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Decentralized energy generation as a means of promoting energy resilience: A review of microgrid-focused policies and programs in a U.S. context

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Summary

Distributed energy resources (DERs) are becoming increasingly promoted as a tool for making electrical distribution and energy systems more resilient to shocks and disturbances. The reliability of energy services being provided to customers will be increasingly affected by increased intensity and increased frequency of natural disasters due to a changing climate, as well as growing concerns over cybersecurity and climate adaptation. Moreover, it is necessary to increase the rate at which the energy sector is transitioning from fossil fuels to renewable energy sources. Microgrids are a common configuration of DERs that increase the resilience of the grid and allow for the integration of renewable energy resources. Microgrid systems are also promoted as an avenue for generation of electricity in a decentralized manner, compared to the status quo of centralized energy generation. As a result, decentralized energy systems are emergent in nature and require new systems of governance, policy frameworks, and regulations. This is true even for the United States, which has a relatively high adoption of microgrid systems. However, there is variability within states on the attitudes toward adoption, rate of adoption, and standards. The relationship between microgrid-focused policies and energy resilience has not been extensively studied, with most studies addressing adoption, system management or configuration, or planning frameworks of microgrids. This research aims not only to examine the relationship between microgrid-focused policies and energy resilience, but to expand the notion of energy resilience beyond the grid functionality to also encompass socio-ecological factors, such as sustainability and vulnerability. This study examines this relationship through policy analysis (content review, content analysis, and policy intensity assessment) of U.S. national- and state-level policy documents, develops criteria for the evaluation of state-level policies, and performs an analysis of microgrid market trends for selected state case studies.

Keywords

distributed energy resources; microgrids; policy analysis; resilience; energy

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Abbreviations

Abbreviation	Full form
IHS	Institute for Housing and Urban Development Studies
DOE	U.S. Department of Energy
DERs	Distributed Energy Resources
PV	Photovoltaics
DG	Distributed Generation
CHP	Combined Heat and Power
DR	Demand Response
ESS	Energy Storage Systems
ISO	Independent Systems Operator
PUC	Public Utilities Commission
WUI	Wildland-urban Interface
PREPA	Puerto Rico Electric Power Authority
ERCOT	Electric Reliability Council of Texas
SGR	Simple Growth Rate
CAGR	Compound Annual Growth Rate
BIL	Bipartisan Infrastructure Law
CBA	Community Benefit Agreement
RPS	Renewable Energy Portfolio Standards
TFP	Transmission Facilitation Program
IOU	Investor-owned Utility
DVC	Disadvantage Vulnerable Community

1. Introduction

1.1 Background

Energy production is both a driver of climate change and a sector that holds opportunity for transformative change and mitigation of climate change impacts. According to global emissions data, the electricity and heat sector contribute more to greenhouse gas emissions than any other sector, with 15.18 billion tonnes of carbon dioxide equivalents emitted in 2020 (Ritchie, Rosado, & Roser, 2024). Changing climate at the global scale will lead to more extreme weather events and disrupt the provision of electricity to consumers, particularly those that are most vulnerable (i.e., those with medical conditions and age groups of children and elderly). Decentralization of electricity systems is one of the primary strategies in the energy transition when considering the restructuring of energy production. Yet, the undertaking of decentralization, coupled with the energy transition, will require innovations in the governance and policy surrounding the energy sector. This is primarily due to the extent of institutional changes that are necessitated by a shift from a centralized system of production to a decentralized system.

Decentralization brings additional considerations for the governance and structure of electricity systems. With decentralized production, there is a shift from consumers to “prosumers” (i.e., consumers that are simultaneously producers of electricity), which requires restructuring of the system governance due to the increased number of actors involved in production and the greater need for transparency (Brisbois, 2020). One of the implementations of decentralization involves microgeneration, or more commonly referred to as microgrids, which can operate in grid-connected or islanded modes. Increasingly, microgrids utilize renewable energy generation over diesel generators, and they also increasingly utilize more than one type of technology (i.e., solar photovoltaic panels and battery energy storage). Microgrids are promoted for their resilience benefits, including disaster resilience, climate resilience, and energy resilience (Ajaz, 2019). Furthermore, “resilience benefits of clean energy microgrids are particularly valuable in disadvantaged communities who may not have consistent access to clean, reliable electricity” (Verclas, Jones, Zitelman, & McCurry, 2023). Clean energy microgrids are supported as a solution for aiding in the energy transition and creating a more decentralized energy grid. By 2035, the U.S. Department of Energy (DOE) has the “aim for microgrids to represent essential building blocks of the future electricity delivery system to support resilience, decarbonization, and affordability” (Office of Electricity, n.d.). Moreover, microgrids have the potential to mitigate against “major power disruption events due to their ability of islanding and potential to sustain the penetration of renewables” (Hussain, Bui, & Kim, 2019). This becomes increasingly prevalent not only due to the need for carbon reductions, but also to manage the threat of increased extreme weather events due to climate change that create grid interruptions (Masrur, Sharifi, Islam, Hossain, & Senjyu, 2021).

There is a deficit in academic literature and empirical examples of decentralized electricity governance, in part due to the evolving nature of these systems and in part due to the lag time of academic literature (Brisbois, 2020). Therefore, there is a need to further study how government is facilitating the energy transition through policy frameworks centred around microgeneration. Additionally, the United States has the highest capacity share of microgrids in the market, by country, however, there is an absence of standardized recommendations and requirements at the federal-level on what state-level microgrid policy and planning should encompass (Ajaz, 2019). With states not being held to specific federal regulation, the responsibility then falls on states’ policymakers, state energy offices, and public utility commissions to establish their own rules, regulations, and requirements for program policies for safely and fairly provisioning future retail and wholesale distributed energy generation

(National Association of Regulatory Utility Commissioners, 2024). According to Prehoda et al. there are limited studies on the implementation of microgrids for resilience and the policy directed towards incentivizing microgrids for this use (Prehoda, Schelly, & Pearce, 2017). A study of empirical analysis of drivers behind microgrid adoption in the U.S. found that states with higher resilience concerns, i.e., higher frequency of natural disasters, are more likely to adopt microgrids, while environmental concerns and energy choice laws were not significant in rates of microgrid adoption (Ajaz, 2019). However, in this study, energy democracy does not consider how the presence of microgrid focused policy would impact uptake of the technology. In addition, it lacks consideration of community, or bottom-up approaches, being possible significant drivers of microgrid adoption. Energy democracy as a process can be defined as the process of resisting, reclaiming, and restructuring the energy sector to integrate more renewable resources, distributed generation resources, and local ownership of generation resources (Szulecki & Overland, 2020). When considering energy democracy as a sociotechnical transition, the policy instruments identified that highly relate to energy democracy goals of reclaiming and restructuring energy systems fall under economic institution instruments and new energy system institutions (Burke & Stephens, 2017). However, they note that the effectiveness of these policy instruments in practice need further attention, as they do not address target and plan elements of the policies (Burke & Stephens, 2017). With the lack of studies on policies aimed at microgrids, there is also a lack of investigations into the intersection of policy and the promotion of resilience through policy.

1.2 Research relevance

With microgrid uptake being promoted as a means of increasing the resilience of the grid, and as a primary method of decentralized energy production, it is necessary to assess policy that is aimed at restructuring energy systems in this manner. Additionally, there is a lack of study into the role that energy resilience plays within this policy, and in turn, how these microgrid projects impact their communities. Therefore, it is necessary to research the intersection of decentralized energy policy, microgrid installations, and energy resilience due to the increasing need of major energy grid transformations. This research will use a policy analysis of national-level infrastructure funding programs and state-level decentralized energy/microgrid policy as the method for assessing the institutional efforts put towards restructuring energy infrastructure and to what extent the policies incorporate resilience concepts and measures.

1.3 Research objectives

The objective of this research is to address how governance, through policy frameworks, can facilitate decentralization of energy production through uptake in applications of micro-generation technologies, i.e., microgrids, in a manner that increases resilience in the urban context. In pursuit of this objective, this study will address the following research questions…

1.4 Research questions

1.4.1 Main research question

How are microgrid-focused policies in the United States acting as drivers of energy resilience?

1.4.2 Research sub-questions

What are the characteristics of national-level infrastructure policies in relation to decentralized energy production? What role does national-level infrastructure policy play in promoting energy resilience?

To what extent do state-level policy frameworks support microgrids as an implementation strategy for decentralization of energy production and increasing energy resilience? How are incentivizes, standards, and regulations employed within these frameworks?

How has market penetration of microgrids changed in the period after the enactment of each state-level policy on microgrids? Do market trends (i.e., technology mix, state-level production capacity, and growth rates) reflect state policy objectives and resilience best practices?

2. Literature review

This section discusses the concepts relevant to this research study within the existing literature, academic discourse, and industry practices. First, distributed energy resources and microgrid technologies are discussed to provide background on the types, applications, and specifications of the technology in order to further discuss how the technology relates to energy resilience. Then, an overview of resilience provides background to the related concepts of energy resilience. Energy resilience is chosen for this study over grid resilience, which can be narrowly defined as the ability of the energy grid to cope with shocks and disturbances, as the nature of this study is broader in its exploration of policy measures as avenues to increase sustainability, cope with shocks, and address vulnerability within the energy system. Energy resilience is further broken down into the main sub-concepts of sustainability, coping to shocks, and vulnerability. Lastly, the relationship between policy instruments and energy policy is discussed. These discussions provide the foundation for the conceptual framework, which is introduced at the end of the chapter.

2.1 Distributed energy resources

Distributed energy resources (DERs) are characterized as small, modular, energy generation and storage technologies that typically provide less than 10 megawatts (MW) of power for on-site power generation (U.S. Department Of Energy, 2002). The technologies that are categorized as DERs include wind turbines, photovoltaics (PV), fuel cells, microturbines, reciprocating engines, combustion turbines, cogeneration, and energy storage systems. Distributed generation (DG) is an aspect of the DER paradigm that is focused on local electricity production for commercial solutions at small scales, including microturbines, fuel cells, and combined heat and power (CHP) plants; however, DG is more convenient when a small-scale cogeneration technology is used, compared to both electricity-only DG and traditional district heating (Chicco & Mancarella, 2009). In other words, DG is made more efficient through the use of renewable energy sources and cogeneration technologies (i.e., microturbines, fuel cells, and CHP). Additionally, DG provides benefits in decreased real power loss and reactive power loss, improved voltage profile, decreased fluctuations, higher load capacity, and benefits for the general public and economy (Shukla, Mukherjee, & Singh, 2024). Microgrids further fit into the paradigm of DER as they are local generation and distribution systems that integrate multiple DERs into the electricity grid, while having the ability to be connected or disconnected to the main distribution system (Chicco & Mancarella, 2009).

2.2 Microgrids

2.2.1 Types

The U.S. Department of Energy defines a microgrid as "a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid" (Duke Energy Sustainable Solutions, 2021). Within this entity, there can be a mix of different energy generation technologies, presence or absence of battery energy storage, and different types of grid connection, operation, and management schemes. The categorization of microgrids is based on their grid connection, with the three main types being remote, grid-connected, and networked microgrids. These classifications are predicated on the modes in which the microgrid functions. The operational modes are either grid-connected or islanded modes, in which islanded microgrids supply power to consumers when disconnected from a utility grid, or when there is a utility grid disturbance that disrupts electricity generation (Federal Energy Management Program, 2021). Remote microgrids function entirely separate from a utility grid, effectively always operating in an islanded mode, and typically can include battery energy storage technology. Grid-connected microgrids function in both grid-connected and islanded modes through a switching mechanism, while networked microgrids are several DERs or microgrids that are connected to the same circuit segment of the utility grid at a larger scale and include community microgrids and smart cities (Duke Energy Sustainable Solutions, 2021). Of the mix of DERs utilized in microgrids, the most common technologies are CHP, hydro, solar, storage, and wind. For the purposes of this study, the primary focus is on microgrid installations that use renewable energy generation over installations that use, for example, natural gas or diesel generators.

2.2.2 Applications

Of the above types of microgrids, each serves several, similar applications. When considering remote, or off-grid, microgrids, the primary function of the microgrid is to supply power to areas that are physically isolated or lack transmission and distribution infrastructure that would connect them to the grid, either due to lack of affordability or lack of feasibility for the geography of the area. The applications of grid-connected and networked microgrids primarily relate to energy security concerns due to the nature of the typology being linked to the provision of energy when there is an outage or disturbance to the main utility grid, as well as making the grid more efficient through load shifting for demand response (DR). Additionally, these concerns of energy security are often shown through the coupling of microgrid setups with energy storage system technologies, which also allow for load shifting to meet demand during peak hours. Energy storage systems (ESS) balance power during a failure through storage of energy during off-peak hours that help maintains the stability of the electrical network (Choudhury, 2022). Through this stabilization of the electrical network, DERs and ESS assist in fulfilling the need for energy security, and thus contribute to the resilience of the electrical network. The Consortium for Electric Reliability Technology Solutions enumerates the benefits of microgrids as follows: (1) reduced GHG emissions; (2) reactive power support for voltage profile enhancement; (3) heat load integration of cogeneration; (4) decentralized energy supply; (5) subsidiary services; (6) demand response (Hirsch, Parag, & Guerrero, 2018). This paper does not provide an extensive review of all of the technical features, specifications, modelling, or optimal configurations of microgrids due to the nature of the research being conducted being aligned more with policy and resilience than the technical components of microgrids.

2.3 Resilience

2.3.1 Frameworks

There are various perspectives of resilience, particularly regarding urban resilience, as there is not a universally accepted definition. The two schools of thought surrounding resilience are divided along the primary concerns of the ability of the system to bounce back from a disturbance or disaster and the concern of the system being able to absorb change while allowing for transformative change to the system to pursue more equitable development (Amegavi, Nursey-Bray, & Suh, 2024). The latter perspective of urban resilience is representative of social-ecological definitions of resilience while the former perspective of urban resilience is representative of socio-technical resilience. For the purposes of this study, the resilience perspective that will be further developed is the social-ecological perspective of resilience, as the extent to which the transition to DER requires transformative change is higher than the sole need of returning a system to a previous state after shock. When considering definitions of resilience, Folke et al. postulate that adaptability and transformability are core components of resilience thinking as well as when fostering social change in social-ecological systems (Folke et al., 2010). There are works that further integrate resilience thinking within the context of urban climate challenges. Tyler and Moench's climate resilience framework characterizes system resilience in terms of flexibility and diversity, redundancy and modularity, and safe failure. Within these general characteristics, it is further developed how agents and institutions shape system resilience by "building agent capacities, strengthening systems and reinforcing institutions that link agents and systems" (Tyler & Moench, 2012). However, when this framework is applied in practice, it should be tailored to the local context. Policy and the planning process could also be a means of developing indicators of urban climate resilience, as seen in Tyler et al., with cities utilizing the elements of the urban climate resilience framework in order to develop indicators that suit the local context (Tyler et al., 2016). With this in mind, this study will compile a set of indicators related to energy resilience.

