ensuring an equitable transition (Stram 2016, Papadis and Tsatsaronis 2020, Denholm et al. 2021).

California has been a leader in renewable energy policy since the 1990s, setting progressive regulations that often become the foundation for other state and federal policies (Farrell and Hanemann 2009, Vogel 2018). Following the 2000 energy crisis, which resulted in record-high retail electricity prices and power outages, the state intensified its commitment to renewable energy; the 2002 Renewable Portfolio Standard (RPS) program, mandated by SB 1078, set a landmark requirement that 20% of retail electricity must be provided by renewable energy by 2017 (Sher 2002). In 2018, SB 100 was passed to increase the RPS to 60% by 2030 while also mandating that all of California's electricity comes from zero-carbon resources by 2045 (De Léon 2018). In terms of emission reduction, the 2016 SB 32 extended AB 32's initial target to mandate a 40% reduction below 1990 emission levels by 2030 (Pavley 2016). However, there is often a discrepancy between clean energy targets and retail gas utilities that operate under the assumption of static or increasing natural gas demand (Karas et al. 2021). California is no exception; the number of peaker plants, which are natural gas plants that only run when needed to meet peak demand, grew from 29 in 2001 to 74 in 2020 (Roy et al. 2020). Peaker plants are more flexible but less efficient than regular natural gas plants, resulting in higher emissions that cause disadvantaged communities to experience twice as much ambient concentrations of nitrogen oxide, sulfur oxide, and particulate matter (CEC 2017a). Even if natural gas plants run for less time overall, more frequent starts and stops will result in more overall emissions (Casey et al. 2016). To maintain its position as a leader in environmental policies, the state must retire its natural gas fleet and continue to deploy renewable resources without causing an energy shortage. Furthermore, the state will lose the Diablo Canyon Power Plant's (DCPP) firm, zero-carbon energy in 2025.

California's last nuclear plant, DCPP, was the state's largest plant by capacity and generation in 2020, contributing 9% to the state's total power mix (CEC 2021b, EIA 2021b). The San Onofre Nuclear Generating Station (SONGS) had a similar nameplate capacity prior to its closure in 2012, which caused an immediate rise in electricity prices, natural gas usage, electricity imports, and carbon emissions (EIA 2012, Davis and Hausmann 2016). California is currently developing regulations to ensure that DCPP's closure does not see a similar effect, such as the SB 1090 mandate that DCPP's capacity is replaced entirely with carbon-free energy. Past studies have found that nuclear generation is necessary for providing stable energy while reducing emissions in the energy sector (Ghanadan and Koomey 2005, Greenblat 2015, Kim 2020, Aborn et al. 2021). However, PG&E has not re-evaluated its decision to shutter DCPP since 2016, so it is unlikely that the plant will continue to operate. Instead, there is a lack of research on whether California's current regulations can fully prepare for this critical transition away from nuclear energy.

I investigated California's response to past energy shortages to understand if current regulations adequately prepare for DCPP's retirement. The plan will be adequate if it complies with the SB 1090 mandate that DCPP's retirement does not cause an increase in emissions. To do this, I (1) examined if DCPP's retirement could cause an increase in natural gas usage and (2) analyzed California's regulatory response to past energy crises and how these responses shape current policies. First, based on the observed effects of the SONGS closure, I expected to find a positive relationship between a nuclear plant closure and a rise in natural gas usage. I compiled secondary data from the U.S. Energy Information Administration (EIA) and used a statistical analysis to compare carbon emissions and natural gas imports before and after the closure of seven nuclear plants. Second, I expected to find that fossil fuels are often used to combat energy shortages. I examined regulations addressing the 2000 energy crisis, the 2020 rolling blackouts, and the SONGS closure and used my findings to assess California's regulatory plan for DCPP's retirement. Lastly, I used my findings to propose policy suggestions to address ongoing challenges to California's electricity grid as the state continues to transition to a zero-carbon energy sector.

California's regulatory boards

California has established three governing institutions to ensure that the state's energy is safe, affordable, reliable, and clean: the California Energy Commission (CEC), the California Public Utilities Commission (CPUC), and the California Independent System Operator (CAISO). The CEC serves as the primary planning agency that drives most of the state's energy policies. It has regulatory authority over California's 55 Publicly Owned Utilities (POUs), including RPS enforcement. The CPUC establishes policies and sets annual procurement requirements for Load Serving Entities (LSEs). LSEs supply electricity to consumers by producing or buying electricity and include four Investor-Owned Utilities (IOU): Southern California Edison (SCE), San Diego Gas & Electric (SDG&E), Pacific Gas & Electric (PG&E), and Southern California Gas Company (SoCalGas). SCE, SDG&E, and PG&E supply around 75% of the state's electricity (EIA 2022a). LSEs also include Community Choice Aggregators (CCAs) and Energy Service Providers (ESPs), both of which are non-utility entities that provide electric services to customers within their jurisdictional boundaries. CAISO manages the transmission lines that constitute 80% of the state's electric grid and regulates the market by predicting electricity demand, and the remaining 20% are lower-voltage lines managed by electric utilities themselves (CAISO 2022). Although these three institutions are independent of each other, close collaboration is required to reach the state's clean energy goals. Recognizing how these regulatory boards interact is the foundation for understanding the process by which California creates energy policies.

California's decarbonization programs

California has developed four main programs to meet its SB 100 and SB 32 climate action goals: the Low Carbon Fuel Standard (LCFS) to address transportation fuels, the cap-and-trade program to regulate industrial emissions, the Zero-Emission Vehicle (ZEV) mandate to reduce vehicle emissions, and the RPS to reduce emissions from electricity generation. The Resource Adequacy program was developed alongside the RPS to ensure that LSEs meet their peak load with a 15% reserve margin, and the CPUC sets annual requirements for LSEs through Mid-Term Reliability (MTR) Rulings. Since the development of the RPS, California has made significant investments in renewable energy. As defined by the CEC, eligible renewable resources include biomass, geothermal, solar, wind, and small hydroelectric facilities. In 2020, California exceeded the RPS's interim target that required 33% of electricity retail sales to come from renewable sources by 3% (EIA 2022a). The largest contributor to renewable energy is solar, which produced 17% of California's in-state generation in 2021 (EIA 2022a). However, natural gas is still the state's largest contributor to in-state generation and total power mix, accounting for around half of utility-scale generation (CEC 2021b, EIA 2022a, Figure 1).

