Climate Change in Vulnerable Communities: U.S. Mitigation Policy and Environmental Justice

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Abstract

Climate change has already damaged environments, ecosystems, and communities around the world, and without bold policy responses, these impacts are projected to intensify throughout the twenty-first century. In the United States, climate change disproportionately harms the nation's most vulnerable communities: low-income Americans and communities of color who lack the resources to respond to the degradation of their environments, health, communities, and economies. As the U.S. considers policies to mitigate climate change, policymakers must craft solutions to alleviate the inequitable distribution of costs from carbon pollution and incentivize the early retirement of carbon-emitting infrastructure.

Introduction

Across the globe, fossil fuel production and consumption drive climate-related degradation of the environment. According to the International Energy Agency (2020), the world economy produced roughly 566 quads of energy in 2019 with 90.6% coming from oil, coal, natural gas, and biofuels/waste.[1] The U.S. alone produces roughly 100 quads of energy per year and contributes significantly to global carbon dioxide (CO_2) emissions and the rising atmospheric CO_2 concentration (Office of Energy Statistics, 2021). Rising atmospheric CO_2 levels lead to increases in global mean temperatures. These heightened global temperatures trigger the melting of polar and glacial ice, causing higher sea levels, and accelerate the occurrence and intensity of heatwaves, droughts, ocean acidification, storm damage, flooding, wildfires, and shifting species distributions. Additionally, the production and consumption of fossil fuels to meet energy demand discharge air, ground, and water pollution into the surrounding environment.

As deteriorating ecosystems deepen their impact on the health, communities, and economic stability of people around the world, the U.S. faces a crisis of widening inequality. Lower-income Americans and communities of color lack the resources to respond to climate change. Income inequality in the U.S. has increased by about 20% since 1980, and only the top fifth of households have gained wealth since the Great Recession (Horowitz et al., 2020). According to Bhutta et al. (2020) at the Federal Reserve, Black and Hispanic households hold only 13% and 19% of the median wealth of white households, respectively. As a result, the U.S. faces a climate crisis that leaves the nation's most vulnerable communities exposed, while wealthier Americans can guard against the most severe climate impacts.

To mitigate the harmful effects of climate change, the United Nations Intergovernmental Panel on Climate Change (IPCC) has set an ideal target to limit global temperature increase to 1.5° C above pre-industrial levels (Griffith et al., 2020). Similarly, parties to the Paris Agreement, which President Biden recently rejoined on behalf of the U.S., have agreed to limit global warming to 2° C while pursuing efforts to achieve the IPCC's target of 1.5° C (United Nations Framework Convention on Climate Change, 2018). However, the IPCC predicts that a continuation of current international energy policies will increase global mean temperatures between 2.7° and 3.1° C, and current pledges by world governments correspond to a projected 2.3° to 2.6° C increase. Without carbon-free energy policies, baseline temperatures could increase by 4.1° to 4.8° C (Climate Action Tracker, 2020).

The world can achieve meaningful limits on global average temperatures and reduce the effects of climate change through the adoption of carbon-free technology. However, the fossil fuel market has

[1] One *quad* is equivalent to roughly 25.21 million tons of oil equivalent (*Mtoe*) or one quadrillion (10^{15}) British Thermal Units (*BTUs*).

ensured a baseline frequency of climate disruption through at least the next century, and these negative externalities disproportionately harm low-income and marginalized communities across the U.S. Clean energy subsidies and financing can harness existing technology to achieve a high electrification of the economy, incentivize the early retirement of carbon infrastructure, and ensure vulnerable communities receive the benefits of carbon-free energy. Without a focused policy response to these market failures, the country may miss an opportunity to meet IPCC and Paris Agreement targets and lower the intensifying costs of climate change for the nation's most vulnerable communities.

Climate Disruption in the United States

Figure 1 identifies four primary factors that contribute to the disparate impacts of climate change on low-income communities in the United States: (1) natural disasters and ecosystem change, (2) health outcomes, (3) community stability, and (4) economic loss and insecurity.