2.3.2 Energy resilience

Energy resilience is a subset of urban resilience that arose due to an increase in the attention towards the vulnerabilities of energy systems from the threats of extreme weather events, vandalism and terrorism, and cyber-attacks. As a result, increasing the resilience of energy systems is posed as a long-term solution to coping with these threats. Furthermore, microgrids and DERs have been posed as a specific action to take to enhance the resilience of electricity systems, however, there is some contention whether microgrids in particular make the grid more resilient to disturbances and disasters due to the discrepancy in materials and maintenance directed towards the centralized grid (Ajaz, 2019). Despite this, there is still validity in considering microgrids impact on energy resilience, as the academic discussion surrounding microgrids centers on their disaster mitigation and resilience benefits as key drivers for microgrid uptake.

Gatto and Drago define energy resilience as "the ability of an energy system to retain, react, overcome, and overpass perturbations caused by a shock in economic, social, environmental and institutional terms, coming from the learning capacity to adapt to change" (Gatto & Drago, 2020). This definition captures the normative understanding of resilience as applied to an energy system experiencing shocks, however, it makes no mention of system change or capacity for long-term transformative change. Resilience is also closely related to vulnerability, as vulnerability can be used as a proxy for resilience. Resilience in energy policy is tied to vulnerability due to vulnerability acting as a proxy for sustainability and future sustainable development (Gatto & Busato, 2020). In this regard, transformative change of energy systems is addressed by coupling vulnerability and long-term sustainability needs. However, this relationship is somewhat implicit and should be more explicitly expressed within theoretical definitions. In this paper, energy resilience will be defined as follows: *the ability of an energy system to adapt to shocks and disturbances, retaining the necessary functions of the system, while allowing for transformative change of the system to facilitate long-term sustainable development*. Energy resilience within this paper will be captured by the following three dimensions: sustainability, coping with shocks, and addressing vulnerability.

2.3.3 Sustainability and DERs

Affordable, clean energy is driven by clean energy technologies, as well as institutional factors. This is the case when considering the energy transition and path dependence. Path dependence constrains the future options and decision-making choices of the energy system due to technological lock-in, as well as by the decision-making of actors that prefer to uphold the status quo of fossil fuel production and consumption (Cherp, Jewell, & Goldthau, 2011). Lock-in and sunk costs of infrastructure mean that changes to energy systems will have to work against these forces in order to undergo a transition (Loorbach, Frantzeskaki, & Avelino, 2017). That is why the energy transition and the DER paradigm require advance decision-making that favors renewable energy resources, as current decision-making will result in sunk costs and feedback loops that will impact long-term sustainability. As a result, sustainability of microgrid projects is impactful to not only current communities and populations, but to future populations as well.

Within the U.S. Department of Energy's Combined Heat and Power and Microgrid Installation Database, the types of technologies in microgrid installations include the following: CHP, biogas, diesel, fuel cell, hydro (hydroelectric power facility), natural gas, solar (photovoltaic, or PV, solar panels), storage (energy storage technologies), wind (wind turbines), and advanced controls. The technologies that are categorized as renewable energy sources include solar, hydro, and wind. Alternative energy sources include biogas and fuel cell, although some studies classify biogas, or bioenergy, as a renewable resource. For trends within renewable energy resources from 2010 to 2020, solar and wind have significant increasing trends, hydropower contributes the largest portion of renewable energy capacity despite having a low growth rate, and bioenergy and geothermal energy have insignificant contributions since 2010 (Ang et al., 2022). Non-renewable energy sources include diesel and natural gas. CHP is a specific configuration for energy generating technologies, in which energy generation is made more efficient through capturing the heat produced in the energy generation process for use in residential or commercial heating. CHP avoids heat waste and distribution losses, and by doing so, can achieve efficiencies of over 80 percent, compared to 50 percent for conventional technologies (US EPA, 2015). Storage is not a generative technology, but when combined with renewable generation, it helps to mitigate the variable nature of renewable DERs by helping to manage electricity generation and demand (Hirsch et al., 2018). As a result, battery energy storage is a key factor in sustainability of microgrids, as it allows for renewable energy generating sources to be more reliable.

2.3.4 Coping with shocks

Energy security is distinguished from energy resilience as energy resilience is concerned with the resilience of the entire grid system, whereas energy security and coping with shocks is concerned with the accessibility of energy to consumers, critical functions, and maintaining functionality of grid systems during disturbances. The culmination of these functional needs can be summarized as the reliability of the service. Microgrids capacity to island increases reliability of electricity service, as they can continue to supply power to customers, in the case of an outage, or can separate distribution in order to isolate a fault in the system (Uddin et al., 2023). The inclusion of storage within the microgrid system also allows for increased reliability of the system itself. Disaster mitigation is another aspect of coping with shocks, as one of the major threats in terms of disruption of energy services is natural disasters. In the process of disaster response and recovery, microgrids can power critical infrastructure as well as temporary housing units. According to Shahzad et al., "microgrids can power critical infrastructure such as hospitals, emergency shelters, and communication systems, ensuring these services can operate even after a disaster" (Shahzad et al., 2023). This helps to mitigate how widespread the impacts are in areas coping with natural disasters.

2.3.5 Vulnerability

Social vulnerability is linked to the existing social, economic, and demographic conditions of different social groups, oftentimes relating to the capacity of such groups to cope with natural disasters (Bronfman, Nikole, Castañeda, Cisternas, & Repetto, 2024). These same conditions of social groups are also linked to social equity. A study by Meerow et al. develops an equity framework to assess social equity in urban resilience planning (Meerow, Pajouhesh, & Miller, 2019). The framework uses distributional, recognitional, and procedural dimensions of justice to analyse the equity of resilience planning policies. The distributional dimension of social equity is concerned with the equitable distribution of goods, services, and opportunities, while the interrelated procedural and recognitional dimensions concern the acknowledgment of different groups and the equitable participation within decision-making processes (Meerow et al., 2019). One additional dimension to this framework that is important to address is the structural dimension of social equity, in that structural inequities should be addressed to ensure that transformative and lasting change is taking place. This aligns with concerns that resilience policy and literature do not challenge the status quo, and can even reinforce systems that are socially or environmentally harmful (Béné et al., 2018). As a result, it is necessary to acknowledge that transformative change and adaptive capacity should be addressed through a resilience lens, as well as which groups benefit from resilience (Béné, Wood, Newsham, & Davies, 2012).

Decentralized energy systems have been promoted as an intervention for increasing energy access (Cherp et al., 2011). When considering microgrid installations specifically, disadvantaged communities can benefit from the clean and reliable provision of electricity that microgrids can offer. Disadvantaged communities can be vulnerable to power disruptions or outages, as well as have slower recovery times in the event of disturbances (Verclas et al., 2023). Microgrid benefits to disadvantaged communities are thus connected to the site selection process of microgrids. It is necessary to have an institutionalized process in which vulnerable populations are involved in the site selection process as well as the participatory planning process of the microgrid (Chalaye et al., 2023). Accessibility and affordability are also components of energy resilience and vulnerability. Accessibility considers access to energy services, and affordability expands upon access to consider meeting one's energy needs at an affordable cost as well as the ability of communities to invest in energy projects (Sharifi & Yamagata, 2016). Thus, microgrids can potentially integrate clean, accessible, affordable, and more reliable energy sources for vulnerable or disadvantaged communities.

2.4 Energy policy instruments

2.4.1 Policy instruments

Table 1: Energy policy instruments

Instruments	**Definition**	**Tools**
Regulatory context	Contextual foundation for future energy systems change	*Statutory priority of demand reduction and DG* *Net metering and virtual net metering* *Renewable energy standards* *Participatory planning* *Community choice aggregation* *Community benefit agreements*
Financial inclusion measures	Financial measures and incentives aimed at energy systems change	*Feed-in tariffs* *Subsidies* *Financing and repayment programs* *Revolving loan funds* *Public bonds* *Carbon tax-and-invest* *Cap-and-dividend* *Cooperative financing*
Economic institutions	Community economic development opportunities and new socioeconomic institutions	*Community energy* *Renewable energy cooperatives* *Remunicipalization* *Green public service banks*
New energy system institutions	Institutional reforms of the energy sector	*Energy investment districts* *Microgrids and democratized grid management* *Energy regions* *Sustainable energy utilities*

Table 1 is based upon the findings of Burke & Stephens (2017). This work and its findings developed a conceptual lens in which policy instruments advance the goals of the energy transition and energy democracy, which involves resisting, reclaiming, and restructuring the energy system (Burke & Stephens, 2017). The table shows the types of policy instruments with their respective definition and specific policy tools. The main instruments identified include regulatory context, financial inclusion measures, economic institutions, and new energy system institutions. The goals that these tools aim to achieve include resistance of the dominant energy agenda, or shifting away from the fossil fuel industry, reclamation of the energy sector, or the localization and democratization of energy production and consumption, and restructuring of the energy sector, or movement of the energy sector away from a profit-based system (Burke & Stephens, 2017). These instruments and tools are most relevant to the policy at the national level, as they involve not only consideration of local contexts, but also require major institutional reforms.

2.5 Conceptual framework

Figure 1: Conceptual Framework

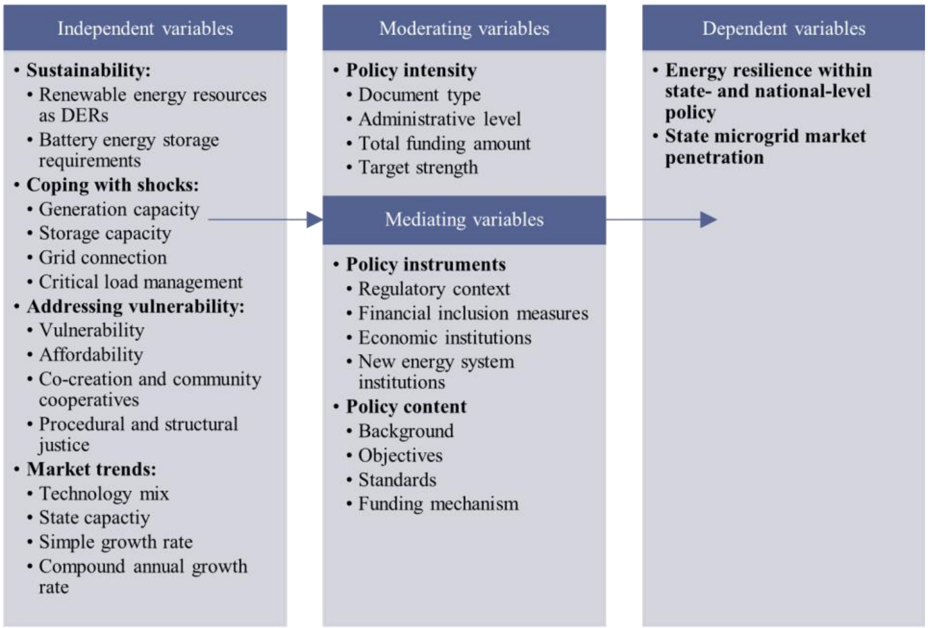


Figure 1 shows the relationships between the variables within this research. This research explores how proxies for sustainability, coping with shocks, addressing vulnerability, and market trends (independent variables), which are moderated by the intensity of the policy (moderating variables) and mediated by the policy content and instruments (mediating variables), facilitate aspects of energy resilience and state microgrid uptake (dependent variables) in U.S. microgrid-focused policies. It is necessary to determine how the policies integrate renewable energy resources as the generation sources of the DERs, as well as whether they require battery energy storage. This is an important factor due to the sunk costs of energy infrastructure once constructed, the need to prevent exacerbation of climate change impacts linked to fossil fuel consumption, and for the accessibility of clean energy to local communities. This is also assessed through the technology mix within the state market. Coping with shocks is assessed through requirements surrounding minimum generation capacity, storage capacity, grid connection, and critical load management. The microgrid generation capacity is linked to how many customers can be served, the availability of storage capacity increases the reliability of the service, the increased reliability allows for service for critical loads to be maintained during a disturbance, and the grid connection also increases the reliability of the network by being able to operate in both grid-connected and islanded modes. Addressing vulnerability is assessed through the extent to which the documents prioritize vulnerable populations, affordability, co-creation and community cooperatives, and procedural and structural justice. This allows for determination of whether policy adequately addresses socio-ecological aspects of resilience, as well as equity and planning for long-term structural change of the energy sector. Total state generation capacity, simple growth rate, and compound annual growth rate assess the changes in state market trends following the implementation of the policy within each state.

The policy instruments of regulatory context, financial inclusion measures, economic institutions, and new energy system institutions influence how tools aimed at energy resilience transitions are utilized in the national-level policy. The policy content, including the background, objectives, standards, and funding mechanisms, influences how energy resilience is carried out within the state-level policy by establishing the contextual foundation of the policy. The policy intensity includes the type of document, administrative level, total funding amount, and target strength, which influences the magnitude of the policy's effect, as it is the level of government's enforcement of a policy intervention.

3. Research design, methodology

This research aims to examine the relationship between microgrid-focused policies in the U.S., at the national- and state-level, and energy resilience. This research utilized an exploratory, mixed methods approach with the inclusion of comparative case studies. The research is exploratory due to the emergent nature of decentralized energy systems and energy governance (Brisbois, 2020). National-level policy and state-level policy are examined, with case studies in California, Colorado, Puerto Rico, and Texas, to give a review of policies across different U.S. contexts. The study uses a mixed methods approach that relies on secondary data collection. The quantitative data collection relies on quantitative data from the microgrid dataset from the U.S. Department of Energy Combined Heat and Power and Microgrid Installation Databases, which is current as of December 31, 2023 (U.S. Department of Energy, 2023). The quantitative data includes the total generation capacity per state, storage capacity per state, generation or storage capacity per DER technology per state, simple growth rate, and compound annual growth rate. The qualitative data collection relies on the collection of data from state legislature policies, state legislature supplementary materials, and national-level policy documents. Within the policy analysis, content analysis via deductive coding, policy intensity assessment, and evaluation of the policies are performed. Criteria and a comparative framework are developed based upon existing policy analysis strategies in order to standardize the comparison of each policy to account for the difference in contexts.