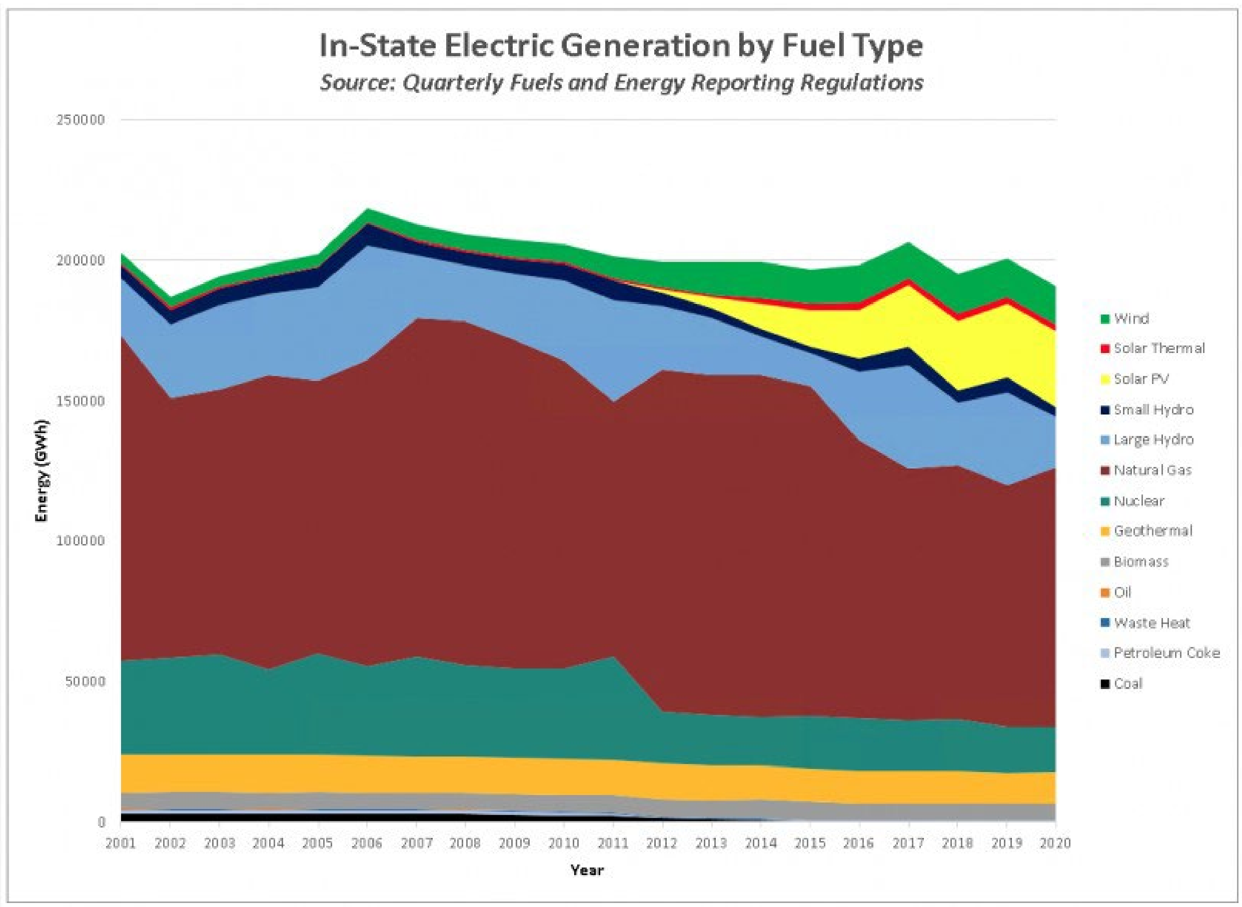

Figure 1. California's in-state energy sector from 2000-2020 (CEC 2020a)

While emissions reduction efforts in the electricity sector is mainly driven by the RPS, energy efficiency programs contribute to decarbonization as well. In 1996, AB 1890 established the Energy Efficiency Public Purpose Program, which set funding levels for research and development of energy efficiency programs (Wilson 1996). As AB 1890 began to be implemented in 1998, the CPUC transformed the market for energy efficiency by allowing private sector entities to provide energy efficiency services. As a result, energy efficiency funds were focused on product developers and suppliers rather than customers, such as incentives to design high efficiency products. After the 2000 energy crisis, the CPUC changed the regulations so that third-party implementers could be eligible for incentives and funding (Keppley 2012). In 2003, the CPUC, CEC, and California Power Authority presented the Energy Action Plan to create a unified policy that emphasizes using energy efficiency to meet the resource demands. The investment in and regulation of energy efficiency has seen high levels of success at reducing overall per capita energy demand: in 2019, despite being the second largest total energy consumer in the U.S., California's residential and commercial per capita energy consumption was the second lowest (EIA 2022a).

The Diablo Canyon Power Plant (DCPP)

DCPP is owned and operated by PG&E, who initially sought a 20-year license extension in 2009 but then decided to retire the plant in 2016. The plant is composed of two identical units with a combined power output of 2240 MW, with plans to retire Unit 1 in 2024 and Unit 2 in 2025 at the end of their respective operating licenses. The plant uses a Once-Through Cooling (OTC) system that withdraws water from the Pacific Ocean to cool the plant and then discharges the used water back into the ocean at a higher temperature. Both the water intake and thermal discharge process have negative effects on local aquatic wildlife (Casanueva et al. 2014). In 2010, the State Water Resources Control Board implemented the California Water Control Policy on the Use of Coastal and Estuarine Waters for Power Plant Cooling, which mandated 19 OTC power plants to either reduce their intake flow rate by 93% or shut down (CEC 2019). PG&E estimated that the cost to retrofit DCPP to comply with the OTC standard would exceed $4.5 billion, which was the biggest reason why PG&E decided not to pursue an extension of the plant's operating license (Bradley et al. 2016). California is currently taking steps to ensure that DCPP's closure does not cause an increase in greenhouse gas emissions.