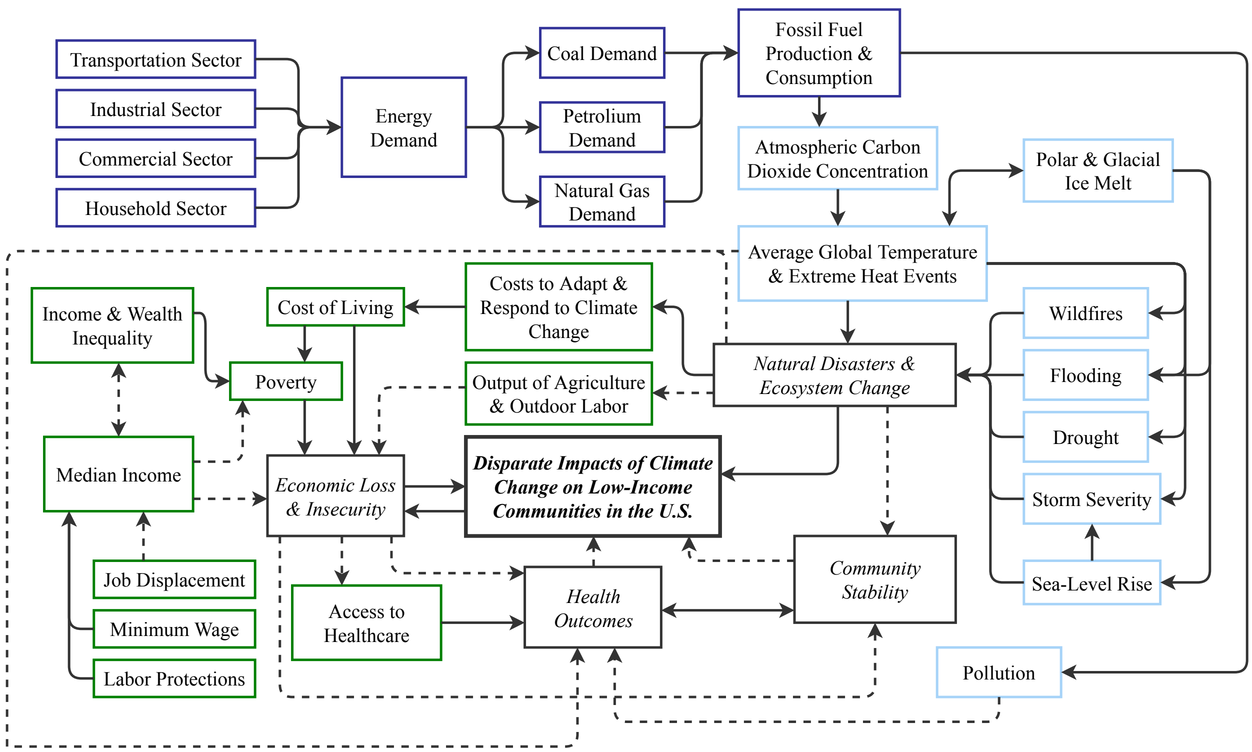

Figure 1: *Causal-loop diagram illustrating how fossil fuel externalities intersect with natural systems and socioeconomic factors to disproportionately impact low-income communities in the U.S. Solid lines denote direct relationships and dotted lines denote inverse relationships.*

Natural Disasters and Ecosystem Change: Climate change causes severe damage to local and regional ecosystems throughout the U.S. and increases the frequency and severity of natural disasters. In coastal communities, melting polar and glacial ice has caused mean sea level to rise by 7 to 8 inches since 1900. The Atlantic seaboard faces the most risk, as relative sea-level rise in this region is projected to outpace a global mean sea-level rise of up to 1.2 feet by 2050 (Sweet et al., 2017). Coastal communities, Hawai'i, the U.S. Pacific Islands, and the Caribbean face saltwater contamination of drinking water sources (Reidmiller et al., 2018). Inland regions confront flooding as well, especially in the Midwest and Northeast, as the severity of heavy precipitation events increases. Meanwhile, more frequent and intense droughts in the Southwest and Southern Plains threaten drinking water accessibility due to decreased snowpack, depleted groundwater, and lengthened summer dry seasons (Jay et al., 2018; Lall et al., 2018). Longer dry seasons with lower mean precipitation fuel wildfires across the western U.S. Throughout this region, human-caused climate change is estimated to have doubled the area of forests burned between 1984 and 2015 (Abatzoglou & Williams, 2016).

Health Outcomes: Climate change worsens health outcomes for Americans across the country. Extreme heat threatens public health, especially in the Southwest, Southeast, and Upper Midwest. By 2050, the average American will endure between 27 and 50 days over 95° F—two to three times the average over the last three decades (Gordon et al., 2014). Extreme heat contributes to illnesses including cardiovascular and respiratory complications, dehydration, preterm birth, and kidney disease, with older adults, children, and pregnant women facing the most risk (Ebi et al., 2018).

Increased temperatures also expand the distribution of vector-borne illnesses as the range of mosquito and tick species expands, spreading diseases such as West Nile, Zika, Dengue, and Lyme Disease. The most common vector-borne disease in the U.S., Lyme Disease incidence has more than doubled since 1991 as deer ticks spread across the Northeast and Midwest (Division of Vector-Borne Diseases [DVBD], 2021; Office of Atmospheric Programs [OAP], 2016). The risk of West Nile virus, the most common mosquito-borne illness in the country, will continue to increase as climate change accelerates mosquito development (OAP, 2016). Though Zika and Dengue have impacted Central and South America most acutely in the Western Hemisphere, hotter temperatures heighten the risk of these diseases in Puerto Rico, the U.S. Virgin Islands, and the Caribbean while threatening southern states in the continental U.S. (DVBD, 2019; DVBD, 2020). Further, rising ocean and inland surface-water temperatures combine with the more severe runoff of heavy precipitation to contaminate potable and recreational water sources with excess nutrients, pollutants, and illness-causing bacteria, viruses, and algae (Ebi et al., 2018).

Nationwide, fossil fuel production and consumption degrade air quality. Over 100 million Americans live in communities where air pollution exceeds health-based air quality standards (Nolte et al., 2018). Fossil fuel burning disperses particulates into the air and increases ground-level ozone. Wildfire smoke poses additional risks to air quality, and increased temperatures and atmospheric CO_2 lengthen the pollen season, increase pollen production, and heighten human immune response to airborne allergens. Together, air pollution contributes to respiratory and cardiopulmonary illness and premature death among the general population (Nolte et al., 2018).

Furthermore, the climate effects of the fossil fuel market threaten the mental health of Americans. Individuals who experience a natural disaster or face an increased risk of natural disasters suffer from higher rates of depression, anxiety, and post-traumatic stress (Fritze et al., 2008). As a result, communities experience increased alcohol and tobacco use after natural disasters (Ebi et al., 2018). As the climate changes, forced displacement, loss of income, and destabilized communities further threaten public mental health.