3.1 Study context

The selected states, and territory, for conducting the policy analysis and case studies are California, Colorado, Puerto Rico, and Texas. The selection criteria for these states, and territory, involved the following characteristics: availability of microgrid policy, exhibiting significant disaster mitigation needs, and variation in state government alignment with sustainability and renewable energy technologies. There are also varying context-specific considerations that apply to each state/territory that influence future energy demands.

3.1.1 California

Within California, there is a population of 39,538,223 residents, 13,550,586 households, and has a total land area of 155, 812.8 square miles (United States Census Bureau, 2022a). California is the third largest state in the United States by area. California's power grid serves 32 million customers, and is managed by California Independent System Operators (California ISO), which manages transmission and operates a competitive, wholesale energy market (California ISO, n.d.). One of the unique characteristics of California's energy sector is that it supports the world's fifth largest economy and state policymakers have a benchmark of 100% clean energy, or carbon-free energy production, by 2045, while navigating affordability, coordination, and reliability concerns (Nikolewski, 2024). As a result, there are multiple challenges that are faced when considering the energy transition of California's power grid. Another factor that the power infrastructure and management must contend with is disturbances due to natural disasters, namely wildfires. Over the period of 2000-2016, $700 million in damages were incurred California's utilities from wildfire damages to transmission and distribution lines (Dale, Carnall, Wei, Fitts, & Lewis McDonald, 2018). This impacts not only reliability, but affordability and grid resilience. Additionally, climate change will increase wildfire risks to electrical transmission and distribution assets in Northern California due to the intensification of climatic conditions that are conducive to wildfires, which occurs in not only in the normal range of wildfires but also across areas that do not fall into historically defined risk areas (Center for Climate and Energy Solutions, n.d.; Dale et al., 2018).

3.1.2 Colorado

Within Colorado, there is a population of 5,773,714 residents, 2,384,584 households, and has a total land area of 103,610.1 square miles (United States Census Bureau, 2022b). Colorado's power grid primarily has concerns with reliability to meet growing consumer demand, as well as that the state's infrastructure needs updating within its distribution system (Boyd, 2024). The Colorado Public Utilities Commission (PUC) regulates power providers within the state, with the two investor-owned electric utilities comprising the market being Black Hills Energy and Public Service Company of Colorado, known as Xcel Energy (Colorado Energy Office, n.d.). There is an additional 22 municipal utility providers and 22 rural electric cooperatives that are not regulated by the PUC due to their operation as not-for-profit corporations. Like California, Colorado is also threatened by wildfires within the wildland-urban interface (WUI). The WUI is defined as areas where human development is located close to or located within wildland vegetation, which is susceptible to wildfires due to the flammable vegetation and the natural occurrence of wildfires within the landscape (Colorado State University, 2022). Because of the increase in population growth within the WUI, there is a greater threat to the populations within those areas to wildfire. As a result, the state has begun carrying out planned outages, or public safety power shutoffs, when there are extreme weather conditions in order to reduce the risk of wildfires (Baker, 2024).

3.1.3 Puerto Rico

Within Puerto Rico, there is a population of 3,285,874 residents, 1,598,159 housing units, and has a total land area of 3,423.3 square miles (United States Census Bureau, 2022c). Puerto Rico is a territory of the United States; therefore, the legal status of the territory differs from that of a state. Puerto Rico entered a "commonwealth" relationship with the United States, in which Congress' authorization and approval of the constitution of the Commonwealth granted Congress the power "to make needful rules and regulations respecting the territory of the United States," including foreign relations (Northrop, 1952). Puerto Rico has a government system similar to U.S. states with three independent, co-equal branches, and U.S. federal agencies, military bases, and a federal district court operates on the island; despite this, Puerto Rico does not have any voting representation within the U.S. Federal government (Price, 2022). For simplicity and the purposes of this study, Puerto Rico and the other selected case studies will be referred to as "states" within the comparative case studies due to their treatment as similar entities under the U.S. DOE. Regarding the island's power infrastructure, the electric grid is managed by the Puerto Rico Electric Power Authority (PREPA). PREPA has a history of mismanagement and under-investment, which has led a current situation where the organization is in debt and is not on track to hit targets of 40 percent renewable energy generation by 2025, the current renewable energy generation is at 10 percent as of 2024 (Flannery, 2024). Additionally, the energy infrastructure on the island continuously faces extreme weather threats, primarily due to hurricanes. In 2017, Hurricane Maria power was not fully restored for nearly 11 months, and instead of utilizing the event as a catalyst to change the management and structure of the power system, investigations found that the main change to the grid was that it became more privatized in its generation, transmission, and distribution; in 2021, private companies of LUMA Energy took over operation of electric power and transmission, and, in 2023, Genera PR took over production of electric power (Hibbert, 2023).

3.1.4 Texas

Within Texas, there is a population of 29,145,505 residents, 11,087,708 households, and has a total land area of 261,193.9 square miles (United States Census Bureau, 2022d). Texas is the second largest state in the United States. The large population and large number of households within the state mean that there are 12.6 million customers of the state's power grid. The Electric Reliability Council of Texas (ERCOT) manages the transmission grid traffic for the state's deregulated power grid, which means that they manage multiple power retailers on the open market, and ERCOT is responsible for the vital role of balancing supply and demand within the grid (Cameron, Albracht, Douglas, & Ferman, 2021). The Texas electricity grid has unique characteristics in that it is not directly connected with other regional grid systems in the U.S., faces threats from extreme weather conditions, and has a high penetration of utility-scale wind power capacity (Walton, 2023). In 2021, Winter Storm Uri created major forced outages within Texas, affecting 4.5 million people for up to four days, and resulting in the deaths of more than 200 people and damages of around $195 billion (Fischer, 2022). In the aftermath of the storm, there has been more investment and legislation supporting grid resilience and preparation for extreme weather events, however, the grid still has vulnerabilities due to its isolation and reliance on natural gas wellheads. As a result, there is increased investment in microgrids and DERs, including virtual power plants, through State Bill 2627 (Walton, 2023).

3.2 Research strategy and methods

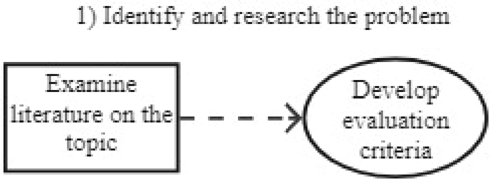
3.2.1 Policy analysis strategies

From Patton and Sawicki's six-step model of policy analysis, the basic methods of policy analysis can be distilled into the following steps: (1) verify, define, and detail the problem, (2) establish evaluation criteria, (3) identify alternative policies, (4) evaluate alternative policies, (5) display and distinguish among alternative policies, and (6) monitor the implemented policy (Patton & Sawicki, 1993). Bardach's eightfold path to practical policy analysis follows the same process as Patton & Sawicki with the addition of validating the chosen policy by presenting the findings from the analysis (Clark, 2017). Evaluation criteria should be measurable and quantifiable and typically fall into the following categories: efficacy, cost, equity, administrative feasibility, unintended consequences, sustainability, and political feasibility (Holquist, 2013). With these varying definitions of policy analysis, the outcome is that there is one policy option that is selected as the final choice for implementation.

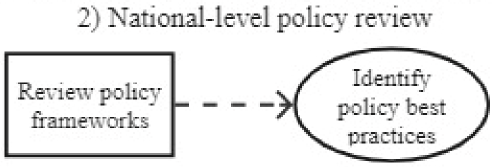
The methodology within this paper will use a combination of the models and processes for policy analysis from Patton and Sawicki, Bardach, the public health approach to policy analysis, and approaches to social equity within policy and planning. For the purposes of this paper, the policy analysis will focus on existing policy options in order to compare the feasibility, efficacy, and efficiency of policies addressing the same problem, in four different U.S. contexts. This allows for better gauging the policy framework (macro-level) and policy implementation (meso-level) in the top-down approach to the problem of the adoption of microgrids as implementations of decentralized energy solutions that aim to promote resilience. Additionally, it is not the focus of this paper to conclusively decide that one policy framework is better than the other, as the comparative nature of the work primarily allows for more insight into the strengths and weaknesses of each framework than would be gained when looking at each framework separately.

3.2.2 Process outline

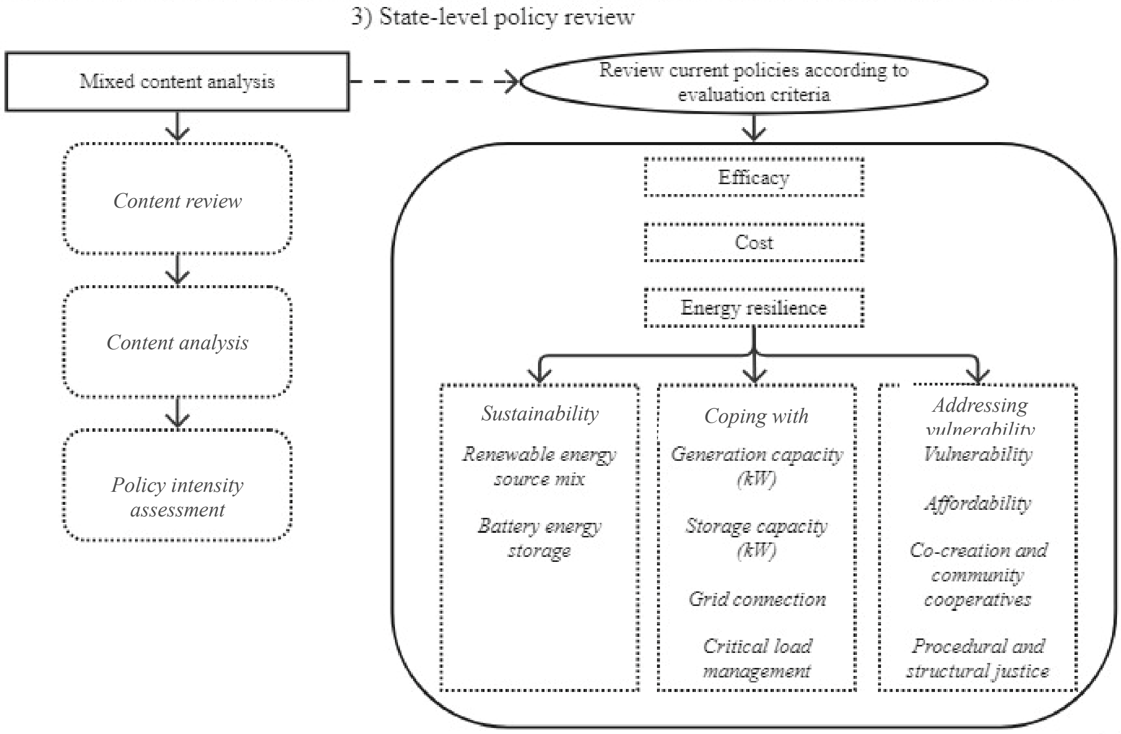
The policy analysis process involves five core steps, each with sub tasks that will be fulfilled in that step.



The policy analysis process will be grounded in the identification and research of the problem, and during this stage there will be examination of the literature on the specific topic, and it will also serve as the basis for the evaluation criteria. Chapter 2 and 3 within this paper help to establish this foundation for the evaluation criteria in Section 3.2.3.

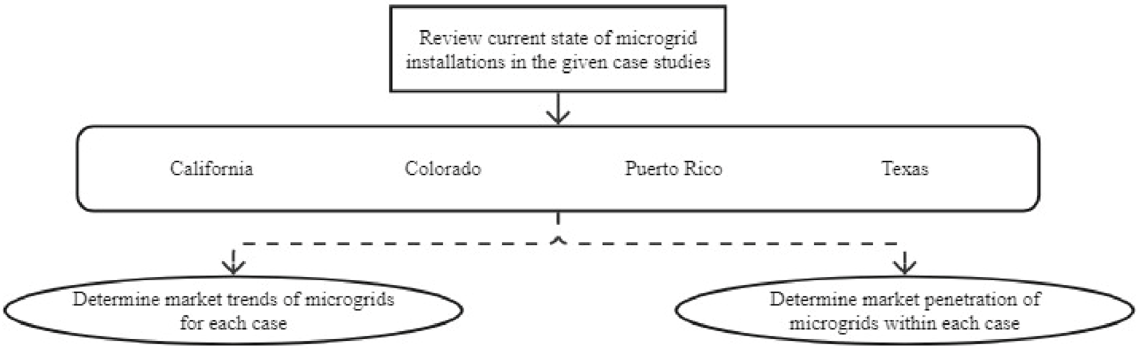


Based upon the public health approach to policy analysis, framing the analysis involves an environmental scan of current trends, literature review of the existing body of research on the given policy problem, and reviewing current policies and best practices (CDC, 2022a). The next two steps in the policy analysis process reflect this approach with the national-level policy review and state-level policy review. The national-level review will focus on regulatory context, financial inclusion measures, economic institutions, and new energy system institutions, and how federal policies could shape the state-level planning and best practices.



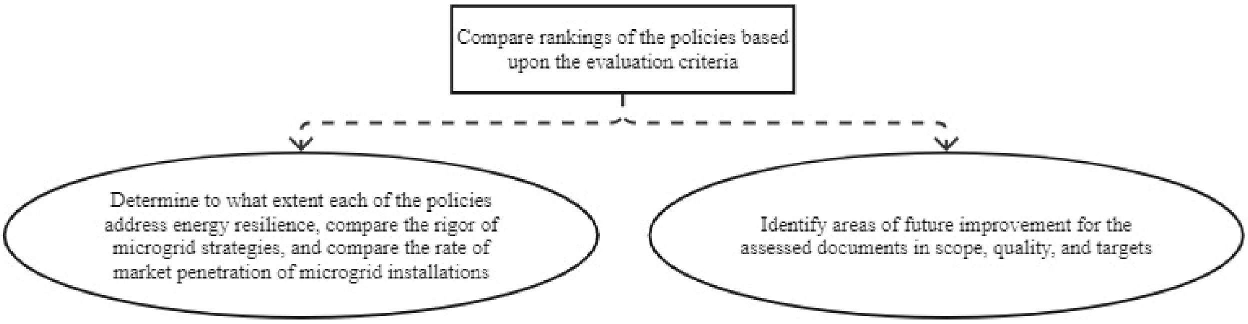
The state-level policy review will take the current policies and examine them within the context of the evaluation criteria. The state-level review will employ a mixed content analysis, which is described in Section 3.2.4, in order to examine the policy documents for best practices along with the three proxies for energy resilience: sustainability, coping with shocks, and addressing vulnerability. This will allow for a comparison of the prioritization of different objectives and proxies within the different documents.