METHODS

Quantitative data collection and analysis

First, I conducted a secondary data analysis on data collected from the EIA (Table 1). Carbon emissions are reported in thousand metric tons, generation is reported in MWh, and natural gas imports are reported in units of million cubic ft.

Table 1. Energy Information Administration datasets used for quantitative analysis.

Form Title	Page	Description
EIA State Electricity Profiles (EIA 2020)	7: Emissions	This table provides data on annual carbon dioxide emissions by fuel sources (coal, natural gas, petroleum, other total), for the reporting year for each state
EIA-923 (EIA 2021a)	1: Generation and Fuel Data	This table provides data on the monthly electricity net generation in MWh for each plant for the reporting year
International & Interstate Movements of Natural Gas by State (EIA 2022b)	n/a	This table describes the international and interstate imports, exports, and net imports by state.

I analyzed 7 plants that closed between 2000 and 2019: Crystal River, San Onofre, Kewaunee, Vermont Yankee, Fort Calhoun, Oyster Creek, and 3 Mile Island (Table 2). Remaining in-state nuclear generation refers to the nuclear energy capacity remaining immediately after the plant closure. The Vermont Yankee plant was Vermont's last nuclear plant and had a low contribution to the state's electricity grid. Furthermore, Vermont only generates a quarter of its own electricity, has a small population, and imports large volumes of hydroelectricity (EIA 2022c). These factors make Vermont drastically different from California, so I excluded Vermont from my analysis. Since the pre-2000 data is often incomplete or used different aggregation methods, I chose plants that closed after 2000 due to data availability and to maintain consistency.

Table 2. U.S. nuclear plants that decommissioned between 2000 and 2019.

Plant Name	State	Closure Date	Plant Generation (MWh)	Remaining In-State Nuclear Generation (MWh)

Crystal River	Florida	Sep 2009	7,283,669	24,047,155
San Onofre	California	Jan 2012	27,862,220	17,480,183
Kewaunee	Wisconsin	May 2013	4,646,711	9,872,471
Vermont Yankee	Vermont	Dec 2014	3,060,582	0
Fort Calhoun	Nebraska	Oct 2016	4,171,832	6,741,340
Oyster Creek	New Jersey	Sep 2018	4,538,456	26,797,808
Three Mile Island	Pennsylvania	Sep 2019	7,081,389	76,538,617

I performed a paired t-test on carbon emissions and repeated the process to examine changes in natural gas usage. I separated the data for each plant into two categories: the 12-month period before the plant closure and the 12-month period after the plant closure. This allows reasonable time for effects to occur without an abundance of confounding variables. I chose a paired t-test due to the small sample size and a one-tailed t-test since I only explored increases in emissions or natural gas imports. I performed the t-tests with a p-value of 0.05 to determine if the 'before' and 'after' groups are statistically different. The null hypothesis is that there is no significant difference between the 'before' and 'after' categories, and any observed difference is due to chance or sampling error. I examined total carbon emissions, natural gas emissions, natural gas imports, natural gas exports, and natural gas net imports.

Policy analysis

Next, I collected textual data through literature reviews, news articles, and discussions with environmental policy experts. I used Google Scholar and the UC Berkeley online library catalog to search for peer-reviewed journals. The keywords I used to find relevant sources include California energy, natural gas, clean energy transition, nuclear replacement, greenhouse gas emission reduction, 2000 energy crisis, energy efficiency, peaker plant greenhouse gas generation, and renewable energy. I focused on three cases to examine California's regulatory response to past energy shortages: the 2000 energy crisis, the 2020 rolling blackouts, and the 2021 State of Emergency.

the 2012 SONGS closure, and the CPUC Mid-Term Reliability Rulings in relation to SB 32 and SB 100. To understand the process/actors of California's energy policies, I researched how the state regulatory boards interact with each other throughout the decision-making process. I examined policy plans for 2023 to 2026 as long-term plans fluctuate greatly as they develop.

Policy analysis framework

The methods for this project were influenced by policy analysis methods that lead to a thorough understanding of the application of scientific findings to real-life issues and the results of such policies. I conducted a literature review to analyze several analysis frameworks: multiple streams, policy network, punctuated equilibrium, and policy triangle. The multiple streams approach assumes that problem identification, policy solutions, and political processes are relatively independent streams of political activity (Kingdon, 1984). Policy network analysis is based on the idea that policy is framed within a context of relationship and dependencies (Selman, 2000). This framework seeks to reveal patterns between different stakeholders. Punctuated equilibrium assumes that policies are stable over time unless disturbed by external factors and seeks to identify the external forces (Baumgartner and Jones, 2010). Lastly, the policy triangle framework assumes that an understanding of policy should be based on analysis of policy context, content, and process/actors (Walt and Gilson, 1994). The policy triangle approach allows for an organized method of analysis that allows for comparisons to be drawn across different policies. I used this framework to understand the interconnections of California's various energy policies.

RESULTS

Quantitative results

The statistical tests show that there is no significant change in total carbon emissions (Table 3). There is also no significant change in carbon emissions from coal, petroleum, and other sources. There is, however, a significant increase in carbon emissions from natural gas (NG) sources when excluding Vermont (VT) as an outlier, with a T value of 2.0206. In other words, while there was no overall rise in carbon emissions, there was an increased use of natural gas in the 12-month period after a nuclear plant closure.

While there is no significant change in exports or net imports of NG, NG imports have a significant T value of 2.8022. Total NG refers to the summation of NG imports and in-state NG generation, which has a significant T value of 2.6260. The significant T values are identified with an * sign in the table.

Table 3. T values of changes in emissions and natural gas imports before and after nuclear plant closures.