Community Stability: The third and fourth primary factors identified in this analysis impact a community's ability to respond to changing social, economic, environmental, and health risks. The human geography of a community informs its structure, economy, and cultural identity, all of which a changing environment threatens to destabilize. As drought and wildfire events increase in frequency, annual crop yields in the Midwest are expected to decrease 10% by 2040, and the Southwest and Southern Plains could see yield losses up to 50% by 2100 (Gordon et al., 2014). Even if U.S. agriculture at-large adapts to a changing climate, local farming communities face further insecurity and destabilization.

Sea-level rise and increased storm severity threaten to displace communities across the country, and wildfires will continue to uproot communities and impede wildlife-related activities such as hunting and fishing in the western U.S. (Reidmiller et al., 2018). Regions reliant on tourism endure economic damage as the natural environment shifts. Rising ocean temperatures and acidification diminish marine biodiversity, threatening both fishing and tourism in coastal regions (Reidmiller et al., 2018). In Native communities, livelihoods often rely on industries most affected by climate change, including agriculture, forestry, hunting, fishing, recreation, and tourism (Jantarasami et al., 2018). Further, environmental degradation impedes indigenous spiritual and cultural practices tied to their land and natural environment (Jantarasami et al., 2018). For communities built around these industries and natural systems, climate change threatens their cultural identity and economic security as industries, jobs, and people are displaced.

Economic Loss and Insecurity: Though economic security and community stability intertwine, the U.S. faces unique challenges to its economy from climate change. Increased runoff from heavy precipitation and coastal flooding will stress already deteriorating water infrastructure across the country and introduce pollutants and excess nutrients into the potable water supply (Lall et al., 2018). By 2030, sea-level rise and storm surges are estimated to increase the annual cost of coastal storms in the U.S. by $3.5 billion, with annual economic losses from hurricanes amounting to $7.5 billion (Gordon et al., 2014). While threatening fishing and coastal tourism industries, current CO_2 emission levels place sea-level rise on track to submerge between $66 and $106 billion of coastal property nationwide by 2050 (Gordon et al., 2014). The projected mismatch of water demand and supply from drought will further stress water accessibility and infrastructure (Reidmiller et al., 2018).

In the transportation sector, heightened temperatures and storm severity may expand service disruptions and introduce energy shortages. Within the energy sector, rising temperatures decrease the efficiency of thermo-combustion energy generation and increase demand for electricity to power air conditioning (Reidmiller et al., 2018). This would require up to 95 gigawatts of new energy supply and cause a $12 billion annual increase in energy costs over the next 20 years, straining the country's electric grid as natural disasters impair energy infrastructure (Gordon et al., 2014).

For the agricultural industry, decreased crop yields in the Midwest, Southern Plains, and Southwest are expected to offset increased yields in the North and Upper Great Plains (Gordon et al., 2014). This could disrupt the price stability of commodity crops and raise food prices for Americans across the country (Reidmiller et al., 2018).

Market Failures and the Costs for Low-Income Americans

Through natural disasters and destabilized ecosystems, worsened health outcomes, damage to local communities, and economic insecurity, the fossil fuel market levies costs onto Americans that the price of fossil fuel-based energy does not reflect. These negative externalities constitute a market failure that warrants policy considerations. Instead of bearing the full costs of production, carbon-based energy suppliers externalized their most harmful costs through free access to the atmosphere. People across the U.S. and around the world face the cost of this carbon pollution in damages to their health, communities, livelihoods, and environments.

The upper and right sections of *Figure 1* display how the carbon-based energy system results in the environmental impacts of climate change. The lower and left sides trace the contributing factors that lead to the disparate impacts on low-income communities. People of color, especially Black, Hispanic, and Native communities, experience higher rates of poverty and lower median incomes than the national average (Semega et al., 2020; Jantarasami et al., 2018). At both the individual and community levels, these populations have higher rates of economic insecurity, increased costs of living relative to income, and limited access to healthcare. Low-income Americans spend as much as 25% of their income on food, electricity, and water—basic necessities with rising costs due to climate change (Morello-Frosch et al., 2009). These communities have fewer resources to invest in deteriorating water and power infrastructure to combat rising costs. Meanwhile, low-income workers populate the industries most harmed by fossil fuel externalities, including agriculture, tourism, and recreation. Reduced output in outdoor labor industries could decrease labor productivity by up to 3%, further threatening income sources for these communities (Gordon et al., 2014).

Lower-income outdoor workers in construction, utilities, agriculture, and landscaping also face heightened health risks from extreme heat and air pollution. Low-income Americans and people of color are more likely than higher-income and white Americans to live near sources of fossil fuel pollution. Additionally, heat islands in low-income urban neighborhoods increase surface-level temperatures (Morello-Frosch et al., 2009), and these Americans often lack air conditioning or the transportation to access cooler areas with less asphalt and more tree cover during extreme heat events (Ebi et al., 2018). While climate change increases the transmission of vector-borne diseases, research indicates that economic development and housing improvements can lower the transmission of these diseases. However, low-income populations experience higher rates of housing insecurity, and with limited access to healthcare, struggle to prevent and treat climate-related health conditions (Ebi et al., 2018).

