Pathways to Sustainable Housing

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Abstract

The world is observing unprecedented, devastating, yet growing effects of climate change. GDP has been slow for decades; Covid-19 has disturbed the economy; energy prices are rising; unemployment remains high; consumer debt and budget deficit are climbing; wealth inequality is at an all-time high. Still, 89% of the energy consumed in the United States comes from non-renewable sources. Amid this challenging time, the question this work tries to answer is how can we protect our climate and environment through innovative development policies and practices that concurrently promote social equity and preserve economic viability? To answer this question, I explore five sustainable housing goals: climate protection, policy innovation, environmental protection, social equity, and economic growth.

I use data and empirical analysis to show sustainable development challenges and conflicts are significant. I share lessons learned from cities and states that act as pioneers of climate and environmental protection; I explore a balanced integration of economic, environmental, and social goals through zero-energy building in the traditionally siloed policy sector of low-income housing; I show that a lack of consideration for social equity can turn environmental initiatives into luxury goods that surrender equity to profitability; I show that a lack of consideration for economic viability can lead to underinvestment in environmental and social equity initiatives.

The overall insights derived from this study suggest that state housing agencies and local governments, particularly in large cities and in communities that are more vulnerable to environmental risks, are in a unique position to stimulate and drive climate and environmental protection. Significant between-agency differences in housing policy innovation persist, and future policy innovation research should explore factors that impact the utility of policy innovation and barriers the environmental sustainability movement faces at the organization level and beyond. Existing challenges to distributed energy generation need further study. This research highlights the need for greater policy attention to affordable housing needs in core urban areas, neighborhood diversity, and costs of gentrification.

Pathways to Sustainable Housing

General Audience Abstract

The world is now observing unprecedented, devastating, yet growing effects of climate change. Covid-19 has slowed the economy; energy prices are rising; unemployment remains high; consumer debt and budget deficit are climbing, and wealth inequality has reached an all-time high. While renewable energy is rapidly growing in worldwide adoption, still 89% of the energy consumed in the United States comes from non-renewable sources. Sustainability thinking encourages integrated, interdisciplinary approaches and policies that holistically address multiple contemporary problems. Sustainable development requires a balanced integration of economic, environmental, and social justice goals with traditionally siloed policy sectors, such as housing, as a goal of governance. Policy integration is deemed necessary because some policy sectors – like environment and climate – alone are not capable of achieving all objectives and, thus, must work with other sectors. Despite the importance of sustainability to the future of the planet, there are inherent economic, environmental, and social justice conflicts involved in reaching sustainable development, and conflict resolution has not been easy.

The overarching question in this work is how can we protect our climate and environment through innovative housing policies and practices that promote social equity and preserve economic viability? I explore five glocal sustainable housing goals, namely climate protection, policy innovation, environmental protection, social equity, and economic growth. The overall insights derived from this study suggest that state housing agencies and local governments, particularly in large cities and in communities vulnerable to environmental risks, are in a unique position to stimulate and drive climate and environmental protection. Significant between-agency differences in housing policy innovation persist, and future policy innovation research should explore factors that impact the utility of policy innovation and barriers the environmental sustainability movement faces at the organization level and beyond. This research highlights the need for greater policy attention to affordable housing needs in core urban areas, neighborhood diversity, and costs of gentrification. There are barriers to distributed energy generation that need to be studied.

Dedication

This dissertation is dedicated to Mandana, who gave me strength when I thought of giving up.

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CHAPTER ONE: INTRODUCTION

1.1. Research Problem

While I was defending this dissertation on February 19th, 2021, Texas was recovering from a long, historic, record-breaking winter storm, causing vast power outages, dozens of deaths, and damages that cost billions of dollars. We have been building our civilization by the dead remains of animals and plants, which we call fossil fuels, and we are collectively emitting over 50 billion tons of greenhouse gases each year, globally. Now, the world is observing unprecedented, devastating, yet growing effects of climate change. GDP has been slow in the last decades; Covid-19 has affected the economy; energy prices are rising; unemployment remains high; consumer debt and budget deficit are climbing; wealth inequality is at an all-time high. Still, 89% of the energy consumed in the US comes from non-renewable fossil fuels, taking us into the climate change era.