4) Market Trends



The subsequent case studies of the market trends within each state serve to evaluate the implementation of the policy frameworks on the meso-scale. Within this evaluation, data on microgrid installations will be evaluated in order to create a profile for each state's market trends and market penetration.

5) Discussion and recommendations



The final step of discussion and recommendations allow for comparing the full results of the policy analysis and identification of areas of future improvement for each policy framework. This will allow for the determination to what extent each of the policies address energy resilience and to what extent the market trends reflect state microgrid objectives.

3.2.3 Evaluation criteria

Based upon the context of the study and the nature of these policy frameworks and directives, five evaluation criteria were selected to assess the policy frameworks. These criteria include: (1) efficacy, (2) cost, (3) sustainability, (4) coping with shocks, and (5) addressing vulnerability. Criteria focused on administrative feasibility and political feasibility were not included because these frameworks are already in effect within their respective states. Criteria for (3) sustainability, (4) coping with shocks, and (5) addressing vulnerability, each have specific indicators. The indicators for sustainability include presence of technical requirements for renewable energy source(s) as DERs and battery energy storage. The indicators for coping with shocks include the technical specifications for potential project's total generation capacity (kW), the total storage capacity, grid connection, and planning for management of critical loads. The indicators for addressing vulnerability include the expressed prioritization of vulnerable populations, affordability strategies, presence of community cooperatives and co-creation strategies, and plans for procedural and structural justice. Criteria 3-5 will be assessed through both the primary content analysis of the policy documents and through the market trends of reported microgrid installations within each state. In Table 2, it contains the policy analysis evaluation criteria and the scoring definitions for each category. Materials from the CDC's Office of Policy, Performance, and Evaluation were used to guide the construction of the table used within this paper (CDC, 2022b). The categories are evaluated using a tiered system from level one to level three (i.e., low, medium, and high), where the level number corresponds to the number of points earned per policy framework when scoring each category. Efficacy is gauged by how effective the policy is in producing a set of clear, mandated minimum standards, in each context. Cost addresses how much funding is allocated for each policy to be implemented, on a scale of favourability. Sustainability, coping with shocks, and addressing vulnerability address energy resilience of the policy and current state of the respective contexts. The points earned per category will then be compiled to give a total score for each policy framework out of 15 total points.

Table 2: Evaluation Criteria

			Energy Resilience			
Criteria:	*Efficacy*	*Cost*	*Sustainability*	*Coping with shocks*	*Addressing vulnerability*	Score:
Scoring Definitions	**Low**: Unclear minimum standards for infrastructure **Medium**: Clear minimum standards for infrastructure **High**: Clear and mandated minimum standards for infrastructure	**Less favorable**: No funding source. **Favorable**: Moderate aims to meet funding needs. **More favorable**: Adequate aims to meet funding needs.	**Low**: Meets neither indicator **Medium**: Meets one indicator **High**: Meets both indicators	**Low**: Meets one indicator **Medium**: Meets two indicators **High**: Meets three or more indicators	**Low**: Meets one indicator **Medium**: Meets two indicators **High**: Meets three or more indicators	**Level 1: 1 pt** **Level 2: 2 pts** **Level 3: 3 pts** **___ total out of 15 points**
Policy 1	☐ Low ☐ Medium ☐ High	☐ Less favorable ☐ Favorable ☐ More favorable	☐ Low ☐ Medium ☐ High	☐ Low ☐ Medium ☐ High	☐ Low ☐ Medium ☐ High	**___ total points**
Policy 2	☐ Low ☐ Medium ☐ High	☐ Less favorable ☐ Favorable ☐ More favorable	☐ Low ☐ Medium ☐ High	☐ Low ☐ Medium ☐ High	☐ Low ☐ Medium ☐ High	**___ total points**
Policy 3	☐ Low ☐ Medium ☐ High	☐ Less favorable ☐ Favorable ☐ More favorable	☐ Low ☐ Medium ☐ High	☐ Low ☐ Medium ☐ High	☐ Low ☐ Medium ☐ High	**___ total points**
Policy 4	☐ Low ☐ Medium ☐ High	☐ Less favorable ☐ Favorable ☐ More favorable	☐ Low ☐ Medium ☐ High	☐ Low ☐ Medium ☐ High	☐ Low ☐ Medium ☐ High	**___ total points**

3.2.4 Operationalization

The data collection method involved the extraction of documents that were relevant to microgrids, distributed energy generation, and grid resilience (e.g. Infrastructure Investment and Jobs Act, state-level regulations and funding programs, and local ordinances). Following the data collection and processing, a mixed content analysis was carried out for the selected documents. The mixed content analysis consisted of a qualitative analysis via content review and content analysis through coding of the documents, and a policy intensity assessment. The policy documents at the federal level were assessed through a content review only, and the policy documents at the state level were assessed through the content review, content analysis, and the policy intensity assessment. This allows for a thorough assessment of the policy content, policy structure, and policy intensity, according to the energy resilience evaluation criteria above.

Table 3: Operationalization

Variable	Conceptual Backing	Indicators	Source
Mediating	(Burke & Stephens, 2017)	Qualitative: Regulatory context Financial inclusion measures Economic institutions New energy system institutions	Content Review: Infrastructure Investment and Jobs Act
Mediating		Qualitative: Background Objectives Standards Funding mechanism	Content Review: CA SB1339 CA MIP CO HB 22-1013 CO HB 22-1249 PR Reg. 9028 TX SB2627 TX HB1500
Moderating	(Hu, Xue, Liu, Qiping Shen, & Xiong, 2023)	Qualitative: Document type Administrative level Total funding amount Target strength	Policy Intensity Assessment: CA SB 1339 CA MIP CO HB 22-1013 CO HB 22-1249 PR Reg. 9028 TX SB 2627 TX HB 1500

Independent	(Burke & Stephens, 2017; Chalaye et al., 2023; Meerow et al., 2019; Sharifi & Yamagata, 2016)	Qualitative: Sustainability Coping with shocks Addressing vulnerability	Primary Content Analysis: CA SB 1339 CA MIP CO HB 22-1013 CO HB 22-1249 PR Reg. 9028 TX SB 2627 TX HB 1500
Independent		Quantitative: Total generation capacity (MW) per state Storage capacity (MW) per state Generation/storage capacity per DER technology (%) per state Simple growth rate (%) Compound annual growth rate (%)	Market Trends: U.S. Department of Energy Combined Heat and Power and Microgrid Installation Database

Table 3 shows the operationalization of the policy analysis, with the independent, mediating, and moderating variables described in relation to their conceptual backing, indicators, and source. The relationship between the variables can also be seen in Section 2.5.

For the mediating qualitative variables, indicators for effective energy policy instruments of the national-level policy documents include regulatory context, financial inclusion measures, economic institutions, and new energy system institutions. The relationship between these indicators and the specific tools that contribute to these instruments is defined within Section 2.4.1. These indicators target the extent to which the provisions facilitate institutional energy systems change.

For the mediating qualitative variables, indicators for effective standards and state-level energy policy include background, objectives, standards, and funding mechanisms. These indicators influence how microgrid objectives and standards are presented within the policy framework and provides a foundation for the evaluation of the policy's efficacy and cost.

For the moderating qualitative variables, the indicators that affect the magnitude of the effect of the policy on energy resilience include document type, administrative level, total funding amount, and target strength. These indicators affect the policy's intensity, or the level of government enforcement of a policy implementation and attitudes towards the implementation. The relationship between the indicators and the values used to define them is further explained within Section 3.2.6.

For the independent qualitative variables, the following measures are identified for the sustainability, coping with shocks, and addressing vulnerability indicators, respectively:

renewable energy source mix and battery energy storage; generation capacity (kW), storage capacity (kW), grid connection, and critical load management; and vulnerability, affordability, co-creation and community cooperatives, and procedural and structural justice.

> The sustainability indicator is comprised of the following measures: the policy requirements must involve mandatory inclusion of some degree of renewable energy source in the DERs of a proposed project, such as solar, wind, hydro, or biogas, and requirements must mandate some degree of battery energy storage for redundancy.
>
> The coping with shocks indicator is comprised of the following measures: the policy requirements must outline that there be a minimum required generation capacity (kW), minimum required storage capacity (kW), requires new projects have grid connection unless it is serving a specialized facility (i.e., airport, military base, hospital, research facility) or a rural, or remote, area, and requires managements plans for critical load management in the event of extreme weather or another type of grid disturbance.
>
> The addressing vulnerability indicator is comprised of the following measures: the given policy must require that vulnerable populations or disadvantaged communities be prioritized in site selection planning, or to target communities with greater energy needs (i.e., have unreliable energy service or lack of clean, affordable energy), require that projects conduct their planning processes with either co-creation methods or opportunities for community cooperatives, and the policy must include a long-term strategy for procedural and structural justice (i.e., long-lasting change to the system).

For the market trends of current, operational microgrid installations in California, Colorado, Puerto Rico, and Texas, indicators include total generation capacity (MW) per state, storage capacity (MW) per state, generation/storage technology mix per DER (%) per state, simple growth rate (%) (SGR), and compound annual growth rate (%) (CAGR). In such, the case study profiles of the market trends within each state will be part of an iterative process of review according to the evaluation criteria to serve as triangulation of the state policy evaluation of sustainability (renewable energy source mix and battery energy storage) and coping with shocks (minimum required storage capacity (kW) and minimum required generation capacity (kW)).

3.2.5 Primary qualitative content analysis

Table 4: Code System and Keywords

Code	Keywords
Sustainability	emissions; reduction; greenhouse gases; climate change; fossil fuels; carbon neutral; clean energy; renewable
Coping with shocks	disaster; disaster mitigation; mitigate; extreme weather; disturbance; outage; reliable; reliability
Addressing vulnerability	resilience; externalities; displacement; dependence; equity; equitable; justice; disadvantaged; underserved; access; accessible; affordable; disproportionately; vulnerable

The qualitative analysis at the state-level will follow a qualitative content analysis of the policy documents and guidelines, using MAXQDA 24.2.0. This will be conducted for the three independent variables (sustainability, coping with shocks, and addressing vulnerability). For each category, a lexical search will be performed to code the categories to specific keywords, at the sentence level, within the documents. The sentences will be manually reviewed and attributed to the code after the lexical search. Then, analysis will be performed to determine the percent code coverage of each code in each document (i.e., the percentage of the document covering sustainability, coping with shocks, addressing vulnerability, and the uncoded percentage of the document). In Table 4, it outlines which keywords are attributed to which codes. This process also assists in the manual content review of the documents.

3.2.6 Policy intensity assessment

Table 5: Policy Intensity Assessment Indicators and Values

Indicator	Value
Document type	1=Interim planning 2=Program 3=Regulation 4=Mandate
Administrative level	1=Local 2=State 3=Federal
Total funding amount	1=No allocated funding 2=Some funding allocated for a short period 3=Adequate funding source over a set period
Target strength	1=Qualitative target 2=Some quantitative targets 3=Detailed quantitative targets

The policy intensity assessment uses a policy intensity index in order to assess policy intensity, or the level of government enforcement of a policy implementation and attitudes towards the implementation, based upon the scope and nature of the policy (Hu et al., 2023). Within the index, the policy enforcement intensity is determined by type of document, administrative level (i.e., federal, state, or local), total funding amount, and target strength. For the type of document, a value from 1 to 4 are assigned to the document based upon the policy level as follows: (1) interim planning, (2) program, (3) regulation, (4) mandate. In this study, a mandate is ranked highest due to the nature of mandates being regulations that state governments must enforce to specified standards (Zaretsky, 1993). Regulations fall underneath mandates, as individual regulations are effective but lack the standardization that mandates provide. Programs and interim planning follow mandates and regulations due to programs, including funding programs, being contingent of the state, or participant, opting-in to the program; interim programs are ranked lowest as they primarily act as guiding tools for setting goals but lack the proper enforcement mechanisms. For the administrative level, the attributed values are ranked as follows: (1) local, (2) state, and (3) federal. The administrative level captures the scope of the policy due to the different levels of jurisdictions captured by each level of government. For the total funding amount, policies are ranked as follows: (1) no allocated funding, (2) some funding allocated for a short period of time, and (3) adequate funding over a set period. This determines whether there is adequate funding for the action items in the policy to be carried out. The target strengths assess the targets' level of specificity and detail within the policy as follows: (1) qualitative target, (2) some quantitative targets, and (3) detailed quantitative targets. This ensures that there are measurable targets within the policy. The policy intensity is calculated by summing the indicators' scores listed in Table 5. A higher policy intensity implies more vigorous policy enforcement, with the highest possible total score being 13 points. The outcome of the policy intensity assessment contributes to the scoring on the assessment of the efficacy of the policies.

3.2.7 Market trends quantitative analysis

The market trends quantitative analysis utilized data from the U.S. Department of Energy Combined Heat and Power and Microgrid Installation Database as of December 31, 2023. Generation, or storage, capacity per DER technology (%) per state was calculated using the microgrid summary dataset's state/territory by technology generation data for current microgrid installations. The technology mix per state includes the generation capacity, by percentage, of the following technologies: CHP, solar, wind, hydro, fuel cell, diesel, natural gas, biogas, and storage. The microgrid technology mix, by percentage, for installations before the respective policy implementation and the technology mix, by percentage, after the policy implementation are also calculated, using data on the installation-scale.

SGR and CAGR were calculated using the microgrid installation dataset in order to separate the microgrid installations based upon operational year. For the simple growth rate of microgrid generation capacity in each state, the microgrid generation capacity (MW) for the state prior to the policy implementation is subtracted from the microgrid generation capacity (MW) for the state after the policy implementation, divided by the microgrid generation capacity (MW) for the state prior to the policy implementation, and then multiplied by 100.

$$SGR = \frac{Generation\ capacity\ pre\text{-}policy\ implementation(MW) - Generation\ capacity\ post\text{-}policy\ implementation(MW)}{Generation\ capacity\ pre\text{-}policy\ implementation\ (MW)} \times 100$$

For the compound annual growth rate of microgrid generation capacity in each state, the total microgrid generation capacity (MW) is divided by the microgrid generation capacity (MW) prior to the policy implementation, raised to 1 over the time period of implementation, and subtracted by 1.

$$CAGR = ((\frac{Total\ generation\ capacity\ (MW)}{Generation\ capacity\ pre\text{-}policy\ implementation\ (MW)})^{\frac{1}{time\ period}}) - 1$$

3.2.8 Limitations of the study

There are some shortcomings due to the nature of assessing policies in separation from practice. Policies are only effective to the extent that their implementation is carried out in a manner that follows the policy and does not create unintended impacts or consequences. Additionally, addressing the current market trends of the state microgrid markets after the enactment of the state-level policies does not mean that the policies themselves directly contributed to changes in the market, the data is more so used as a method of triangulation for some outlined policy objectives and regulations, particularly whether the mix of generation technologies is renewable and whether installations have specifications that allow them to cope with shocks (i.e., battery energy storage). Moreover, there are limitations to further assessing the Infrastructure Investment and Jobs Act provisions due to the limited time period that the act has been in place, with only one fiscal year of grant funds being awarded, and with most states not having a defined grant award process finalized for the distribution of funds to microgrid projects.