As previously noted, indigenous nations suffer unique impacts from climate change, and the threat of community displacement evokes similar experiences of settler colonialism for these communities. Native Americans on tribal lands earn only 69% of the national median income, and federal trust authority over their lands frustrates the ability of tribal nations to mitigate and adapt to climate change (Jantarasami et al., 2018).

These unique circumstances illustrate how low-income and vulnerable communities bear the greatest costs of climate change in the United States. This distributive failure creates an unjust burden on low-income Americans alongside an inequitable degradation of the earth's biosphere. Because the fossil fuel market has failed to internalize the wide array of costs it levies on the nation's most vulnerable communities, this market warrants the consideration of policies that protect these communities and ensure the energy market efficiently and equitably meets the nation's energy demand.

Mitigation Options for a Carbon-Free Economy

With an appropriate policy response, the U.S. can lower the disparate costs of climate change for the nation's most vulnerable communities. This article continues with an analysis of current policy against the projected outcomes of two carbon-free policy options that could mitigate disparate climate impacts, accelerate the economy's transition towards net-zero CO_2 emissions, and position the U.S. to meet IPCC and Paris Agreement targets.

A limit of 1.5° to 2° C would significantly reduce the effects of climate change, especially for low-income communities. To achieve this goal, global CO_2 emissions must reach net-zero levels by 2050 (Tong et al., 2019), and the IPCC projects that a continuation of current international energy policies will increase global mean temperatures by 2.7° to 3.1°C (Climate Action Tracker, 2020). However, the IPCC assumes the early retirement of existing CO_2-producing infrastructure in its projections (Griffith et al., 2020). When considering the committed emissions of existing infrastructure over their average lifetimes, global temperatures will increase by an estimated 1.5° to 2° C—even if every country immediately achieved a 100% zero-carbon adoption rate for all new energy infrastructure (Tong et al., 2019).

Eliminating CO_2 emissions in the electricity market can dramatically reduce total CO_2 emissions and promote electrification over other energy sources, thus maximizing the benefits of existing carbon-free technology while incentivizing early retirements. This article examines the following federal policy options in consideration of the IPCC and Paris Agreement targets.

- *Policy Option A:* Subsidize and finance the purchase and installation of distributed renewable energy infrastructure (e.g., rooftop solar, solar gardens, small-wind systems, and storage batteries).

- *Policy Option B:* Subsidize and finance the construction of centralized carbon-free electricity generation (e.g., large-scale solar and wind farms, hydroelectric systems, and nuclear power stations).

Option A: Distributed Renewable Energy

The *status quo* energy market and regulatory system arose from the natural monopoly of centralized energy generation, transmission, and distribution. Direct competition between centralized utilities would require redundant, overlapping infrastructure with reduced economic efficiency. Therefore, states and the federal government grant legal monopolies to investor-owned utilities, and in exchange, public utility commissions set prices at non-monopoly levels (Tomain, 2014). Alternatively, distributed energy generation from solar and small wind systems can increase competition, lower energy prices, and decrease climate impacts through reduced CO_2 emissions, curtailed pollution, and increased electricity supply.

The *Appendix A Logic Model* outlines how subsidies and financing for distributed renewable energy (DRE) systems can decarbonize the economy through the adoption of rooftop solar and small-wind systems *(Intermediate Outcome 1a)*. With the widespread adoption of DRE systems, this report predicts net electric costs would decrease for consumers (*I.O. 2a*) through increased market efficiency, revenue from excess supply, and reduced reliance on utility-provided power. Increased installation rates and lower electric costs result in reduced CO_2 emissions (*I.O. 3a*). Steady reductions in CO_2 emissions to net-zero by 2050 can achieve IPCC and Paris Agreement targets while mitigating the disparate climate effects on low-income communities.

However, *Logic Model A's* outcome pathway poses risks that require policy consideration. Difficulties in calculating appropriate subsidies and financing incentives could reduce DRE installations. Therefore, this analysis recommends *Fix 1a*, which would require utilities to buy excess supply from DRE systems at the market rate per kilowatt-hour (kWh). Currently, the National Energy Act requires utilities to buy excess supply at their marginal cost of production per kWh, allowing utilities to profit from excess DRE supply (Tomain, 2014). The benefits of DRE systems increase under a market-rate requirement. Second, tax credits in *Fix 2a* cover the out-of-pocket capital costs for DRE consumers, supplemented by increased financing if adoption rates remain low. Tax credits reduce costs for lower- to middle-income consumers with low tax liability, raising benefits and broadening installation rates.

Fix 3a ensures the decreasing share of utility-dependent consumers do not face the rising capital costs of utility transmission and distribution (T&D) through cross-subsidization. Federal policy can decouple the capital costs of service connection and grid maintenance from the capital costs of generation. All service connections, including DRE system owners, would pay for their connection to the grid. *Fix 4a* requires landlords and property management companies to connect their DRE systems to renters and share revenue from excess supply, but they still receive benefits from subsidies, financing, tax breaks, and revenue shared with renters from market-rate excess supply. Together, these fixes can ensure *Option A* equitably distributes benefits to low-income populations.

This article recommends *Fixes 5a and 6a* to calibrate *Option A* to meet IPCC and Paris Agreement targets. If subsidized DRE systems fail to out-compete fossil fuel energy because of time costs, constrained DRE supply, and/or increased energy consumption from lowered electric prices, *Fix 5a* would tax CO_2 emissions to internalize the costs of carbon pollution. Levying and escalating carbon taxes during implementation would deter the consumption of fossil fuels while promoting carbon-free electrification and early retirements of fossil fuel infrastructure throughout the energy sector.