The country is facing striking economic problems. The share of adults living in middle-income households has decreased from approximately 60% in the 1980s to close to 50% today. The shrinkage in the size of the middle-class households, whose main source of income is their jobs, has been accompanied by slow-growing wages, paycheck to paycheck living, soaring health care costs, spiking hidden costs, and other issues that tend to be left off the table due to being difficult to measure, such as issues of respect, work-life balance, and family stability. A recent Federal Reserve survey finds nearly 40% of American adults do not have enough cash, savings, or a credit card to cover and quickly pay off a $400 emergency cost.

Income inequality in the U.S. is the highest of all the world's seven largest so-called advanced economies (i.e., the G7 or Group of Seven), and it continues to climb. The OECD

(Organization for Economic Co-operation and Development) finds in 2017 the U.S. had a Gini Index of 0.434, a 26% increase from the 1980s, whereas the Index ranged from 0.326 to 0.392 in other G7 nations in the same year. The Pew Research Center reports the wealth gap between America's richest and poorer families has constantly increased, and the black-white income gap has persisted. There are over half a million homeless people in the country, and with affordable houses becoming increasingly unavailable to renters we expect to see more homeless people in the coming years.

1.2. Research Rationale

The residential sector makes up approximately 16% of the U.S. GDP through consumer spending on fixed investments and housing services, and it accounts for about 21% of energy consumption in the U.S. Due to the residential sector's significant environmental, economic, and societal impacts, comprehensive policymaking reforms in this sector can reduce uncertainties around the national economy, energy security, declining natural resources, and climate change. In light of the need for improving the living conditions of households, the residential sector itself is facing many challenges, including a decreasing rate of fixed investments. Currently, almost half of all renter households in the U.S. are cost-burdened, often due to poverty and, in large metro areas, rapidly rising housing prices, which places the U.S. among the top OECD member countries with the highest median rent burden. Historically, low-income households and racial minorities in the U.S. have lived in proximity to toxic waste sites, suffered from air and water pollution, and experienced disproportionate costs of energy, transport, healthcare, and safety. Even access to green space, recreation, and civic services has been dependent upon income and race and become an environmental justice issue. Climate change is set to reshape future population distributions, triggering large-scale migrations away from affected areas and disproportionately escalating existing hardships faced by low-socioeconomic status populations.

Sustainability thinking has long encouraged integrated, interdisciplinary approaches and policies that holistically address multiple contemporary problems. Sustainable development requires a balanced integration of economic, environmental, and social justice goals within traditionally siloed policy sectors, such as affordable housing, as a goal of governance. Policy integration is necessary because no policy sector – like environment and climate – alone is capable of achieving all sustainability objectives and, thus, must work with other sectors. Despite the importance of sustainability to the future of the planet, there are inherent economic, environmental, and social justice conflicts involved in reaching sustainable development, and conflict resolution has not been easy. The development and recognition of green building rating systems in the early 2000s represented the real estate market's response to the need for environmental sustainability and climate change mitigation. Green buildings are planned, designed, constructed, operated, and recycled to increase environmental, health, and productivity performance over that of conventional buildings, and green building rating systems reward relative levels of compliance or performance with certain environmental goals. Siting and building affordable housing according to green building standards can reduce operating costs, increase the assisted families' access to education and employment, promote the residents' health and safety, and mitigate negative environmental impacts. Since local governments are in a unique position to understand local problems and develop effective responses, decentralization of decision-making and taking a bottom-up approach to reforms for sustainable development can be advantageous. This research aims to help guide such reforms.

1.3. Research Structure and Questions

This research explores five sustainable housing goals: climate protection, policy innovation, environmental protection, social equity, and economic development (Figure 1.3.1). Chapters 3-7, each include an independent study of one of the five goals and introduce pertinent strategies. Chapter 3 explores how city characteristics shape climate and environmental protection policies in U.S. cities; Chapter 4 analyzes the integration of green building with the largest low-income housing production program in the U.S. and the innovativeness of state housing agencies; Chapter 5 investigates the feasibility of statewide, zero-energy affordable housing by analyzing historical data on climate, energy use, and solar system costs; Chapter 6 scrutinizes the adoption of a reductionist sustainability planning language that surrenders equity to profitability; Chapter 7 probes into the local provision of voluntary density bonus programs to stimulate the local market supply of green affordable housing. All the studies are based on empirical quantitative research and deductive reasoning. The following paragraphs describe specific research questions addressed in each chapter.