4. Results, analysis and discussion

4.1 Content review – Federal policy

The Infrastructure Investment and Jobs Act, or the Bipartisan Infrastructure Law (BIL), was signed into law in 2021. It establishes 60 new programs for the Department of Energy, including 32 deployment programs, 16 demonstration programs, and 12 existing Research, Deployment, Demonstration, and Deployment programs which receive expanded funding (Grid Deployment Office, n.d.-a). The BIL also establishes several provisions that are administered by the Grid Deployment Office, including the following programs detailed within Section 4.1.1. The programs that this content review will focus on are Provision 40101, 40103(b), 40106, and 40107 due to their connection to microgrid programs and resilience initiatives. The following review will include the background, objectives, and funding mechanisms of each provision, in order to determine the characteristics of national-level infrastructure policies in relation to decentralized energy production and the role of resilience.

4.1.1 Content review

The Grid Resilience State and Tribal Formula Grants program is the primary grant program aimed at improving resilience of electric grids of states, U.S. territories, and Indian tribes. It is administered by the National Energy Technology Laboratory and supported by BIL provision 40101(d) *Preventing Outages and Enhancing the Resilience of the Electric Grid / Hazard Hardening*, with the aim to fortify the American power grid against extreme weather that is exacerbated by the climate crisis, such as wildfires and other natural disasters (National Energy Technology Laboratory, n.d.). Within provision 40101(d), grants can be made to States and Indian Tribes, which can then be awarded to eligible entities, and must submit an application each fiscal year with a plan for (1) describing criteria and methods for awarding grants to eligible entities, (2) adoption after notice and a public hearing, and (3) describing the proposed funding distributions and recipients of the grants (117th Congress, 2021). The formula grants will distribute $2.3 billion over five years. The funding is distributed based upon a formula that includes the following factors: population size, land area or areas with a low ratio of electricity customers per mileage of power lines, probability of disruptive events based upon the number of federally declared disasters or emergencies within the previous ten years and severity of disruptive events based upon population and economic impacts, and a locality's historical expenditures on mitigation efforts, with a higher weight given to States or Indian Tribes with higher per capita expenditures (117th Congress, 2021). The program funds awarded to the state, or territory, are then used to meet goals identified by the state's government and will hold competitive selection processes to identify projects to award the funds to directly. The goals of each state, or territory, for the funding vary.

Provision 40103(b) on *Program Upgrading Our Electric Grid and Ensuring Reliability and Resiliency*, or the Grid Innovation Program, aims to innovate transmission, storage, and distribution infrastructure, for enhancing resilience and reliability, and to establish public and rural electric cooperatives to enhance regional grid resilience by providing federal financial assistance through coordination with electric sector owners and operators (117th Congress, 2021). The projects will be given priority for interregional transmission projects, clean energy generation, and distribution grid assets that utilize backup power and reduced transmission requirements via innovative approaches, which include innovative planning processes, partnerships, or advanced technologies (Grid Deployment Office, n.d.-b). Within the Grid Resilience and Innovation partnerships program projects, 58 projects have been selected for either grid resilience utility and industry grants, smart grid grants, or the grid innovation program, which provide $3.5 billion in funding across the projects (Grid Deployment Office, n.d.-c). Of these projects, there are 11 which involve California, Colorado, or Texas as one of the state recipients, Puerto Rico is not represented within any of the 58 projects.

The Section 40106 Transmission Facilitation Program (TFP) is focused on providing federal funding to projects that develop new large-scale transmission lines, upgrade existing transmission lines, and that connect microgrids in select states and U.S. territories (Grid Deployment Office, n.d.-a). One of the specific TFP avenues for funding is through public-private partnerships aimed at connecting microgrids. Up to $200 million can be allocated to individual projects that connect remote and isolated microgrids as part of transmission projects in existing infrastructure corridors in U.S. territories, Alaska, and Hawaii, with an emphasis on interconnecting microgrids to enhance resilience and grid reliability (Grid Deployment Office, n.d.-e). The eligible projects include construction of a new or replacement of an existing electric power transmission line, increasing transmission capacity of an existing electric power transmission line, or connecting an isolated microgrid to an existing transmission, transportation, or telecommunications corridor in Alaska, Hawaii, or a territory of the United States (117th Congress, 2021). Additionally, the Secretary of Energy can enter capacity contracts for the transmission capacity of eligible projects, in which the Secretary will pay for market value for the use of the transmission capacity and in scheduled amounts for facilitating the construction of the project (117th Congress, 2021).

The Section 40107 Deployment of Technologies to Enhance Grid Flexibility, or the Smart Grid Grants program, works to expand the existing Smart Grid Grant Program in order to include more grid enhancing technologies that increase capacity of existing transmission system, technologies that prevent weaknesses that lead to wildfires or other system disturbances, utilize more renewable resources, and increase monitoring and analysis of transportation and building electrification impacts on the grid (Grid Deployment Office, n.d.-a). The program was previously funded by the Recovery Act of 2009 and the expansion of the program invests $3 billion from fiscal years 2022-2026 to deploy smart grid technologies at scale (Grid Deployment Office, n.d.-d). In amendments to the existing program, there is now inclusion of advanced transmission technologies, such as dynamic line rating, flow control devices, advanced conductors, network topology optimization, or other hardware, software, and protocols that increase the operational transfer capacity of a transmission network for funding, as well as specifying in cases of extreme weather or natural disasters to have technology with the ability to redirect or shut off power to minimize backouts to avoid further damages (117th Congress, 2021).

4.1.2 Content review results

4.1.2.1 Regulatory context

The tools found in the BIL and provisions that indicate regulatory context include the statutory priority of demand reduction and DG and community benefit agreements (CBA). The BIL sets the legislative framework and foundation for the funding and planning of future energy systems change. The BIL establishes statutory priority of demand reduction and distributed generation, to a certain extent. Particularly with the Smart Grid Grants program and the Transmission Facilitation Program, it focuses heavily on the improvements to the grid management, transmission, and storage that are necessary when planning and constructing infrastructure for the more variable, distributed generation (Burke & Stephens, 2017). Where the programs are somewhat lacking is with demand reduction. While there are numerous programs aimed at facilitating increased DG, there are only a few programs that address demand reduction (these are not discussed in section 4.1.1 as they fall outside the scope of microgrid- or resilience-focused provisions). These programs include the Energy Efficiency Revolving Loan Fund Capitalization Grant Program and the Energy Efficiency and Conservation Block Grant Program. The block grant program is a community energy program in which it provides $550 million in order to assist states, local governments, and Tribes in reducing energy use, reducing fossil fuel emissions, and improving energy efficiency (Office of State and Community Energy Programs, n.d.-a). The revolving loan fund similarly sets up a $250 million fund that assists states in establishing a revolving loan fund, which is distributed for residential and commercial energy audits, upgrading, and retrofitting (Office of State and Community Energy Programs, n.d.-b). The BIL also heavily favours renewable energy and carbon reduction, however, it does not establish federal renewable energy portfolio standards (RPS) or clean energy standards. CBAs are found within the Grid Resilience State and Tribal Formula Grants Program. The formula grants program uses a formula to awards funds to states, which are then distributed to individual projects in the state through a "competitive selection process." This model of funding distribution can be largely defined as a community benefit agreement, which are "legal measures designed to distribute the benefits of projects or programs among a community" (Burke & Stephens, 2017). The purpose of such a selection process aids in creating measures tailored to the local context; however, the standards that are required for a "competitive selection process" are somewhat ambiguous and the stringency of such standards are left to the state's jurisdiction.

4.1.2.2 Financial inclusion measures

The provisions within the BIL can all primarily be categorised as financing programs, particularly grant programs with funding awarded per fiscal year for states that apply to the funding program. In addition, there are revolving loan funds, as seen with the Energy Efficiency Revolving Loan Fund Capitalization Program, and cooperative financing, as seen with the Grid Innovation Program. The Grid Innovation Program utilizes the establishment of public and rural electric cooperatives, using federal financial assistance through coordination with electric sector owners and operators, to enhance regional grid resilience.

4.1.2.3 Economic institutions

The economic institutions utilized by the BIL and its provisions include community energy, renewable energy cooperatives, and remunicipalization. There is crossover between the programs that address energy efficiency and community energy. The Energy Efficiency Revolving Loan Fund Capitalization Program, the Energy Efficiency and Conservation Block Grant Program, and Grid Resilience State and Tribal Formula Grants Program all address the energy at the community level. These programs are localized in order to more effectively achieve the respective objectives of the programs. These appropriately address community economic development opportunities, but less effectively address the development of new socioeconomic institutions. The profit-model of energy systems is still prevalent within the frameworks of the provisions. The renewable energy cooperatives, which is a component of the Grid Innovation Program, still rely on "electric sector owners and operators" entering a public or rural cooperative. This does not open the cooperative model to the possibility of consumer-owned resources. The Transmission Facilitation Program also utilizes public-private partnerships, which touches upon remunicipalization, to have public institutions have a greater role in the distribution of energy, as there was a trend of privatization of municipally-owned assets since the 1980s (Burke & Stephens, 2017).

4.1.2.4 New energy system institutions

The tools for new energy system institutions represented within the BIL and its provisions, including energy investment districts, microgrids and democratized grid management, and energy regions. There is extensive crossover between these tools and individual provisions, as the aim of new energy system institutions is large-scale institutional reforms, which are facilitated through large-scale infrastructure upgrading and investment districts. Additionally, all of the provisions concern microgrids and democratized grid management, DG, reliability, or resilience to some extent. Energy regions are utilized to some extent within the Transmission Facilitation Program, Smart Grid Grants Program, and the Grid Innovation Program, due to their large-scale and interregional context. The connection between the provisions and the institutional reform within the context of the intervention could be better explained. For example, how connecting rural or isolated microgrids to the grid could provide benefits to the local communities, as well as avenues for cooperatives or local economic development, could be better enumerated.

4.2 Content analysis – State policy

The content review in this section presents the background, objectives, standards, and funding mechanisms for the selected state policies on microgrid development and deployment. The content review is followed by the results of the primary content analysis, which discuss the extent to which each policy document addresses sustainability, coping with shocks, and vulnerability. The results of the policy intensity assessment are also reported at the end of this section.

4.2.1 Content review – Background, Objectives, Standards, and Funding Mechanisms

4.2.1.1 SB 1339

Within California Senate Bill No. 1339, it sets out action items for the Public Utilities Commission, with involvement from the State Energy Resources Conservation and Development Commission and the Independent System Operator, to facilitate the commercialization of microgrids for distribution customers of large electrical corporations by December 1, 2020.

The legislature found that the key issues that must be addressed when commercializing microgrids include: how microgrids operate and their value, improving the electrical grid with microgrids, how microgrids can play a role in implementing policy goals, how microgrids can support California's policies to integrate a high concentration of distributed energy resources on the electrical grid, how microgrids operate in the current California regulatory framework, and microgrid technical challenges. Furthermore, the bill states that the PUC, ISO, and State Energy Resources Conservation and Development Commission must take action to transition the microgrid from an emerging technology solution to a "successful, cost-effective, safe, and reliable" commercial product that aids in the State of California meeting its future energy goals and that provides an additional way for customers to manage individual energy needs (SB-1339 Electricity: Microgrids: Tariffs., n.d.).

SB 1339 does not provide explicit standards for the development of microgrids but enumerates actions for future microgrid development. The actions that must be taken by the PUC include the following: development of microgrid service standards necessary to meet state and local permitting requirements, development of methods to reduce barriers for microgrid deployments, development of guidelines that determine what impact studies are required for microgrids to connect to the electrical corporation grid, develop rates and tariffs to support microgrids while ensuring system, public, and worker safety, codify standards and protocols via the formation of a working group, and develop a standard for direct current metering to streamline the interconnection process and reduce costs for direct current microgrid applications.

The bill does not appropriate funding for carrying out the action items within the bill.

4.2.1.2 CA MIP

California's Decision Adopting Implementation Rules for the Microgrid Incentive Program (MIP) involves the creation of an investor-owned utility (IOU) MIP implementation plan.

The Microgrid Incentive Program "targets placement of community microgrids in disadvantaged vulnerable communities (DVCs) to support populations impacted by grid outages… [and] seeks to advance microgrid resiliency technology, advance system benefits of microgrids equitably across DVCs, and inform future regulatory resiliency action to the benefit of all ratepayer customers" (Rizzo, 2023).

The minimum requirements for MIP projects are that, for eligibility, they must serve a geographic DVC, be a critical facility, or be a facility that provides important community resilience services. In addition, the microgrid must be "sized and operated to serve a minimum of 24 consecutive hours of energy in Island Mode as determined by a typical load profile within the Microgrid Boundary; and when operating in Island Mode, the aggregate emissions from Project Resources and non-Project Resources must be no greater than equivalent grid power" (Rizzo, 2023). Additionally, the projects must comply with the emissions standards adopted by the California Air Resources Board, and in accordance with the distributed generation certification program requirements of Section 94203 of Title 17 of the California Code of Regulations.

The MIP has a total program budget of $200 million.

4.2.1.3 HB 22-1249

Colorado House Bill 22-1249 concerns the creation of a microgrid roadmap for improving electric grids in the state and making an appropriation.

As part of the grid resilience and resilience and reliability roadmap, microgrid development, stakeholder input, definitions, and reporting are outlined as specific action items for inclusion within the roadmap.

Due to the nature of HB 22-1249, it lacks clear minimum standards for the technical specifications of critical facilities and infrastructure, however, the bill is clear in the specific planning process of the roadmap and scope of the bill. The roadmap process involves the participation of the public and relevant stakeholders, with public comment occurring, stakeholder (i.e., microgrid developers, public utilities commission and commission staff, office of the utility consumer advocate, utilities, representatives of disproportionately impacted communities, representatives of communities at highest risk for power outages, municipal, county or city representatives, commercial and industrial utility customers, representatives of labour organizations, and public safety representatives) meetings with consideration of stakeholder input, and guidance from the resiliency office for wildfire mitigation. Before January 1, 2030, and at least every five years afterwards, the department and resiliency offices will review and, if necessary, update the roadmap. The initial grid resilience and reliability roadmap shall be produced on or before January 1, 2025.