A streamlined subsidy and financing process alongside public information campaigns can also address consumer reluctance to adopt DRE systems. Nonetheless, consumers will still rely on utility-provided electricity for standby power. *Fix 6a* incorporates *Option B* into this recommendation to ensure that centralized electricity maintains service reliability while meeting CO_2 emissions targets.

Option B: Centralized Carbon-Free Energy

The current U.S. electricity market increasingly depends on natural gas to fuel power plants alongside the significant but declining use of coal-fired plants (Zamuda et al., 2018). Without an accelerated carbon-free energy transition, rising temperatures will decrease the generation efficiency of thermoelectric combustion plants, requiring the construction of up to 25% more generation capacity by 2040 and increasing CO_2 emissions (Zamuda et al., 2018). Combustion generation also needs cooling water, yet by 2050, increased surface-water temperatures and decreased water availability could reduce production output potential by 7.3% to 13.1% (Van Vliet et al., 2016).

The *Appendix B Logic Model* details how *Option B* can stabilize electric costs and service through subsidies and financing for centralized carbon-free electricity generation, ultimately achieving net-zero CO_2 emissions. This analysis predicts that subsidies and financing will increase the construction of large-scale carbon-free energy *(I.O. 1b)*, allowing a centralized electricity market to reach net-zero emissions by 2050 *(I.O. 2b)*. Reaching this target set by the IPCC and Paris Agreement would reduce the disparate impacts of climate change on low-income communities *(End Outcome)*. However, as with

Option A, relying on subsidies and financing alone to reach net-zero carbon emissions produces significant risks that require policy fixes.

Ideally, a carbon-free energy subsidy would equal the marginal social benefit of carbon-free energy. However, difficulties with calibrating the subsidy and transitioning to new technology could prevent the use of carbon-free technology for all new generation. To reach net-zero carbon emissions by 2050 and a 1.5° to 2° C limit on global warming, the U.S. (and other major carbon-emitting economies) must force the early retirement of CO_2-emitting infrastructure. Considering these risks, *Fix 1b and 2b*, respectively, provide tax deductions to utilities for the capital costs of a carbon-free transition and tax CO_2 emissions to incentivize the early retirement of fossil fuel infrastructure. Additionally, solar and wind power can threaten service reliability during intermittent weather (Zamuda et al., 2018), so *Fix 3b* includes federal funding and financing for the deployment, research, and development of electricity storage facilities, demand-side management technologies, hydroelectric stations, and nuclear power.

This outcome pathway assumes *Option B* policies and the improved efficiency of non-combustion generation can incentivize early retirements of carbon infrastructure across the economy. Alongside carbon taxes, *Fix 4b* sets regulatory emissions standards that gradually increase behind carbon taxes to achieve net-zero emissions. This supply-side backstop ensures the U.S. energy sector meets commitments under the Paris Agreement. *Fix 5b* recommends joint enactment with *Option A* to ensure that federal policy achieves net-zero emissions and equally distributes the benefits of carbon-free energy.

Weighing the Outcomes of Policy Action

Appendix C weighs the predicted outcomes of current policy with *Option A* and *Option B* in an outcome matrix, and it shades criteria in gray for which joint implementation of both alternate options would improve outcomes. The goals of this analysis seek to maximize effectiveness, reduce costs, and limit negative side-effects while considering feasibility and promoting equity. The *status quo* fails to accomplish all three criteria for effectiveness, justifying consideration of policy alternatives to achieve (1) net-zero carbon emissions, (2) improved efficiency to meet increased energy demand, and (3) reduced impacts of climate change on low-income communities.

This analysis predicts that both policy alternatives could reach net-zero carbon emissions by 2050, depending on the rate of implementation. However, joint implementation provides more pathways to reach all three effectiveness goals and room for error in setting appropriate subsidies, financing, and tax levels. For example, DRE systems decrease the need for centralized generation, allowing policymakers more room to consider the costs and benefits of widespread nuclear power. The uncertainty of climate sensitivities, environmental projections, and economic predictions makes such considerations vital to successful climate change mitigation.

The *status quo* and both policy alternatives levy increased costs on the government and investor-owned utilities, but the immediate costs of transitioning under *Options A and B* exist in the short-term, while under current policy, the costs of climate change will increase at a higher rate over the long-term. Both policy alternatives offer significant reductions in consumer cost per kWh, providing further evidence for a high-electrification strategy. Considerably, projections in the existing literature and the logic modeling of this analysis predict the greatest decrease in consumer energy costs under varying combinations of both policy alternatives.

This report examines equity through two measures: (1) the predicted proportion of renters to homeowners receiving electricity from distributed generation, and (2) the predicted average renter cost per kWh as a percentage of average property owner cost per kWh. Low-income households in the U.S. are more likely to rent their home than higher-income households (U.S. Census Bureau, 2020). Low-income, Black, and Hispanic Americans also endure higher rates of rent burden than moderate- to high-income and white Americans (U.S. Government Accountability Office, 2020).[2] Tailoring mitigation policy to these equity criteria would widen the availability of renewable energy and ensure low-income

[2] The U.S. Department of Housing and Urban Development considers households to be rent burdened if they pay greater than 30% of their income in rent.

communities do not pay higher energy costs through cross-subsidization. Both current policy and *Option B* fail to achieve an equal proportion in the first equity criteria or 100% in the second equity criteria. *Option A* achieves the highest equity of any individual option in both criteria, but joint implementation further increases equity.