Test	Mean (before)	Mean (after)	SD	n	T Value
Total emissions	54,850	56,971	4,625	6	1.1232
Coal emissions	26,955	25,265	4,633	6	-0.8939
Petroleum emissions	1,922	1,608	353	6	-2.1787
Other emissions	889	882	13	6	-1.3531
NG emissions	25,084	29,217	5,010	6	2.0206*
NG imports	323,349,711	344,215,831	19,701,025	7	2.8022*
NG exports	336,381,029	357,510,498	39,838,986	7	1.4032
NG net imports	-21,791,692	-13,199,741	56,403,958	7	0.4068
Total NG	329,774,228	351,760,462	22,252,074	7	2.6260*

Policy analysis results

I then examined the development of California's climate, emissions, and energy policies and how these policies have contributed to California's current policies (Table 4). I found that the Integrated Resource Plan (IRP) is the overarching process for creating electricity procurement policies and programs and is the primary method for implementing SB 100 requirements (Figure 2). The IRP process repeats every two years, with the 2019 IRP marking the completion of the first cycle. CPUC's Mid-Term Reliability (MTR) decisions were previously used to establish procurement guidelines for LSEs and is now integrated into the IRP process. The discussion section will explore in depth (1) the effect of the 2000-2001 energy crisis on current energy policies, (2) a comparison between the policies surrounding the 2012 SONGS closure and the planned DCPP retirement, and (3) suggestions for California's regulatory body to address existing challenges to the energy sector. The discussion section will also explore environmental justice concerns that energy transition policies must address to ensure a just and equitable transition to a clean energy future.

Table 4. Content, context, and process/actors of California's energy policies.

Policy	Content	Context	Process/Actors
Assembly Bill 32 (2006)	Requires state to lower GHG emissions to 1990 levels by 2020. SB 32 (2016) updated AB 32, raising GHG target to 40% below 1990 levels by 2020.	Required CARB to develop a Scoping Plan, updated every five years, that lays out the regulatory plan for meeting AB 32 goals. Created cap-and-trade program.	CARB is the lead agency. The Climate Action team includes 18 state agencies and helps direct efforts to reduce GHG emissions and engage state agencies.
Senate Bill 350 (2015)	Raised renewable electricity procurement goal from 33% by 2020 to 50% by 2050. Set a 2030 target for doubling energy efficiency.	Developed IRP process to ensure that utilities take the necessary steps to reach statewide goals.	CEC is the lead agency. CARB and CPUC are involved in the IRP process, and CAISO reviews transmission line needs (Figure 1).
Senate Bill 100 (2018)	Set goal of 50% renewables by 2026. Increased the 2030 renewable energy goal from 50% to 60%. Requires all retail electricity to be carbon-free by 2045.	Carbon-free resources include renewables and natural gas with carbon capture and storage. 2045 goal states that at least 50% of retail sales are met by renewable energies.	Requires the CEC, CPUC, and CARB to create a Joint Agency Report, evaluating challenges and opportunities in implementing SB 100.
2013 Integrated Energy Policy Report (IEPR)	Mandated that SONGS capacity is replaced with both clean energy and fossil-fuel resources	IEPR decision was based on ensuring supply adequacy and mandated that replacement resources come online by 2024	CEC prepares IEPR biennially to identify and solve the state's energy needs.
OTC Regulation Policy (2010)	Mandated 19 OTC power plants to either reduce their intake flow rate by 93% or decommission.	In 2019, State Water Board amended the policy to extend operating licenses for four natural gas plants.	State Water Board finalizes decisions on OTC plants proposed by CPUC.
CPUC D. 21-11.008 (2021)	Decision approved increase of Aliso Canyon's underground storage capacity.	This decision bypassed previous CPUC limitation on Aliso Canyon's capacity after a 2015 leak released 100,000 tons of methane.	CPUC, Aliso Canyon

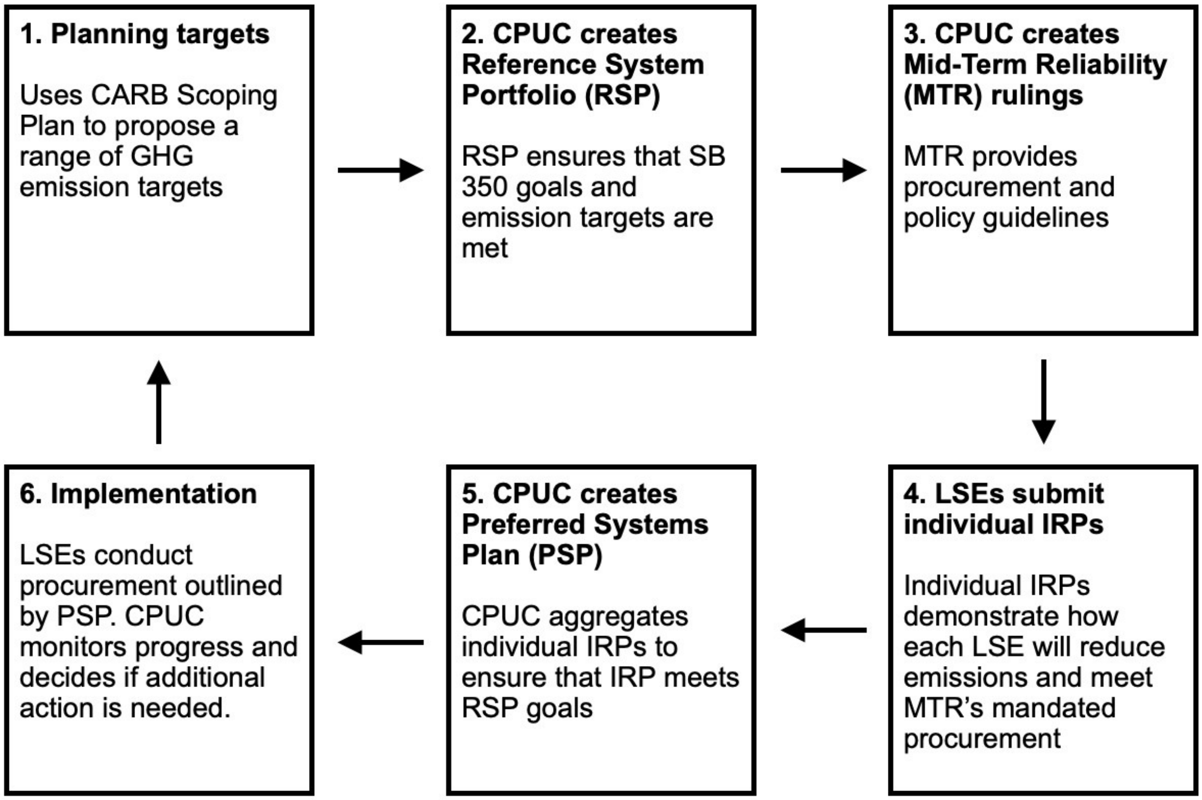

Figure 2. Process and actors of Integrated Resource Plan (IRP) process.