The bill appropriates $22,470 for the program administration in the production of the roadmap by the office of the governor for use by the Colorado energy office. This is adequate for the purposes of the bill.

4.2.1.4 HB 22-1013

Colorado House Bill 22-1013 concerns the creation of a grant program to build community resilience to electric grid disruptions through the development of microgrids.

The primary objective of the bill targets microgrids for community resilience and makes a legislative declaration, enumerates definitions, and creates a grant program.

Like HB 22-1249, HB 22-1013 lacks clear minimum standards for the technical specification of eligible projects, however, the bill is clear in the scope of which projects are eligible for grant funding. Within the bill, only cooperative electric associations and municipally owned utilities that serve rural communities are eligible for application to the grant program. For service of an eligible rural community, eligibility of the area will be determined based upon the following criteria: the rural community's degree of exposure to severe weather or natural disasters, the nature of risk to the community's interests based upon the natural disaster risk, availability of alternative resources to meet the community's needs, the utility's potential for promoting energy efficiency and demand-side management programs, and existing financial resources of the rural community for risk mitigation. The primary concern of the projects includes the mitigation of natural disaster risk to communities.

Within the appropriation, $3,500,000 is appropriated for microgrids for community resilience grant program for the state fiscal year of 2022-23. According to the bill, any money that is not expended prior to July 1, 2023, will be appropriated to state fiscal years 2023-24, 2024-25, and 2025-26, for the same microgrid grant program purposes. Considering the funding amount during the set time period, the funding amount for enacting the grant program is adequate.

4.2.1.5 Regulation 9028

Puerto Rico's Regulation 9028 concerns the development of microgrids within Puerto Rico, due to the need precedented by the prolonged outages that occurred following Hurricane Irma and Maria. In addition, microgrids are referenced within the regulation "as a means of delivering reliable energy services to customers in need, avoiding the loss of power at critical facilities, promoting customer choice, reducing carbon pollution and spurring economic development while integrating new technology and industry trends into Puerto Rico's energy market" (Comisión de Energía de Puerto Rico, 2018).

The objective of the regulation is to create a regulatory framework for the development and deployment of microgrid systems, which can also foster innovation and economic growth.

Within the articles of the regulation, it specifies microgrid provisions in which microgrids are classified into three categories, specifies technical requirements, as well as requirements for third-party microgrids, or a microgrid that is not a personal microgrid, nor a cooperative microgrid, and sells energy services or other gird services to customers. The regulation also further outlines the registration process, exemptions, and reconsiderations and judicial reviews. The standards for microgrids include a minimum of generation assets, loads and distribution infrastructure, and the minimum requirement for renewable resources to be the primary energy sources it 75% of the system's output. In addition, fossil fuels cannot exceed 25%, and CHP microgrids' thermal energy output of the system must be no less than 50% total energy output.

Being a regulatory policy, the policy does not appropriate funding for carrying out the regulation.

4.2.1.6 SB 2627

Texas State Bill 2627 concerns the creation of funding mechanisms to support the construction, maintenance, modernization, and operation of electric generating facilities.

Within the chapters and subchapters, facility funding, grants and loan criteria, specifications, and backup power packages are specified. The bill specifies grants for distribution infrastructure and electric generating facilities with the goals of facility modernization, facility weatherization, reliability and resiliency facility enhancement, or vegetation management.

Texas backup power packages specifically apply to microgrid configurations. Within the backup power packages, it specifies that the operation of such facility can be provided funding for those that which the following applies: uses interconnection technology and controls that enable immediate islanding from the power grid and stand-alone operation for the host facility; is capable of operating for at least 48 continuous hours without refuelling or connecting to a separate power source; is designed so that one or more Texas backup power packages can be aggregated on-site to serve not more than 2.5 megawatts of load at the host facility. In addition, it specifies that it includes power sources from "a combination natural gas or propane with PV panels and battery storage" (S.B. No. 2627, 2023).

This funding appropriated within this bill for loans for the ERCOT power region include \$120,000 per MW of capacity provided by a facility interconnected before June 1, 2026, or \$80,000 per MW of capacity provided by a facility interconnected before June 1, 2029. Grant awarding is based upon the evaluation of individual projects for appropriate amounts. For grants, the commission may not provide more than \$1 billion, and for loans, not more than \$7.2 billion. For backup power packages, the amount for a grant may not exceed \$500 per kW of capacity.

4.2.1.7 HB 1500

Texas House Bill 1500 is an amendment to the Utilities Code for the Public Utility Commission of Texas, the Office of Public Utility Counsel, and ERCOT power region.

Some of the major amendments related to energy resilience include changes to the voluntary mitigation plans, circuit segmentation for outage management, and reliability services for independent organizations.

The standards and definitions updated by the amendment within the utilities code include the definition of distributed renewable generation, renewable energy technologies, and actions that the PUC can take in the event of a significant power outage. Distributed renewable generation is defined as electric generation with a capacity of not more than 2,000 kW provided by a renewable energy technology that is installed on a retail electric customer's side of the meter. Furthermore, renewable energy technologies are defined as any technology that is naturally regenerated over a short period of time or is derived from the sun, wind, geothermal, hydroelectric, wave, or tidal energy, or from biomass or biomass waste products, including landfill gas. Additionally, during significant power outages, the PUC has the ability to procure, own, and operate, or enter into a cooperative agreement with other transmission and distribution utilities to procure and operate transmission and distribution facilities that would aid in restoring power to the utility's customers after the outage.

Being an amendment to the Utilities Code, the bill does not appropriate funding within it.

4.2.2 Primary content analysis

Table 6: Qualitative Content Analysis Results

Code System	CA SB1339	CA MIP	CO HB 22-1013	CO HB 22-1249	PR Reg.9028	TX SB2627	TX HB1500
Sustainability	7%	3%	5%	3%	10%	0%	4%
Coping with shocks	15%	4%	16%	34%	5%	9%	11%
Addressing vulnerability	15%	13%	21%	34%	7%	0%	1%
Not coded	63%	80%	62%	52%	80%	91%	85%
Coded	37%	20%	38%	48%	20%	9%	15%
Whole text	100% (8,997)	100% (21,344)	100% (12,161)	100% (13,122)	100% (59,967)	100% (31,635)	100% (79,704)

Table 6 displays the results of the primary content analysis for the state policy documents. The documents vary in their percentage coded and in their respective lengths.

4.2.2.1 Sustainability

For percentage of the document concerning sustainability, Puerto Rico's Regulation 9028 covers the highest percentage at 10%, while Texas State Bill 2627 has no mention of renewable energy regulation, and California's MIP and Colorado's HB 22-1249 have 3% of the document devoted to sustainability regulation. Regulation 9028 explicitly states that a "statutory goal of microgrids is to reduce energy consumption based on fossil fuels through local renewable energy generation" (Comisión de Energía de Puerto Rico, 2018). Additionally, Reg. 9028 goes further to specify the inclusion of "alternative renewable energy sources," which include conversion of municipal solid waste, land fill gas combustion, anaerobic digestion, and fuel cells. The regulation also specifies technical requirements of microgrids for eligible generation resources. The primary energy source of the microgrid must be one of more of the defined renewable energy sources, and 75% of the energy output of the system during the first year, and every year thereafter, must be from a renewable resource, with no more than 2,500 Btu per total energy by non-renewable generation. Additionally, it is required that "the sum of installed renewable energy generating capacity and electrical energy storage capacity (in MW) of the Microgrid shall exceed the expected peak demand of the Microgrid" (Comisión de Energía de Puerto Rico, 2018). Regulation 9028 has the most stringent specifications for microgrids out of all the policy documents, with some policies, including SB2627 and HB1500 not specifying any renewable technical requirements for microgrids; however, HB1500 does define distributed renewable generation, and states that it includes electric generation capacity by a renewable energy technology of no more than 2,000 kW.

4.2.2.2 Coping with shocks

When considering coping with shocks, Colorado's policy documents have a higher proportion of their total content dedicated to energy security concerns. Within HB 22-1249, there is an emphasis on reliability of microgrids and identification of critical facilities and infrastructure threatened by natural disasters, for prioritization. These critical facilities include emergency services, public works, energy, telecommunication and broadband, hospitals and health-care services, government, schools, and information technology facilities. Despite the MIP having 3% of the document coded as dedicated to coping with shocks, there are still clearly defined requirements for energy security within the regulation. Planning is included for Public Safety Power Shutoff (PSPS) events, necessary energy storage systems, and specification of grid connection and islanding in event of natural disasters events. Puerto Rico has similar requirements as California, with requirements of exceeding peak demands of the microgrid in energy generating capacity and electrical storage capacity. Texas' policies are similar to Colorado in that they emphasize reliability, however, reliability is discussed in a manner of how it can be carried out as an expressed power by the PUC. In HB 1500, it states that "the commission may use a verbal directive to direct an independent organization to take an official action in an urgent or emergency situation that poses an imminent threat to public health, public safety, or the reliability of the power grid" (Holland, 2023). This concerns the delegation of responsibility during emergency situations; however, it does not place any requirements for service during emergency situations, nor does it give expressed planning for PSPS events. SB 2627 also discusses reliability of eligible projects at length and specifies the duration that power backup packages must provide power during a distribution (48 hours) as well as requirements for grid connection.

4.2.2.3 Addressing vulnerability

When considering addressing vulnerability, Colorado and California have more comprehensive reference to vulnerable populations, affordability, and co-creation and community cooperatives. SB 1339 covers some aspects of structural justice with the legal codification of just and affordable rates for all public utilities. Where aspects of vulnerability are addressed most closely to the indicators is within California's MIP. The MIP aims to achieve the following community benefits: (1) increase electricity reliability and resiliency for critical public facilities in communities that are at higher risk of electrical outages; (2) prioritize serving communities with higher proportions of low-income residents, access and functional needs residents, and electricity dependents; (3) enable communities with lower ability to fund development of backup generation to maintain critical services during grid outages. This shows the explicit prioritization of vulnerable populations, accessibility, and affordability. Colorado also has an exhaustive co-creation process outlined for the Microgrid Roadmap. Puerto Rico also makes more reference to the co-creation process and ownership of microgrid installations at the community level. Texas largely excludes the indicators of addressing vulnerability but does make some reference to service accessibility.

4.2.3 Policy intensity assessment

Table 7: Policy Intensity Assessment Results

Indicators	CA SB1339	CA MIP	CO HB 22-1013	CO HB 22-1249	PR Reg.9028	TX SB2627	TX HB1500
Document type	1	2	2	1	3	2	3
Administrative level	2	2	2	2	2	2	2
Total funding amount	1	3	3	3	1	2	2
Target strength	2	2	2	2	3	1	1
Total	6	9	9	8	9	7	8

Table 7 shows the results of the policy intensity assessment across the examined policy documents. The rankings for each indicator are given, as well as the total score for each policy document. California's Microgrid Incentive Program, Colorado's HB 22-1013 Microgrid Grant Program, and Puerto Rico's Regulation 9028 scored the highest with 9 total points. California's SB 1339 scored the lowest at 6 total points, but this is mostly due to the type of document being interim planning and lack of funding.

4.3 Comparative case studies

4.3.1 Market trends

Table 8: Market Trends Analysis Results

Technology Mix	California	Colorado	Puerto Rico	Texas
CHP	48.87%	67.65%	7.69%	30.60%
Solar	19.97%	15.53%	48.08%	5.98%
Wind	0.97%	2.77%	5.13%	5.89%
Hydro	0.06%	-	38.46%	-
Fuel Cell	1.87%	-	-	-
Diesel	14.52%	5.73%	-	8.46%
Natural Gas	1.76%	0.92%	-	48.88%
Biogas	1.01%	-	-	-
Storage	10.33%	7.21%	0.64%	0.29%
Total Generation Capacity (MW)	**465.7**	**54.1**	**15.6**	**849**
Total Storage Capacity (MW)	**48.1**	**3.9**	**0.1**	**2.5**
SGR	25.66%	8.80%	281.94%	3.20%
CAGR	3.88%	4.31%	21.10%	1.59%

4.3.1.1 Technology mix

Table 8 shows the technology mix by percentage of all microgrid installations per case, the total generation capacity in megawatts (MW), and the simple growth rate (SGR) and compound annual growth rate (CAGR) of the energy generation capacity of the microgrid installations per case for the period of time after their respective policy implementations. For the technology mix per state, California has the greatest variety within the technologies used in the state, and primarily utilizes CHP (48.87%), solar (19.97%), diesel (14.52%), and storage (10.33%) technology. Wind, hydro, fuel cell, natural gas, and biogas make up less than 10% of the technologies used in all installations, combined. In Colorado, the primary technologies used include CHP (67.65%), solar (15.53%), storage (7.21%), and diesel (5.73%), while wind and natural gas represent less than 3% and less than 1% of technologies found in all installations, respectively. In Puerto Rico, the technology mix has a majority representation of solar (48.08%), hydro (38.46%), CHP (7.69%), and wind (5.13%), with less than 1% storage. Texas has a majority representation of natural gas (48.88%), CHP (30.60%), and diesel (8.46%). Solar, wind, and storage, combined, make up approximately 12% of the remaining mix of technologies. The total generation capacity for all installations per state are 465 MW in California, 54.1 MW in Colorado, 15.6 MW in Puerto Rico, and 849 MW in Texas. Without considering the implications of the technology mix of each state, Texas has both the highest total generation capacity at 849MW, and the highest total number of installations at 322 total installations. Puerto Rico has the largest proportion of renewable energy technologies throughout their 23 total installations, comprising 91.67% of their energy generation technology mix. Comparatively, only 21% of California's, 18.3% of Colorado's, and 11.87% of Texas' energy generation technology mix are renewable energy generation technologies.