Service reliability measures the side effects of each policy scenario. This article's problem analysis examines how natural disasters, extreme heat events, demand surges, and deteriorating grid infrastructure threaten the reliability of electric service, and current policy poses the highest risk in this category. Decentralized DRE systems protect service reliability from natural disasters, demand surges, extreme heat, and national security threats, but variable weather patterns could impair service without proper energy storage technology and standby power from centralized generation. The centralized generation of *Option B* faces the inverse risks to service reliability while joint implementation best protects the reliability of electric service.

This article analyzes feasibility through (1) potential roadblocks to implementation and (2) political considerations. The *status quo* requires no new legislative or regulatory changes, but public utility commissions and elected officials may face pressure to reduce costs and improve service reliability as climate change weakens grid infrastructure and affects the price and supply of electricity—as experienced in the 2021 Texas Power Crisis. Both alternate options require substantial action through new federal legislation alongside administrative and regulatory costs. Under both policy alternatives, carbon taxes and the devaluation of fossil fuel assets and investments may spur considerable pressure to soften policies that internalize the cost of carbon pollution. Additionally, *Fix 4a* could build political pressure from property owners to lessen the sharing of DRE-system benefits with renters.

Conclusion

As the impacts of climate change increase over the next decade, the U.S. and international community enter a critical window for mitigation policy action. IPCC projections and commitments under the Paris Agreement require policymakers to consider a wide range of proposals to achieve net-zero carbon emissions by 2050 and incentivize the early retirement of fossil fuel infrastructure. This analysis supports the joint implementation of two policy options to meet these goals through the subsidization and financing of DRE systems, centralized carbon-free power generation, and high electrification of the economy. Though climate change remains a global concern, the negative externalities of fossil fuels have left low-income communities and people of color uniquely susceptible to its impacts within the U.S. This policy problem demands a government response to protect the nation's most vulnerable communities, and successful climate action could position the U.S. to stimulate the world's transition to carbon-free energy.