California's response to energy shortages

I examined the 2000-2001 energy crisis, 2020 rolling blackouts, and the 2021 State of Emergency to identify persisting issues of the energy sector and identify patterns in California's response to energy emergencies. I found that regulations repeatedly grant exemptions for fossil fuel sources to address energy shortages and revealed a pattern of dependency on natural gas generators to meet baseload demand. In 2019, the State Water Board extended the OTC license for four natural gas plants to ensure system reliability because of the unforeseen retirement of 640 MW in 2018 and planned retirement of 680 MW in 2019 (Fitzgerald et al. 2020). These gas plants were originally slated to retire due to the State Water Board's OTC regulations, implemented in 2010, to reduce the amount of marine water that coastal plants use in their cooling systems. With regards to DCPP, PG&E directly referenced the cost of retrofitting the plant to comply with OTC regulations as a deterrent to the utility's decision to renew DCPP's operating license (Bradley et al. 2016). This inconsistency reveals that regulators do not uphold fossil-fuel energy sources to the same standards as other resources. Moreover, when the Encina Power Plant was retired as planned due to its non-compliance with OTC standards, it was replaced by a 525 MW peaker plant (CEC 2015). This is an example of treadmill decarbonization, as one source of fossil fuel was replaced by another. I also found that the 2019 MTR prohibited the development of new natural gas plants but failed to restrict the operation or expansion of existing gas plants (CPUC 2019a). This finding shows that regulatory exemptions for natural gas generators preceded the 2020 rolling blackouts.

Regulatory response to the 2000-2001 crisis

California responded to the 2000-2001 energy crisis with an unprecedented series of demand-side policy initiatives; $1.3 billion was allocated for demand reduction initiatives, of which $900 million was invested in energy efficiency programs (EIA 2005). Since then, per capita GHG emissions have dropped 24% from the 2001 peak of 14.0 tons per person to 10.7 tons per person in 2018 (CARB 2020). To address supply shortages, California increased its dependence on peaker plants to meet peak electricity demands; the number of peaking plants grew from 29 in 2001 to 74 in 2020 (Roy et al. 2020). Peaker plants have higher greenhouse gas emission rates per MWh generated than baseload natural gas plants and are disproportionately used on poor air quality days, further exacerbating poor air quality conditions (De Gouw et al. 2014, Casey et al. 2016). Although the demand-response policies were effective and California mitigated the crisis, the energy shortage problem was not adequately addressed.

2020 rolling blackouts

Despite the steps taken to stabilize the energy sector since 2000, extreme weather conditions and a lack of adequate planning caused rolling blackouts in 2020 for the first time since the 2000-2001 crisis (Batjer et al. 2021). As climate change persists, extreme weather events will become more frequent and intense, so it is essential that CPUC's demand forecast system is updated to address issues before they arise. In November 2020, CPUC began phase 1 of its 2021 MTR ruling with the main goal of ensuring reliable electric service in case of an extreme weather event in 2021. The main result of this proceeding is that CPUC ordered IOUs to respectively procure 1000 MW and 1500 MW of additional resources for summers 2021 and 2022 (CPUC 2021a). Although the MTR avoided rolling blackouts amid 2021's record-breaking heat dome, the mandated resources were procured using existing peaker plants and an increase in capacity of existing natural gas capacity, neither of which is prohibited by the language of the 2019 PSP. CPUC's approval to increase the Aliso Canyon underground storage facility is particularly concerning. CPUC set a limitation on the facility's storage capacity following a 2015 leak that released over 100,000 tons of methane, and after the leak was permanently plugged, the plant had been operating at 50% capacity (CARB 2016). In 2021, the CPUC board voted unanimously to increase the facility's storage capacity by over 20% (CPUC 2021b). Despite implementing this increased capacity as an interim solution, the CPUC did not specify a timeline for the re-evaluation of this decision.

As a result of these regulatory actions, California's carbon emissions due to electricity generation increased from 40,874 thousand metric tons in 2019 to 43,444 thousand metric tons in 2020, which was the first increase in emissions since the 2012 SONGS closure (EIA 2022a). This increase in emissions cannot be attributed to the increased residential electricity consumption due to the COVID-19 pandemic, as both overall consumption and transportation emissions decreased from 2019 values (CEC 2020b).

2021 State of Emergency

In July 2021, Governor Newsom proclaimed a State of Emergency to address California's projected peak-period shortage of 3500 MW in 2021 and 5000 MW in 2022 (Newsom 2021). The proclamation allowed the construction of new emergency natural gas generators greater than 10 MW, exempting them from environmental regulations set by the California Environmental Quality Act. As a result, four new plants contributing 1200 MW have been constructed on top of the extended OTC licenses of four gas plants contributing 3750 MW (Fitzgerald et al. 2020, Fooks et al. 2021). The operating license of these new plants are valid for up to 5 years, extending past DCPP's planned closure in 2025, and all four plants have received operating licenses for the maximum allowed length. There is no language in the CPUC's MTR or CEC's License Approvals that restrict seeking license renewals, and regulators have not proposed proceedings to address license expiration. Furthermore, since these new gas plants were constructed under an emergency proclamation, they are not included in the PSP or MTR. This allows the CPUC to state that it has replaced DCPP with entirely new resources even if these plants continue to operate. Lastly, in September 2021, the DOE approved a 60-day request to exempt six gas plants from the National Ambient Air Quality Standards set by the Clean Air Act, thereby allowing the plants to operate at maximum output without regard to federal emission limits (Turk 2021). If energy shortages persist, California might continue exempting fossil fuel plants from environmental regulations to achieve grid reliability. Continued reliance on fossil fuels to supply base-load power will hinder California's realization of a zero-carbon energy sector.