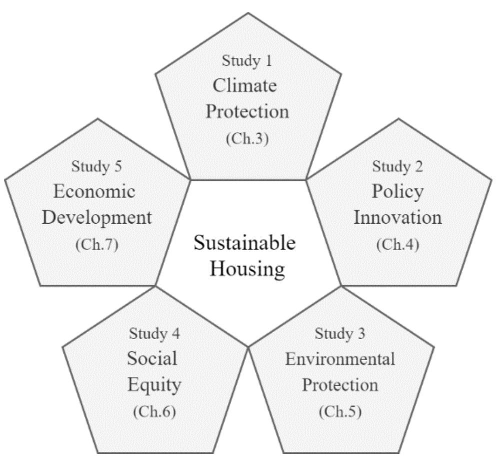


Figure 1.3.1 Sustainable housing goals and dissertation structure

Climate Protection: There is a growing body of climate change scholarship, exploring why some localities increasingly act as pioneers in climate and environmental protection, how others learn and follow, what differences exist in adopted policies, and what processes and conditions enable policy change in different contexts. For instance, case studies suggest that proximity to ambitious pioneers with sophisticated policies is associated with the spread of climate actions to neighboring jurisdictions. However, there is hitherto no systematic review and meta-analysis that draws from and seeks to learn across the various case studies that test different explanations for local climate change policy adoption. Chapter 3 presents a systematic review and meta-analysis of quantitative research published before the end of 2018 on drivers of climate change policy adoption in U.S. cities, marshaling lessons learned from various studies to draw synthesized conclusions. It aims to contribute to the literature by analyzing what we know so far and proposing a foundation for more systematic and cumulative assessment going forward.

Policy Innovation: Along with the devolution and retrenchment of federal housing support, the increased engagement of state governments in housing policy has followed an innovation process that involves the adoption of new policies not previously implemented. Chapter 4 aims to explain this affordable housing activism through the lens of policy innovation. To provide a better understanding of state-led housing policy innovation, this article explores the following questions about the Low-Income Housing Tax Credit (LIHTC) program: What components of green building are promoted by the states? What happens to innovative green building criteria after adoption? Are all the states contributing equally to environmental sustainability? Why are some housing agencies more innovative than others in adopting and maintaining green building criteria?

Environmental Protection: Despite overall progress, the rate of adoption of green building criteria has decreased, few US states have comprehensive criteria, and many have dropped important criteria, such as on-site renewable energy generation, often due to perceived additional costs to developers and, in some cases, due to perceived progress in building codes. Despite its significance as an opportunity to drive innovative solutions to address environmental sustainability and economic development through affordable housing in the U.S., zero-energy affordable housing has received little attention in literature, policy, and practice. If proved to be cost-effective, zero-energy developments can benefit residents and society as a whole by increasing housing affordability, environmental sustainability, and efficient distribution of federal financial incentives. Chapter 5 explores the existing gap to zero energy in the context of the LIHTC program: How much should state housing agencies raise energy efficiency and renewable energy requirements to bridge the gap to zero-energy LIHTC units? How much does a zero-energy LIHTC building cost to developers at present? Is a zero-energy LIHTC building more cost-effective than a conventional building over its lifecycle? What types of additional support does the construction industry need to bridge the gap to zero energy?

Social Equity: The economic and environmental aspects of redevelopment initiatives have, in many cases, surpassed or obscured the equity aspects, and efforts towards environmental protection, consciously or not, have resulted in the creation of luxury goods that subordinate equity to profit-minded urban developments that displace existing households or increase their cost of living. Chapter 6 contributes to the growing body of scholarship on urban sustainability governance by quantifying price premiums, price spillovers, and neighborhood changes connected with the new construction of private-market-led, green-certified single-family houses. We explore whether the construction of these houses can trigger a process of neighborhood change by increasing the value of nearby properties and displacing existing long-term residents. We examine four interrelated questions: Do green-certified houses have transaction price premiums? Do green-certified houses cause positive spillover effects? Do green-certified houses cause neighborhood change and gentrification? Has the willingness to pay for green-certified houses decreased over time?