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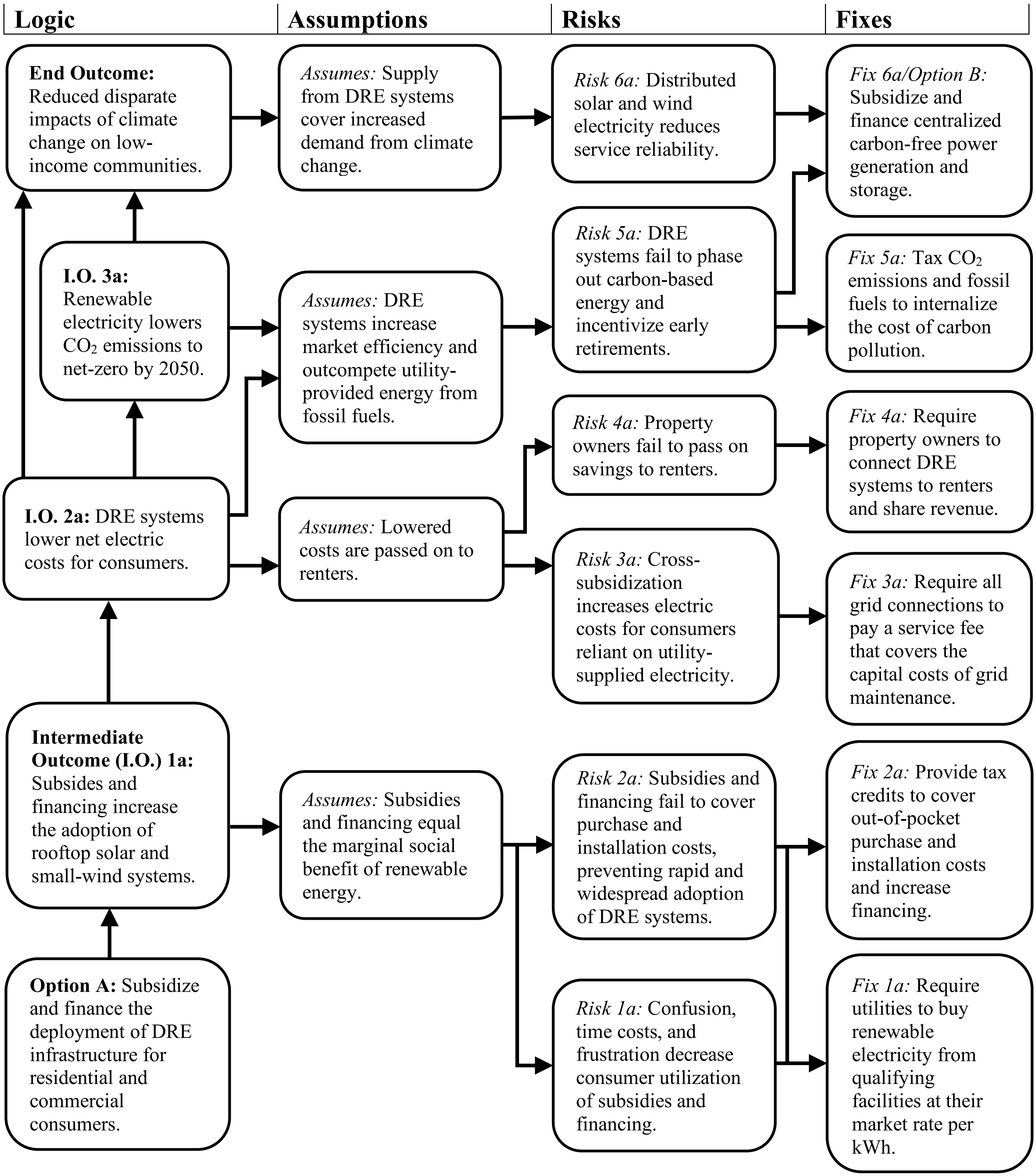
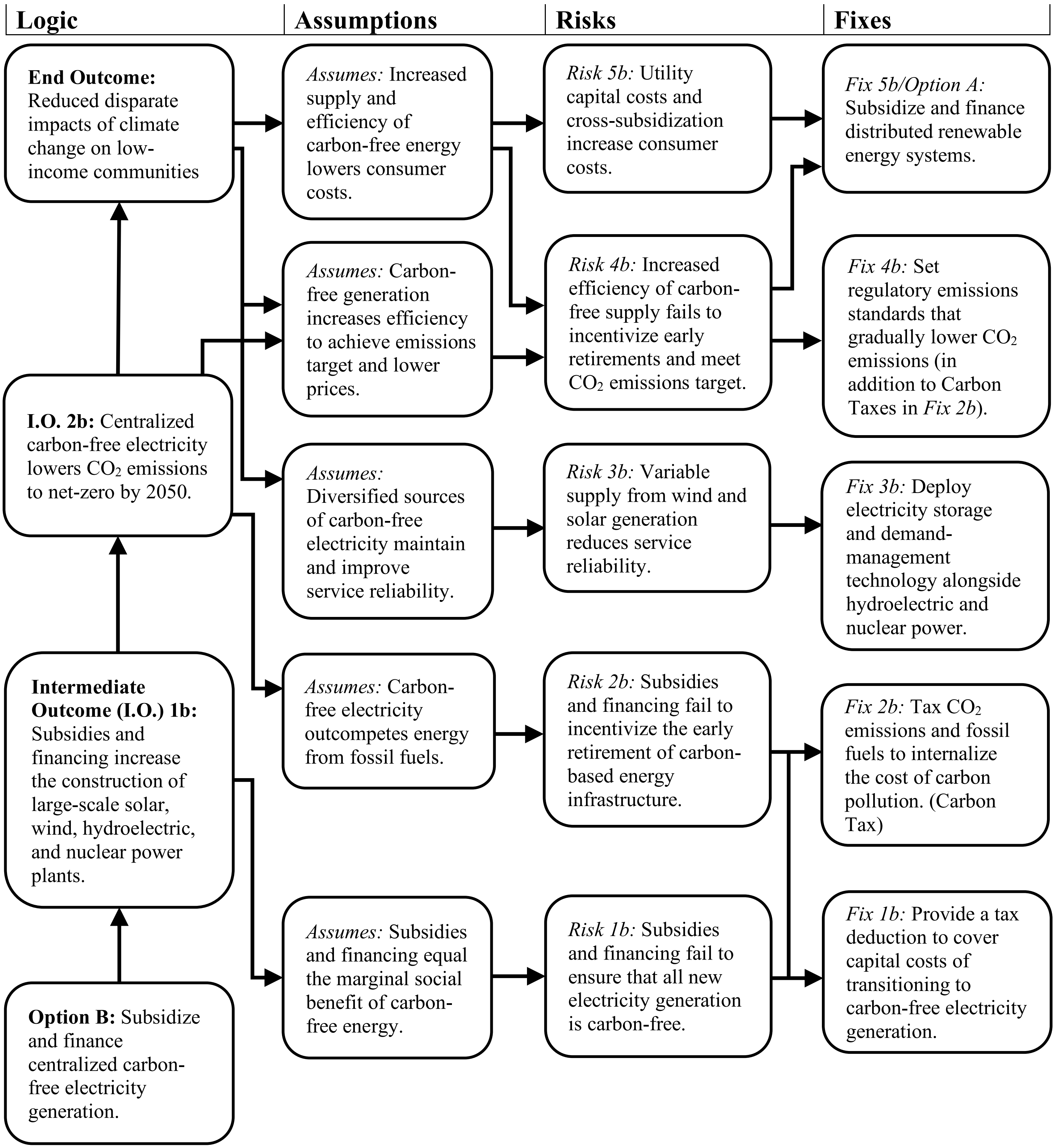
Appendix A: *Logic model of Option A – federal subsidies and financing for distributed renewable energy.*



Appendix B: *Logic model of Option B – federal subsidies and financing for centralized carbon-free power generation, transmission, and distribution.*



Appendix C: *Outcome matrix of the status quo, policy option A, and policy option B. Criteria are shaded in gray for which joint implementation of options A and B would improve outcomes.*