Comparison between SONGS closure and DCPP's planned retirement

To understand how California's response to past energy emergencies have affected policies planning for the state's energy future, specifically in relation to DCPP's replacement energy, I analyzed the SONGS closure, the 2019 and 2021 PSPs, and the 2013 to 2021 MTRs. It is essential to identify and learn from the shortcomings of past regulations, so I compared the regulatory response to the SONGS closure and the approach to planning DCPP's replacement. I found that the lag time from ordered procurement to availability of a replacement resources might cause an immediate increase in natural gas reliance and identified three issues to regulators' approach to sourcing DCPP's replacement energy. I then focused on near-term policies because my initial analysis suggested that the five-year period from 2023 to 2026 will be a critical transition period for California's electric grid. The scheduled retirement of 6,000 MW of natural gas plants and DCPP in this period might exacerbate ongoing problems of resource adequacy, especially in conjunction with the state's continued efforts to achieve its SB 32 and SB 100 goals (Fooks et al. 2021). I found that California's policies are unlikely able to guarantee the availability of replacement resources before DCPP's planned retirement, and instead, continue using natural gas generation to address projected energy shortages.

My findings suggest that DCPP's clean replacement energy needs to be online before the plant is retired to prevent a similar rise in carbon emissions and fossil fuel reliance caused by the SONGS closure. After the initial equipment failure at SONGS, CPUC had a year to decide on the permanent closure of the plant. As such, there were limited plans preceding the SONGS closure for replacement energy. I examined policies after the closure and found two factors contributing to the immediate rise in natural gas usage. First, regulations permitted the replacement of SONGS energy with natural gas energy. The CEC's 2013 IEPR decided to replace SONGS' 2300 MW capacity with clean energy and storage (50%) and fossil-fuel resources (50%) (McAllister et al. 2013). The IEPR based this decision on ensuring supply adequacy, further supporting my interpretation that California heavily relies on natural gas energy to account for baseline production. Second, the delay between the closure of SONGS and the arrival of replacement resources exacerbated the need to rely on natural gas energy while waiting for the integration of new clean sources. Following the decisions set by the IEPR, the 2013 MTR set an energy storage target of 1325 MW, ordering IOUs to secure the resources by 2020 with installations completed by 2024 (CPUC 2013). This exposed a troubling lag time between the order, procurement, and installation of new resources, as the energy storage systems will not be available until a decade after the closure of SONGS. My analysis suggests that California must consider these two factors when planning for the replacement of DCPP.

DISCUSSION

I investigated California's energy policies regarding DCPP's decommissioning to determine if the policies sufficiently address concerns about potential increases in carbon emissions and natural gas use. I first examined past nuclear plant closures to determine whether an increase in natural gas usage is a justified concern for DCPP's planned retirement. My analysis supported my hypothesis that nuclear energy is often replaced with natural gas energy. Next, I explored California's regulatory response to past energy crises and how these responses have influenced plans to obtain replacement energy for DCPP. My findings revealed repeated instances of increased natural gas reliance due to energy shortages that might threaten California's ability to replace DCPP's energy with entirely clean resources. I observed this pattern through my investigation of the 2000 energy crisis, the 2020 rolling blackouts, and the 2012 SONGS closure. This pattern also raised concerns for California's future energy sector and suggested that careful planning is needed to achieve the state's bold SB 32 and SB 100 goals, especially when a large source of zero-carbon electricity will no longer be available. Based on the findings of this study, I proposed policy suggestions to address California's ongoing challenges of grid reliability and resource adequacy.

Potential impacts of DCPP's closure on carbon emissions and natural gas imports

While it is difficult to predict an exact value of carbon emissions after DCPP's closure, I examined past nuclear plant closures to identify potential trends. My analysis of carbon emissions revealed that natural gas emissions were the only emissions source that had a statistically significant increase (Table 3). Previous studies found that nuclear energy generation provides clean stable energy that is essential to achieving carbon emission reduction goals (Ghanadan and Koomey 2005, Greenblat 2015, Kim 2020, Aborn et al. 2021). While my results were unable to fully support these previous studies, they suggest a trend of replacing nuclear plants with natural gas generators and natural gas imports. Moreover, the varying effects of nuclear plant closures on total emissions emphasize the need for a robust policy plan to address changes in the electricity grid.

I then investigated natural gas imports. EIA does not report data on the type of imported electricity (whether the electricity was generated from solar, natural gas, etc.) or geographic source of imports (where each state is receiving electricity from), which could have been used to estimate the profile of imported electricity. While there is data on total electricity imports, examining imports without consideration of the type of electricity imported does not lead to a productive discussion on the effects of nuclear plant closures. EIA does, however, report total natural gas imports. While this is not a precise analysis, this approach can provide a baseline for comparison. This is further justified since I focused my qualitative analysis on California; California imports almost all its natural gas, and electricity generation constitutes the largest end-use of natural gas imports (EIA 2022a).

My analysis of natural gas imports showed a significant rise in both imports and total natural gas, which strengthens the suggestion that nuclear energy is often replaced with natural gas energy (Table 3). This result supports previous findings that shuttering nuclear energy sources might lead to increased usage of natural gas (Ghanadan and Koomey 2005, Labriet et al. 2008, Long 2011, Adler et al. 2020).

Overall, the results of my quantitative analysis suggest a pattern of increased reliance on natural gas, and in turn, increased carbon emissions from natural gas generation after nuclear plant closures. To ensure that DCPP's closure does not follow this trend, it is imperative that California's energy policies address past and ongoing issues in its energy sector.

Policies acting on California's energy future

I found that the lag time from ordered procurement to availability of a replacement resources might cause an immediate increase in natural gas reliance and identified three issues to regulators' approach to sourcing DCPP's replacement energy. My analysis also revealed that there is a potential delay between the closure of DCPP and the arrival of replacement resources that might allow for a higher reliance on natural gas energy. This reliance is further exacerbated by the regulating institutions' deferred decision on natural gas eligibility towards future procurement requirements.