Economic Development: Previous research considers a variety of factors that could lead to underinvestment in green, affordable housing, including but not limited to, split incentives, information asymmetries, risk aversion, skill shortages, and analytical failures. There is evidence of the presence of large associations between the presence of density incentives and higher production of green residential buildings in a state or county. Chapter 7 investigates density bonus options for green affordable housing by analyzing construction costs, transaction prices, and spillover effects of green certifications and affordable housing units. We apply our findings on costs and prices to the design of a county-wide voluntary density incentive program, to explore how much additional floor area could compensate local builders for investment in the construction of green affordable housing units in for-sale and for-rent scenarios. We present the results of our density incentive estimates for single-family and multi-family housing of various sizes in for-sale and for-rent scenarios. In the for-sale scenario, builders recover cost premiums at sale times, whereas, in the for-rent scenario, cost premiums are recovered in the long run.

CHAPTER TWO: LITERATURE REVIEW

Chapter Summary

This chapter includes the literature review conducted for the studies in Chapters 3-7. Readers may skip this section to read the individual study of interest since the study-specific literature review is already included in the subsequent chapters. The collective insights from the literature review suggest several areas that merit further research: First, there is a need for integration of climate protection policy adoption literature since there is not a comprehensive synthesis currently available, and the average effect of any associations between local conditions and different policy formulations is unknown. Second, despite its significance as an opportunity to drive quality living conditions for U.S. residents and innovation in housing, green affordable housing has not received much attention in the literature. Third, there is very limited research on zero-energy affordable housing. If proved to be cost-effective, zero-energy developments can benefit residents and society by increasing housing affordability, environmental sustainability, and efficient distribution of federal financial incentives. Fourth, literature has documented the presence of contradictory linkages between economic, environmental, and equity goals of development policy and planning in large-scale initiatives but limited studies have made progress on the links between gentrification and the new construction of green-certified houses to help craft more efficient and equitable housing policies. Finally, previous research considers a variety of factors that could lead to an underinvestment in sustainability initiatives, including but not limited to, split incentives, information asymmetries, risk aversion, skill shortages, and analytical failures, understanding of which is critical to sustainable housing.

2.1. Climate Protection: Climate and Sustainability Policy Adoption

Qualitative and quantitative reviews in urban and environmental studies have synthesized individual studies on climate change risk measurement (Chapman et al., 2017; Tonmoy et al., 2014), adaptation policy adoption (Biesbroek et al., 2018; S. Hughes, 2015), and policy intervention assessment (Dulal et al., 2011; Lwasa et al., 2015; Rose & Dormady, 2011). However, no work has been performed to summarize previously quantified associations between characteristics of urban areas and policy response to climate change in the context of U.S. cities. To consistently aggregate and synthesize findings from individual studies, we followed the PRISMA statement (Moher et al., 2010) to establish a pool of studies from any published peer-reviewed English journal papers in urban affairs and public policy and administration areas that applied regression analyses to explain climate policy adoption by local governments. We used Google Scholar to inspect 123 international journals that focus on current urban and environmental studies, finding thousands of research articles relating to climate change. We read the title and abstracts of about 1250 papers looking for those that explicitly reference the adoption of climate policies in US cities. We then reviewed the references and citations of the 37 papers that met the established criteria and identified a few more relevant studies, resulting in a total of 53 papers included for analysis.

Studies examined often tested policy adoption theories (e.g., theories of local political decision making, political entrepreneurship, multiple streams) or hypotheses based on the study objective (Hultquist et al., 2017; Krause, 2012b; Zahran, Brody, et al., 2008). In addition, authors developed statistical models to compare differences by city size (e.g., small versus large), government structure (e.g., council-manager versus mayor-council), issue scale (e.g., local versus global), policy sector (e.g., government versus community), policy status (e.g., adoption versus implementation), and policy type (e.g., mitigation versus adaptation) to investigate how these changes might impact the distribution of policy benefits (Rosenthal et al., 2015). This section highlights a number of these comparisons as these relate to the study results. For a further description of broad emerging themes (e.g., Democratic responsiveness, organizational capacity, environmental conditions, and governance institutions), see, Swann & Deslatte (2019).