However, this could be attributed to the majority of Puerto Rico's microgrid installations becoming operational during or after 2018, with the exceptions being one installation becoming operational in 2013 and one in 2017. CHP is the highest proportion of energy generation technology in California and Colorado, with 48.87% and 67.65% being CHP, respectively. The CHP classification on the U.S. Microgrid Database does not specify the CHP configurations, therefore, it is unknown what type of fuels the systems use within the installations. The primary options include a combustion turbine, or reciprocating engine, with heat recovery unit (burning natural gas, oil, or biogas) or a steam boiler with steam turbine (burning natural gas, oil, biomass, or coal). The combined heat and power model of energy production increases efficiency of energy production by saving two-thirds of energy that is lost during conventional, separate heat and power generation (US EPA, 2015). As a result, CHP can emit less carbon emissions than conventional heat and power generation, however, the technologies used in CHP configurations still perpetuate the use of non-renewable energy sources and contribute to carbon emissions. Texas has a high reliance on natural gas (48.88%) microgrids, and likely utilizes natural gas as a fuel source in CHP (30.60%) installations. This aligns with Texas' history as an oil producing state, and as the world's third largest natural gas producer (Texas Oil & Gas Association, 2023).

4.3.1.2 Generation capacity, SGR, and CAGR

Variation in total energy generation capacity (MW) is largely due to the difference in size and energy needs of each state. In addition, greater generation capacity does not linearly translate to greater energy resilience or greater energy security. This is due to the need to also consider the technology mix of the microgrids, as having a higher proportion of non-renewable energy generation sources is less resilient in the long-term due to the sunk costs of the infrastructure and due to associated negative externalities. The simple growth rate and compound annual growth rate of microgrid technologies based upon the total generation capacity allows for an illustration of the growth rate of microgrid technology within each state. In California, for the policy implementation period of 2018 to 2024, the SGR was 25.66% and the CAGR was 3.88% per year. In Colorado, for the policy implementation period of 2022 to 2024, the SGR was 8.80% and the CAGR was 4.31% per year. In Puerto Rico, for the policy implementation period of 2018 to 2024, the SGR was 281.94% and the CAGR was 21.10% per year. This is reflective of the 20 of the 22 installations on the island becoming operational during or after the year 2018. In Texas, for the policy implementation period of 2023 to 2024, the SGR was 3.20% and the CAGR was 1.59% per year. The highest CAGR was in Puerto Rico, then Colorado, then California, then Texas. It is also notable that Texas and California already had substantial number of installations that were operational prior to the period of the policy implementations. However, the growth of the microgrid market cannot be attributed solely to the introduction of the policies within each state, but largely serves to illustrate the application of microgrids within each state in order to serve different customers as reflected through their growth rate in generation per year.

4.3.2 Policy implementation changes to technology mix

The following figures depict the percentage of each state's microgrid technology mix for the period of all installations that were operational prior to the individual state microgrid policy implementations, and for the period of time where microgrid installations became operational from the start year of the policy implementation to 2024. The purpose of this comparison is not to attribute the policy as the sole contributing factor to any potential changes within the composition of the microgrid technology mix of each state, but rather to illustrate any larger trends within the market, considering the context of the state, which may or may not be influenced by the implementation of state or federal microgrid policies and funding programs.

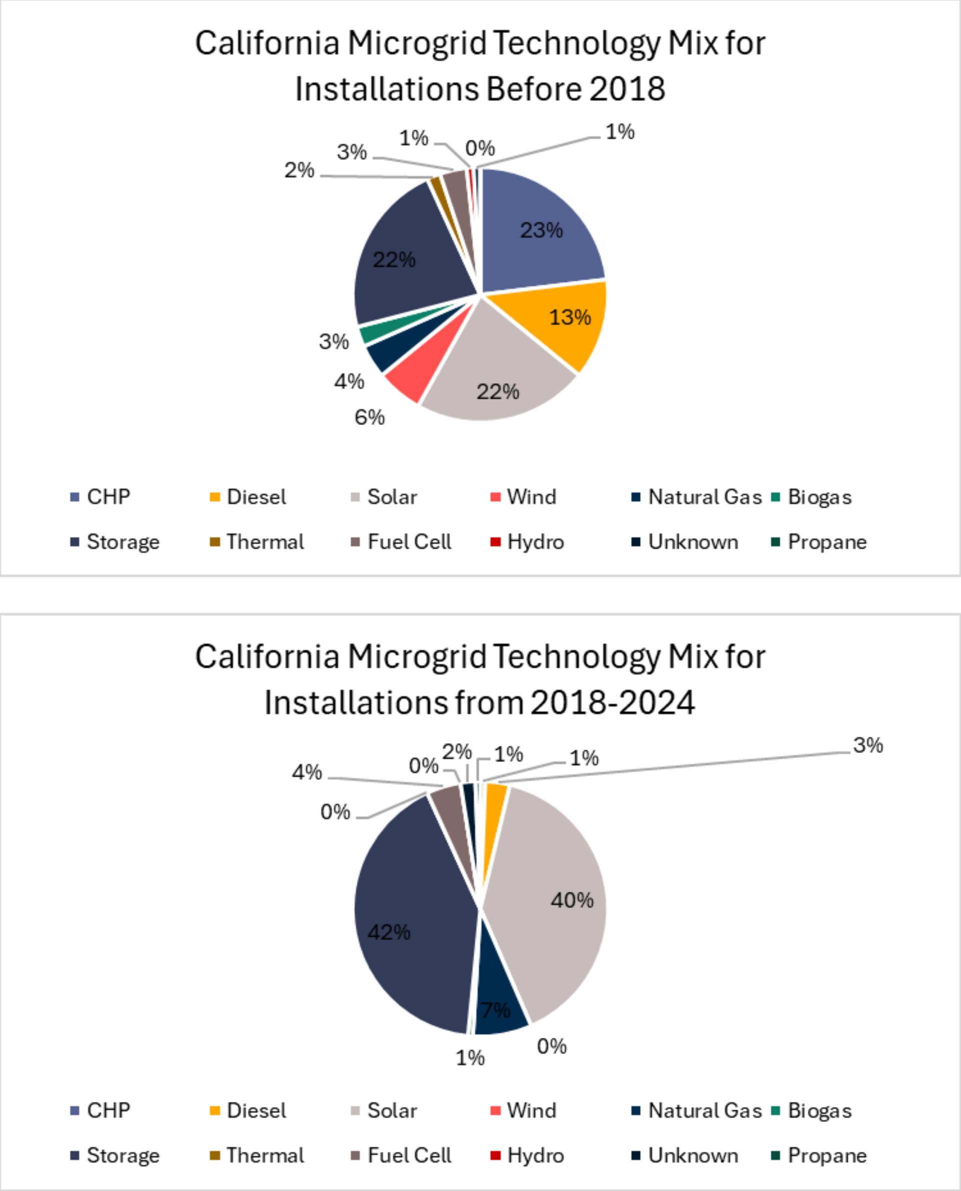


Figure 2: California Technology Mix

California has the greatest diversification within the composition of microgrid technologies in installations within the state. The technology mix for the 48 installations that became operational prior to 2018 include 23% CHP, 22% solar, 22% storage, 13% diesel, 6% wind, and 4% natural gas, with the remaining 9% of technologies being comprised of fuel cell (3%), biogas (3%), thermal (2%), and hydro (1%). For the period of 2018 to 2024, 72 sites became operational, with the technology mix including 42% storage, 40% solar, 7% natural gas, and 4% fuel cell, with the remaining 6% of technologies being comprised of diesel (3%), CHP (1%), biogas (1%), and propane (1%) (propane is reported as part of a community microgrid project that also uses solar and storage, which is one of two reported installations using propane in the entire database). Notably, California is the only state out of the case series that has fuel cell systems, with 11 sites total. In the later period, there is a marked shift from CHP and other sources to greater installation of solar, storage, and natural gas.

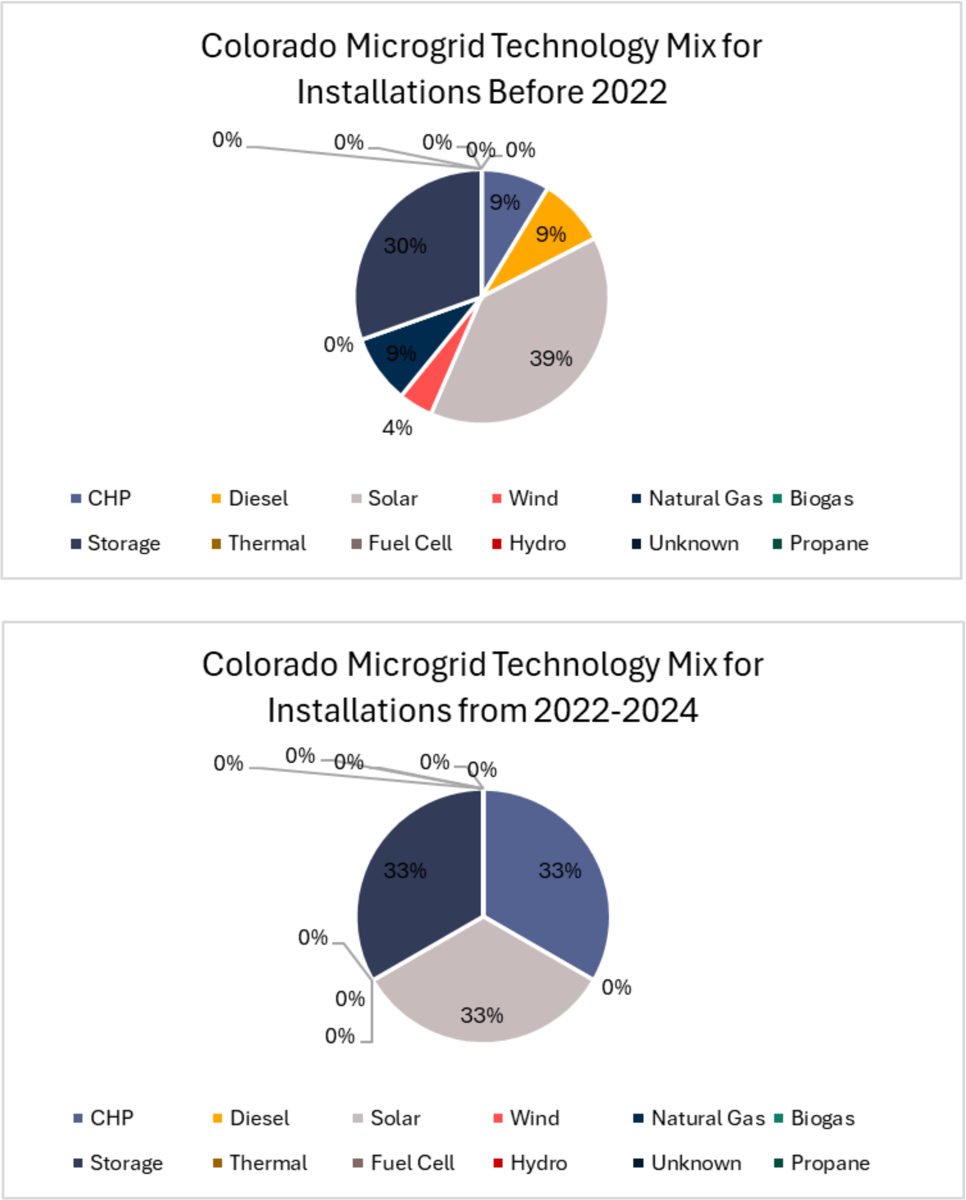
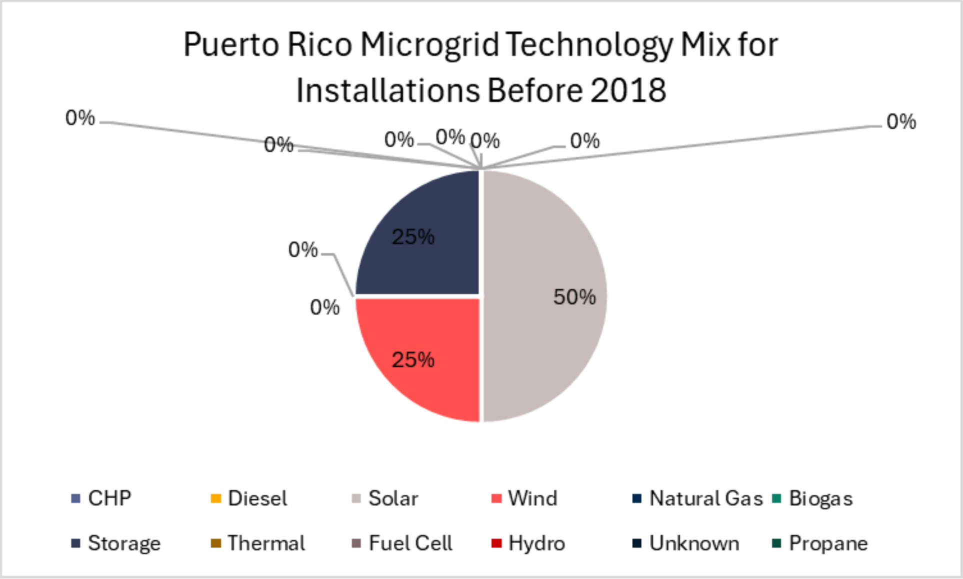


Figure 3: Colorado Technology Mix

The technology mix for the 10 installations that became operational prior to 2022 include 39% solar, 30% storage, 9% CHP, 9% diesel, 9% natural gas, and 4% wind for the total number of technologies utilized across the installations. For the two installations that became operational from 2022 to 2024, one installation has a solar and storage system, and the other is a CHP system. The majority of Colorado's installations have more than one technology per installation, with 9 out of the 10 installations prior to 2022 having solar generation.



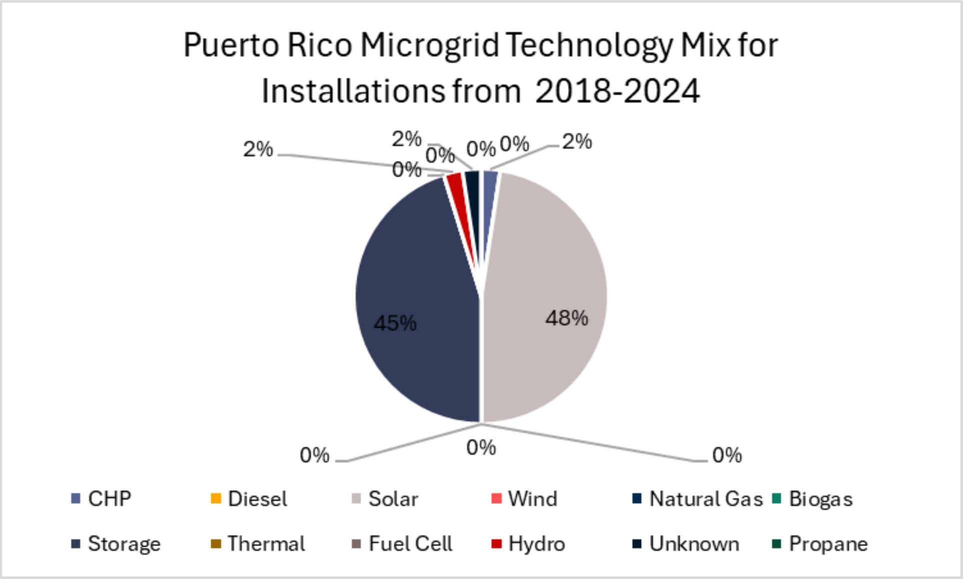


Figure 4: Puerto Rico Technology Mix

Of the two installations operating prior to 2018, one microgrid was a solar and wind facility, while the other was a system with solar and storage. Of the 21 installations that became operational from 2018 to 2024, the majority out of the total technologies represented include 48% solar and 45% storage, and the remaining known 4% include CHP (2%) and hydro (2%). A large proportion of the installations operational in 2018 or later include a solar and storage system, with 15 out of the 21 installations being comprised of a combination of solar and storage.