Underlying issues of the DCPP replacement plan

I found three core issues in California's approach to securing clean replacement energy sources. Since the approval of DCPP's decommissioning in 2018, California's regulatory entities have assessed DCPP replacement plans as part of the IRP and PSP process. While the use of NQC in this process guarantees a replacement of DCPP's capacity, and by extension grid contribution, it does not ensure a replacement of DCPP's zero-emissions energy. The 2019 PSP suggested that emissions requirements for DCPP's replacement will be met if California meets its 2030 emissions reduction goal. However, this approach focuses on a snapshot of 2030 emissions and overlooks cumulative emissions throughout the next decade. Lastly, this approach also disregards avoided emissions of DCPP's continued operation. A robust replacement plan should pursue furthered emissions reductions; Aborn et al. (2021) estimated that emissions savings could reach 35 Mt between 2025 and 2030, but PSPs neglect to include those projected savings in its emissions reduction goals. Overall, regulators must recognize the potential impacts of DCPP's decommissioning and develop a plan that pertains specifically to the plant.

Potential time lag between DCPP's retirement and the arrival of replacement resources

The 2021 MTR ordered the additional procurement of 11,500 MW to come online incrementally between 2023 and 2026, with over 10,000 MW expected to come from battery energy storage systems (CPUC 2021c). While battery storage systems will be essential to achieving grid reliability, expanding storage systems alone will not achieve a zero-carbon future. Specifically regarding DCPP, the MTR ordered the collective procurement of 2,500 MW of zero-emission resources, generation resources paired with storage, and demand response by 2026 to ensure that the replacement of DCPP's output does not cause an increase in GHG emissions. In January 2022, PG&E proposed nine new battery storage totalling 1,600 MW to come online by 2026 (PG&E 2022). PG&E has not yet accounted for the 700 MW gap between the proposed projects and the 2,300 MW of storage it is required to procure under the 2021 MTR. Moreover, IOUs cannot count MTR procurement requirements towards the PSP, so PG&E has yet to secure sufficient resources for the replacement of DCPP under the PSP. Lastly, although the MTR sets the procurement deadline for 2026, LSEs will not incur penalties for insufficient procurement until 2028 (CPUC 2021c).

As observed from the SONGS closure, even a one-year lag time between the closure of a zero-carbon energy source and the integration of clean replacement resources led to an increase in natural gas production. The SONGS closure also illustrated the lag time between the order and integration of new sources, specifically battery storage project. The potential lag time might be aggravated by unpredictable events that disrupt global supply chains, such as the COVID-19 pandemic. Based on the cumulation of these factors, I found that California's policies are inadequate in ensuring the timely arrival of replacement resources.

Natural gas eligibility towards replacement procurement requirements

My investigation of past MTRs revealed that the CPUC has continuously postponed deciding on natural gas eligibility issues (CPUC 2019b, CPUC 2021a). Similarly, the 2021 MTR deferred deciding on whether natural gas resources, including modifications to existing natural gas plants, qualify towards any MTR requirements. Despite CPUC and CEC's finding that zero-emitting resources are not less reliable than thermal resources, both agencies state that nearly the entire natural gas fleet must be retained through 2045 to provide contingency options (Fooks et al.

2021). Both agencies referenced the risks of battery storage projects when justifying the use of natural gas but do not address risks in ageing natural gas infrastructure. The MTR was incorporated in the 2021 PSP, which adopts a 35 million metric ton 2032 GHG target, equating to 73% of the RPS and 86% GHG-free resources by 2032 (CPUC 2021d). Currently, the PSP proposes that existing natural gas resources, including the new gas plants constructed under the emergency proclamation, are retained through 2045 with an additional 0.9 GW to meet reliability requirements. CPUC has again postponed a definitive decision on natural gas eligibility and is awaiting further analysis in coordination with CAISO, which the board hopes to incorporate in the 2022 IRP process. However, California's habit of relying on natural gas to address energy shortages is unsustainable, both in terms of its transition to clean energy and long-term viability of using ageing generators. During 2021 heat-dome and peak temperature period from June 17 to June 18, three of the four plants with extended OTC licenses were forced offline due to the high temperatures, two of which were previously inoperable during the 2020 rolling blackouts as well (CAISO 2021). The Redondo Beach Plant was then granted a second extension of its operating license to 2023 (Fitzgerald et al. 2020). My analysis of policies addressing California's energy future revealed a similar finding to my analysis of California's response to emergency crises: the state continues to rely on natural gas plants to address energy shortages while exempting these plants from environmental regulations.

Overcoming challenges and policy suggestions

California's experience with energy crises has placed the state in a unique position to learn from past regulations to develop careful plans during its transition to renewable energy. I found that emphasizing energy efficiency and demand response services can achieve long-term deep reductions of energy consumption while freeing up capacity for other sectors to decarbonize through electrification. With intensifying droughts, heat waves, and wildfires increasing risk to transmission lines, California cannot rely on imported electricity from neighboring states, thus elevating the urgent need to achieve grid reliability. As the state continues its transition to renewable energy, regulatory bodies need careful planning to ensure resources are available to meet changing grid management needs.

California's regulatory bodies should ensure that energy efficiency investments continue. Despite leading the nation in energy-intensive industries, such as agriculture and manufacturing, California has the second lowest per capita residential energy consumption in the United States (EIA 2022a). The combination of CPUC programs, appliance efficiency standards, and building energy codes continue to observe substantial energy savings. Studies have proven that energy efficiency will be a key aspect of the global transition to clean energy, and California can serve as a model (Geller et al. 2006, Vine et al. 2006). Studies have further accredited the restoration of grid reliability following the 2000-2001 crisis to California's massive investment in energy efficiency (Kushler and Vine 2003, Kushler et al. 2003). While the combination of CPUC programs, appliance efficiency standards, and building energy codes continues to cause substantial energy savings, future PSPs should include incentives for LSEs to enhance existing energy efficiency programs, such as the creation of an emergency load reduction program to pay customers on demand response performance.