Goals	**Criteria**	***Status Quo***	**Option A: Subsidize and Finance DRE Systems**	**Option B: Subsidize and Finance Centralized Carbon-Free Electricity**
Effectiveness	Enables the U.S. to reach net-zero CO_2 emissions by 2050. (+)	The U.S. fails to reach net-zero CO_2 emissions by 2050. (-)	Provides a pathway to net-zero CO_2 emissions with a high rate of implementation. (+)	Provides a pathway to net-zero CO_2 emissions with a high rate of implementation. (+)
	Improves economic efficiency to meet increased demand from climate change. (+)	Higher temperatures reduce the efficiency of combustion-based generation and T&D. Increased supply requires the deployment of new power plants and upgraded grid infrastructure. (-)	Increases the supply of electricity to meet demand. Demand-management technology and carbon-free generation improve efficiency. (+)	Carbon-free energy improves generation efficiency. Impaired T&D efficiency is mitigated by a 2°C limit on warming. (+)
	Reduces the severity of climate impacts on low-income communities. (+)	Higher temperatures and fossil fuel pollution increase the severity of disparate climate impacts. (-)	Reduced pollution, stabilized temperatures, and improved efficiency decrease disparate climate impacts. (+)	Reduced pollution, stabilized temperatures, and improved efficiency decrease disparate climate impacts. (+)
Costs to Implement	Government costs of infrastructure and regulatory management. (-)	The government faces the costs of upgrading a stressed and deteriorating electric grid. (+)	Subsidies, financing, and tax credits increase government costs, partially offset by revenue from carbon taxes. (+)	Subsidies, financing, and tax deductions increase government costs, partially offset by revenue from carbon taxes. (+)
	Utility costs of transitioning to market changes. (-)	Utilities incur increased costs from reduced efficiency and climate-related stress to the electric grid. (+)	Carbon taxes increase the cost of fossil fuel electricity generation. (+) Increased efficiency and service connection fees cover the capital costs of grid connection and maintenance. (-) (Net Δ uncertain)	Capital costs and carbon taxes increase costs during the transition. (+) Subsidies, financing, and tax deductions reduce costs. (-) (Net Δ uncertain)

Goals	Criteria	*Status Quo*	Option A	Option B
Costs to Implement	Average consumer cost of electricity per kilowatt-hour (kWh). (-)	Increased demand, reduced efficiency, and rising capital costs increase average electricity prices per kWh. Residential and commercial costs are projected to increase between 4% and 15% by 2040 (Zamuda et al., 2018). (+)	DRE systems and revenue from excess supply lower the average cost per kWh. (-) Increased generation efficiency lowers costs per kWh. (-) Assuming a high electrification of the economy, increased generation efficiency could save the average U.S. household $1,000-$2,000 per year (Griffith et al., 2020). (-) Climate impacts and carbon taxes place upward pressure on the price of utility-provided electricity. (+)	Increased generation efficiency lowers costs per kWh. (-) Assuming a high electrification of the economy, increased generation efficiency could save the average U.S. household $1,000-$2,000 per year (Griffith et al., 2020). (-) Carbon taxes increase consumer costs without well-calibrated subsidies and financing. (+)
Equity	The proportion of renters to homeowners receiving electricity from distributed generation. (=1)	*<1* Property owners install DRE systems at current rates while renters depend on utility-provided electricity.	With DRE systems connected to renters: *~1* Without DRE systems connected to renters*: <1* Revenue-sharing ensures renters receive the full benefits through reduced prices.	*<1* The adoption of DRE systems continues at current rates, and property owners fail to share revenue with renters.
	Average renter cost per kWh as a percentage of average property owner cost per kWh. (=100%)	*>100%* Consumers that depend on utility-provided electricity pay higher prices through cross-subsidization. Demand surges and reduced efficiency increase consumer prices.	With DRE systems connected to renters: *~100%* Without DRE systems connected to renters: *>100%* Without *Fix 4a*, the percentage is higher than both the *Status Quo* and *Option 2* scenarios.	*>100%* Consumers that depend on utility-provided electricity pay higher prices through cross-subsidization.
Side Effects	Service reliability. (+)	Natural disasters, extreme heat events, and demand surges impair service reliability. Grid infrastructure remains vulnerable to national security threats. (-)	DRE systems protect service reliability from extreme heat, demand surges, natural disasters, and national security threats. (+) Weather patterns could impair reliability without a baseline level of centralized power generation. (-)	The electric grid remains vulnerable to extreme heat, demand surges, natural disasters, and national security threats. (-) Diversified sources and nuclear power buffer weather and seasonal effects on reliability. (+)

Goals	**Criteria**	***Status Quo***	**Option A**	**Option B**
Feasibility	Roadblocks to implementation and regulatory changes. (-)	Continued cost-of-service rate-setting and overlapping utility, state, and federal management. ($\Delta = 0$)	Subsidies, financing, tax credits, renter connections, and carbon taxes require new federal legislation. Mandating utilities to buy power from qualifying facilities at the market rate requires amending the National Energy Act. (+)	Subsidies, financing, tax deductions, and carbon taxes require new federal legislation. (+)
	Political Considerations. (-)	Public Utility Commissions and elected officials may face political pressure to reduce costs and improve service as climate change increases prices and impairs service reliability. (+)	Utilities oppose DRE systems that devalue their capital investments in centralized generation and transmission. Decoupling costs requires utilities to reorient their businesses towards a service-provider model. (+) Revenue-sharing regulations reduce financial benefits for landlords and property management companies relative to homeowners, potentially spurring opposition from these stakeholders. (+) Carbon taxes increase the production costs of fossil fuel-based electricity, increasing opposition from utilities and fossil fuel companies. (+)	Carbon taxes increase the production costs of carbon-based energy, increasing opposition from utilities and fossil fuel companies. (+)