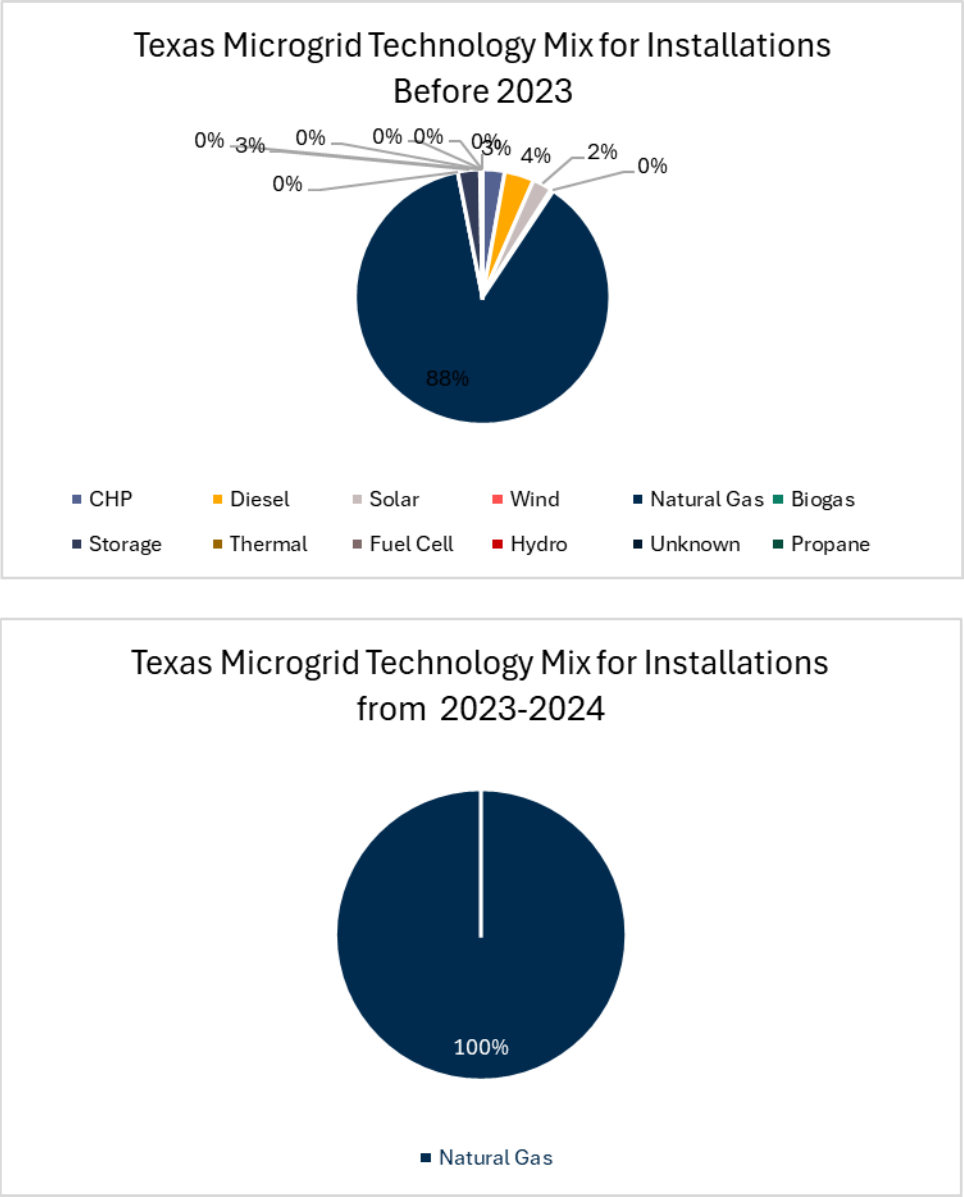


Figure 5: Texas Technology Mix

Of the 302 installations that became operational prior to 2023, the majority of total technologies across installations include 88% natural gas, 4% diesel, 3% CHP, 3% storage, and 2% solar. Of the 21 installations that became operational during 2023, all 26 installations rely entirely on natural gas. The technology profile of Texas has the diversity in technology composition out of the case studies.

4.3.3 Policy evaluation

Table 9: Completed Evaluation

			Energy Resilience			
Criteria:	*Efficacy*	*Cost*	*Sustainability*	*Coping with shocks*	*Addressing vulnerability*	Score:
Scoring Definitions	**Low**: Unclear minimum standards for infrastructure **Medium**: Clear minimum standards for infrastructure **High**: Clear and mandated minimum standards for infrastructure	**Less favorable**: No funding source. **Favorable**: Moderate aims to meet funding needs. **More favorable**: Adequate aims to meet funding needs.	**Low**: Meets neither sub-criterion **Medium**: Meets one sub-criteria **High**: Meets both sub-criteria	**Low**: Meets one sub-criteria **Medium**: Meets two sub-criteria **High**: Meets three or more sub-criteria	**Low**: Meets one sub-criteria **Medium**: Meets two sub-criteria **High**: Meets three sub-criteria	**Level 1: 1 pt** **Level 2: 2 pts** **Level 3: 3 pts** **___ total out of 15 points**
Policy 1 **California**	☐ Low ☐ Medium X High	☐ Less favorable ☐ Favorable X More favorable	☐ Low X Medium ☐ High	☐ Low ☐ Medium X High	☐ Low ☐ Medium X High	**14 total points**
Policy 2 **Colorado**	X Low ☐ Medium ☐ High	☐ Less favorable ☐ Favorable X More favorable	☐ Low X Medium ☐ High	☐ Low X Medium ☐ High	☐ Low ☐ Medium X High	**11 total points**
Policy 3 **Puerto Rico**	☐ Low ☐ Medium X High	X Less favorable ☐ Favorable ☐ More favorable	☐ Low ☐ Medium X High	☐ Low ☐ Medium X High	☐ Low ☐ Medium X High	**13 total points**
Policy 4 **Texas**	☐ Low X Medium ☐ High	☐ Less favorable X Favorable ☐ More favorable	X Low ☐ Medium ☐ High	☐ Low X Medium ☐ High	X Low ☐ Medium ☐ High	**8 total points**

4.4 Discussion

The Bipartisan Infrastructure Law and the selected provisions are a set of funding programs that primarily establish statutory priority of DG and support the transition to microgrids and democratized grid management. When considering the characteristics of these programs, they are comprehensive in covering all areas of needed infrastructure improvements for distributed generation (i.e., generation, distribution, transmission, innovation). However, when considering the application of some programs, there is a lack of measures that call for standardization of state's processes in the distribution of funds. For example, the Grid Resilience State and Tribal Formula Grants program determines the amount of the award using the program formula, and the awarded funds are then distributed to projects within the state, territory, or tribe, based upon a "competitive selection process." However, by allowing the selection process to be at the liberty of the state, territory, or tribe, it allows for variation in minimum standards, priorities, and quality of both the screening process and the project outcomes. The benefits and drawbacks of this approach is that there is room for the funds to be best allocated to the specific needs of the state, territory, or tribe, yet the minimum standards of the selection process for some areas could be less rigorous than other. This has implications considering whether projects that apply for funding target critical needs or disadvantaged communities, in actuality or to a great extent. Additionally, the voluntary nature of the program, and awarding funding on an application basis, means that states, territories, and tribal groups, have to opt-in to the program and could forego applying for funding. The process and voluntary program contribute to the quantitative targets for the program being not clearly defined. Additionally, another area where the BIL could be more robust is in the establishment of renewable energy portfolio standards.

Table 9 displays the completed evaluation for each state policy according to the evaluation criteria. The state-level policy documents examined are reflective of the vast variability in state policy within the United States. Despite having a significant generation capacity from microgrids within the state of Texas, the energy resilience of the policy and current installations score relatively low compared to the other states examined within the case series. This is due to the less stringent, or even absent, requirements for sustainability, coping with shocks, and addressing vulnerability. These shortcomings have implications for the state when considering how their grid has pressing needs for resilience in the aftermath of extreme weather events like Winter Storm Uri. Most of the generation in the state is from natural gas and CHP installations, which will allow for coping with shocks from a disturbance, but also reflects the lack of long-term sustainability measures. California, Puerto Rico, and Colorado score somewhat similarly when considering their commitment to energy resilience. Colorado's policy is somewhat underdeveloped in the specific technical standards necessary for a technological solution like microgrids. The planning for microgrid implementations is well developed and reflects a co-creation process, but expert advisory is needed to further develop the technical requirements for installations within the state, and to better require redundancy features. Colorado also has a portfolio of installations that has CHP as a majority source but has a lower overall total generation capacity than Texas. Puerto Rico excels in its commitment to energy resilience, largely due to the level of detail within the requirements and standards of the microgrid regulation. This is a natural product of the overall objective of the island to utilize microgrids as the base for the modernization of their energy infrastructure and integration of renewables. This is reflected by the market trends showing the majority generation sources being solar and hydro, the high growth rates compared to the other states, and the growth of storage technology after the implementation of the policy. Puerto Rico lacks some of the funding backing from the territory’s government, however, there is a significant availability of funding from the federal government explicitly for Puerto Rico’s Grid Recovery and Modernization, facilitated by the DOE. California has the highest scoring policies due to the comprehensiveness of the policy, detailed standards, and commitment to energy resilience. This is also reflected in the market trends of the state’s portfolio, as they have a diverse mix of technologies, growth in the proportion of solar and storage within installations, and exhibited growth following the implementation of the policy. Where all policies could improve could be in the voluntary nature of their policies, there are not any minimum mandated generation capacities from microgrid installations throughout the state, which is a shortcoming in the sense that the primary concern of these policies is to increase the uptake of microgrid technologies. In addition, the policies lack some necessary elements of procedural and structural justice, with most policies addressing that there are priority needs for vulnerable and disadvantaged communities at a surface level.

5. Conclusions

5.1 Answering the research questions

What are the characteristics of national-level infrastructure policies in relation to decentralized energy production? What role does national-level infrastructure policy play in promoting energy resilience?

From the content review of the BIL and the selected provisions, the policies related to decentralized energy production can primarily be characterized as major infrastructure funding programs providing the contextual foundation for future energy systems change and financial measures for energy resilience. The policy instruments that have the most crossover between the provisions are the statutory priority of DG and support the transition to microgrids and democratized grid management. The statutory priority of DG facilitates shifting away from the fossil fuel industry and traditional production, as well as restructures the energy sector; while the microgrids and democratized grid management relates strongly to the localization of energy production and consumption (Burke & Stephens, 2017).

Most of the provisions include objectives centered around increasing resilience and reliability of service, particularly in rural areas, or making the grid less vulnerable. Where sustainability falls short in the national-level infrastructure policies is with the lack of renewable energy portfolio standards. Specific renewable energy standards are still deferred to states, and, as of 2023, only 28 states and the District of Columbia have RPS (U.S. Energy Information Administration, 2024). Additionally, the national-level policy can fall short in addressing the local implementation of microgrid projects, as introduced in the discussion.

To what extent do state-level policy frameworks support microgrids as an implementation strategy for decentralization of energy production and increasing energy resilience? How are incentivizes, standards, and regulations employed within these frameworks?

From the content review and policy evaluation, microgrids are supported to a considerable extent across the state policies examined, and many focus on goals of increasing energy resilience. For most states, this includes the integration of renewable energy, coping with power shutoff events, and distributing the benefits of the projects on the local scale, or specifically prioritized vulnerable populations. However, addressing vulnerability is somewhat weak across the policies.

The state policies examined do not employ incentives within their policies, but most provide some level of funding source for projects, which allows for greater enforcement of the policy (Hu et al., 2023). Minimum standards for microgrids are somewhat missing across the state-level policy documents. In some cases, this is due to the policies being interim planning or non-regulation-focused policies. When regulations are employed, they tend to enumerate what proportion of microgrid projects should be renewable generation, minimum generation requirements, different definitions of microgrid types, and requirements for potential storage capacity.

How has market penetration of microgrids changed in the period after the enactment of each state-level policy on microgrids? Do market trends (i.e., technology mix, state-level production capacity, and growth rates) reflect state policy objectives and resilience best practices?

From the results of the market trends analysis, all states had experienced growth in their market share of microgrids following the implementation of the policy, with the greatest CAGR growth rates in Puerto Rico (21.1%) and Colorado (4.31%). Although, rapid growth in Puerto Rico could also be attributed to the necessity of building back infrastructure following high-damage hurricanes in 2017 (Hibbert, 2023). The market trends also generally follow the state policy objectives, as most saw a rise in the proportion of storage and renewable generation sources, particularly solar, following the implementation of the policy, which is consistent with Ang et al (2022). The exception to this trend is Texas, as the market has only seen natural gas installations added to its portfolio. This reflects the state policy, as renewable energy is typically mentioned by definition only, but it does not reflect resilience best practices of integrating renewables.

5.2 Recommendations

At the national level, the primary recommendation is to establish RPS standards for states that apply for funding from the grant programs. This can also be extended to the state-level, particularly for Colorado and Texas. In addition, both the national- and state-level can strengthen their minimum standards for installations and projects that are awarded funding. The aspect of energy resilience that can be most strengthened is addressing vulnerability. Many of the policies do not consider, or only mention in passing, the impacts of microgrid projects on the local community or prioritizing vulnerable, or disadvantaged communities. This is a major deficit, as the primary concern of energy service providers, in this context, is to serve people, and this element is lacking from the discussion surrounding resilience and reliability. This should be addressed through methods that suit the context; however, it could look like increasing co-creation and cooperative opportunities, creating energy investment districts, or establishing more detailed CBAs.

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