California's energy goal dictates an unprecedented share of renewable power, primarily through solar, wind, and long-term storage. The intermittent nature of solar and wind power will present grid system challenges, and the balance between supply and demand will likely depend largely on demand response services (Stram 2016). Demand response has the potential to increase grid flexibility, maintain grid stability, and deliver economic benefits to customers by effectively managing peak loads. Enhanced flexibility can minimize projected curtailment. From inadequate planning that caused the 2020 rolling blackouts, it is evident that California must develop a more accurate demand model. California's 2022-2023 budget allocates $7 million to the CEC to improve energy modelling (Newsom 2022). Since CEC's California Energy Demand Forecast system is relied upon statewide for both CPUC's procurement and ISO's transmission planning, improving the system is the first step to implementing demand response programs. CPUC should also increase the targeting of demand response to times and locations of greater value to serve grid needs (Alstone et al. 2005). However, demand response programs will directly affect consumers' utility bills. Meaningful stakeholder engagement is critical to the long-term success of California's climate mitigation plans.

Stakeholder engagement and environmental justice

California's energy transition will introduce greater uncertainty and require more flexibility, and stakeholder participation can be critical in ensuring the quality of long-term policies. I found that continued reliance on peaker plants will have disastrous impacts on air quality, as half of the plants are in disadvantaged communities defined by the CalEnviroScreen as the 25% most environmentally overburdened census tracts (PSE 2020). These communities experience disproportionate pollution burdens from exposures and environmental effects (OEHHA 2022). For example, the Pio Pico Power Plant increased the local ambient 24-hour PM10 concentration from a historic maximum background level of 14% above the 'healthy' standard to 18% (CEC 2012). I also found that the 2021 MTR has no requirement to site new sources in places where they could meet local reliability requirements or help to achieve environmental justice goals.

Public perception is an essential factor to the regulation and development of future energy portfolios. It is necessary to educate the public on the risks and benefits of different energy sources while ensuring that communities play a role in decisions concerning their health and economic well-being, and numerous studies have highlighted the importance of public outreach in energy policy development (Aczel and Makuch 2018a, Aczel and Makuch 2018b, Aczel et al. 2020). Research has also shown that public education can alter behavior and promote practices that increase energy conservation and efficiency (Karatasou et al. 2013, Lutzenhiser 2009, Allcott and Mullainathan 2010).

The energy transition is an opportunity to ensure that communities impacted by energy policies are represented in the decision-making process. California imports electricity from states that depend on coal mining on Native land; the Navajo Nation is the third largest coal miner in the U.S. (EIA 2021c). Curley (2018) revealed that an attempt to transition the Navajo Nation's energy undercut the welfare functions of the Navajo government, which is largely funded by coal extraction. This finding illustrates the importance of considering unequal power relations while shaping transitional policies. Knuth (2019) further revealed the importance of engaging with labor unions while creating blue collar jobs in the clean energy sector. The clean energy transition impacts those that depend on fossil fuels for their income, from corporate executive to working people. To ensure a just transition, impacted communities must be able to advocate for their concerns.

To improve community engagement, I found three key suggestions highlighted by past research. Firstly, technical terms should not be used in the explanation of safety and risks (Abdulla et al. 2019). Secondly, regulators should appoint long-term communications experts to develop trusting relationships with the community (Anbumozhi and Murakami 2020). Lastly, individuals should be involved in the decision-making process and retain the right to refuse policy implementation (MacArthur 2016). Furthering stakeholder involvement can bolster California's efforts in achieving greater energy efficiency while ensuring representation of communities most impacted by future policies.

Limitations and future directions

This study made several broad assumptions to limit the scope of my investigation. First, I analyzed total natural gas imports instead of imports for electricity generation. While electricity generation constitutes the largest end-use of California's natural gas imports, this may not be the case for the other states this study examined in its quantitative analysis. I also cannot conclude on the causality of the increase in natural gas emissions and imports. Moreover, I did not examine changes in total electricity imports. Since imports do not contribute to in-state emissions and imported electricity might use more fossil fuels than a state's energy portfolio, future research should consider the source of electricity imports. Second, my statistical analysis only examined the short-term trend. I limited my comparison to the 12-month period after a nuclear plant closure and did not examine whether these trends persist overtime. Third, this study only studied electricity generation policies. It is likely that heavy-duty vehicles, industrial production, and natural gas use in buildings will remain as major emission sources (Adelman et al. 2021). Future research should include analysis of policies behind past nuclear plant closures, especially to draw comparisons between states that did and did not see a rise in total emissions. The energy transition is a critical time to ensure meaningful stakeholder engagement, and future research should seek to understand what this entails with specific regard to native tribes.

Broader implications

It is worthwhile to contextualise my findings in terms of previous research. Primarily, regulators consistently rely on natural gas to address energy shortage, but the state must prioritize energy efficiency and demand response to address long-term resource procurement. My findings support previous studies that highlighted California's need for a diverse energy portfolio to overcome unprecedented challenges in the face of rising population and climate change (Ghanadan and Koomey 2005). California must address ongoing issues that caused the 2000 and 2020 energy crises, especially since extreme weather events will occur more frequently. Although studies have been conducted on the feasibility of retrofitting DCPP, it is unlikely that PG&E or CPUC will extend the plant's operating license (Dincer and Temiz 2021, Aborn et al. 2021). My study focuses on addressing policy implications under the assumption that the plant will close to highlight shortcomings in California's current regulatory approach. Furthermore, my findings reveal that dependency on natural gas is difficult to overcome, which can serve as a caution for other energy transition plans beyond the retirement of nuclear energy. However, energy transitions must be tailored to the unique circumstances of each region. As we pursue a clean energy future on a national and global scale, universal and unvarying policy plans will not address the distinctive needs of the communities they affect. California has been a longstanding pioneer in the fight against climate change. By continuing to develop bold policy plans for clean energy, California can set the precedence for a successful and just transition to a zero-carbon economy.

ACKNOWLEDGEMENTS

I am thankful to all the people who helped me complete this study. Thank you to Patina Mendez and Sangcheol Moon, for helping me develop my research questions and providing structure. Seaver Wang, Alexander von Meier, and Miriam Aczel, for the endless support and perceptive feedback. Chelsi Sparti, for the insightful discussions on SONGS and for providing me with resources. Wei Shao Tung, for the constructive feedback to improve my writing.

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