Previous studies have found that the adoption of internal government programs (e.g., planning initiatives, green municipal purchasing programs) is generally higher than of community-oriented and climate-specific programs (e.g., recycling programs, rebates for purchasing environmentally-friendly products) (Bedsworth & Hanak, 2013; Gerber, 2013). Since developing climate action plans for internal government operations requires less fiscal and staff capacity than developing similar plans for household and private sector operations (Krause, 2013) and governments have much more control over their own operations, they may initially focus on their own emissions before starting community initiatives (Feiock & Bae, 2011). In addition to economic drivers, Gerber (2013) suggests that the adoption of community- and government-focused policies is also associated with resident and elected official partisanship, respectively.

Few studies in the sample set focused on climate adaptation (i.e., risk management) or have compared and contrasted it with climate mitigation (i.e., risk protection) (Kalafatis, 2018). Gerber (2013) argues that mitigating the causes of climate change (e.g., through a reduction in emissions and reliance on renewable energy) is in contrast with adapting to its consequences (e.g., through emergency preparedness planning). According to Hultquist et al. (2017), mitigation is, in essence, a global problem, whereas adaptation policies are intended to reduce vulnerability at the local level; thus adaptation policies are easier to justify without the need to acknowledge the causes of climate change. In contrast to the collective action problem associated with mitigation policies, adaptation policies can be more self-serving. Models developed by Wang (2013) and Wood et al. (2014) link local adaptation actions to the presence of risk factors (e.g., coastal location and weather-related incidents, respectively). Koski and Siulagi (2016) contend that framing climate change as an environmental hazard – rather than environmental harm – could lead to greater community support. However, once local restrictions on climate adaptation planning are surmounted, continuous success requires institutional capacity (Pitt & Bassett, 2014) and support from state and federal government (Romsdahl et al., 2015). Existing state policies do not currently seem strong enough to support local adaptation planning (Shi et al., 2015).

A notable discussion in the literature relates to how commitment to substantial climate protection is represented; is it through membership in climate networks, implementation of climate change-related activities, or something else (Koski & Siulagi, 2016)? Several studies find that participation in a climate-related network alone might not be the best indicator of confronting climate change (Kalafatis, 2018). In fact, network membership could represent the *intention* to adopt climate change mitigation measures more than their *actual* adoption (Pitt & Bassett, 2014). Krause (2012a) finds ICLEI membership is associated with small to moderate increases in mitigation activities, whereas adoption of the MCPA has no such effect. Moreover, Hughes et al. (2018) argue that choosing a single type of policy in isolation (e.g., ICLEI membership) or aggregate indexes of policy adoption could obscure the motivations behind the adoption of policies as there are many contextual factors that determine the prioritization of specific actions.

With regard to the scale of the impact of policy on adoption, Hughes et al. (2018) suggests that responses to highly local, regional, and global problems are most likely to be influenced by problem severity, the actions of external jurisdictions, and local political leaning, respectively. In other words, strong bi-partisan support for climate policy at the local level is associated with the perception of salient local impacts. Interestingly, Dilling et al. (2017) finds that the influence of state support on policy adoption is lower in areas with higher risk perception and more in areas with lower risk perception, suggesting that high-risk areas have acted more proactively whether assisted by state governments or not. Some studies have controlled for such multi-level governance effects using simple and hierarchical regression analyses (Hughes et al., 2018; Lee & Koski, 2012, 2015). The few studies that use cluster analysis to account for spatial autocorrelation found that a significant amount of variation in policy adoption is explained by the characteristics of neighbors (Brody et al., 2008). Gerber (2013) finds that the inclusion of a local government in a democratic partisan cluster with its neighbors can explain policy adoption even better than support group pressure existing within its own jurisdiction. Table 3.2.2 summarizes and suggests categories for all variables included in reviewed studies.

There is clearly a need for integration of policy adoption literature since there is not a comprehensive synthesis currently available, and the average effect of any associations between local conditions and different policy formulations is unknown. Although sample sizes are often large – between 40 and 7383 geographical areas with an average of 500 observations – several individual studies contained low statistical power and restricted generalizability. Therefore, narrative reviews for synthesizing data across these studies could lead to largely subjective interpretations. In Chapter 3, we present a synthesis of frequently quantified associations described in the body of empirical research on climate policy adoption.

2.2. Policy Innovation: Green Building and Affordable Housing Policy

2.2.1. The need for green LIHTC developments

Sustainability thinking has long encouraged integrated, interdisciplinary approaches and policies that holistically address multiple contemporary problems (Briassoulis, 2017a). Sustainable development requires a balanced integration of economic, environmental, and social goals with traditionally siloed policy sectors, such as low-income housing, as a goal of governance (Kivimaa & Mickwitz, 2006; Runhaar et al., 2014). Policy integration is deemed necessary because some policy sectors – like environment and climate – alone are not capable of achieving all of the objectives and, thus, must work with other sectors (Lafferty & Hovden, 2003). Despite the importance of sustainability to the future of the planet, there are inherent economic, environmental, and social justice conflicts involved in reaching sustainable development, and conflict resolution has not been easy (Campbell, 1996; Wolch et al., 2014).

In light of rapid urbanization and the need for improving the living conditions of low-income households, policy integration has been challenging to implement in the federal political system (Jordan & Lenschow, 2010; Patterson et al., 2018). Historically, low-income households and racial minorities in the US have lived in proximity to toxic waste sites, suffered from air and water pollution, and experienced disproportionate costs of energy, transport, healthcare, and safety (Bullard, 2018; Chegut et al., 2016). Even access to green space, recreation, and civic services has been dependent upon income and race and become an environmental justice issue

(Wolch et al., 2014). Affordable housing is often defined solely based on house price to household income ratio, thus, discounting transportation, healthcare, education, and other trade-offs low-income households should make to survive (Mulliner et al., 2016). Siting and building LIHTC developments according to green building standards have the potential to reduce operating costs, increase the assisted families' access to education and employment, promote the residents' health and safety, and mitigate negative environmental impacts of LIHTC developments (HUD, 2020a).

At the neighborhood level, LIHTC properties built to green building standards can help further revitalize distressed neighborhoods (i.e., the place-based approach) or improve the quality of life of low-income households by moving them to high-opportunity neighborhoods (i.e., the people-based approach) (Davidson, 2009). An increase in the diffusion and clustering of green buildings is associated with positive spillover effects on neighboring buildings, thus reducing the risk of investment in LIHTC developments, improving neighborhood characteristics, and encouraging further sustainability (Chegut et al., 2014). As social justice advocates increasingly demand the siting of low-income housing beyond central cities, improved building quality could make developments more acceptable to the host suburban communities. Recently built LIHTC units are increasingly located in suburban areas with low poverty rates and are associated with positive price impacts both in high-income and low-income neighborhoods when developed and managed well (Deng, 2011; McClure, 2019).

At the building level, there is empirical evidence that green building codes and standards bring a range of co-benefits, such as energy and water efficiency, improved health, safety, productivity, and indoor environmental quality, which significantly reduce the total cost of living throughout the building life-cycle (Breysse et al., 2011; Singh et al., 2010). Life-cycle thinking is particularly consistent with the finance of LIHTC developments, and empirical evidence suggests green LIHTC units can be more cost-effective than non-green units for stakeholders and society as a whole in the long term (Bradshaw et al., 2005; Mueller & Tighe, 2007).

Despite large benefits, affordable housing and green building have positive externalities, thus, multiple factors can lead to underinvestment in these goods in the free market (e.g., split incentives, information asymmetries, risk aversion, skill shortages, and analytical failures) and government intervention is required for an efficient distribution of benefits (Matisoff et al., 2016). Using hedonic modeling of construction costs, rents, and occupancy rates, previous research on the economic performance of green buildings suggests that building to green standards can increase upfront costs but generate sufficient savings that benefit green building owners and operators within an acceptable payback period (Chegut et al., 2019; Matthiessen & Morris, 2004, 2007).

Although the benefits of green building for society as a whole are often larger than the average cost premium to obtain green building certifications, residential developers demand significant price premiums that are likely to affect affordability (Yeganeh, McCoy, & Hankey, 2019). Researchers have often reported up to 10 percent sales price premiums associated with single-family units with green building certifications in US cities (Walls et al., 2017). Therefore, the LIHTC program regulations demanding sustainable construction features like on-site renewable energy generation should include considerations such as rigorous cost-benefit analyses, higher levels of LIHTC subsidy, or other financing mechanisms to preserve affordability. Empirical studies suggest that financing initiatives can have as high as 100%

impact on the adoption of green building technologies in the residential sector (Hughes & Podolefsky, 2015). Therefore, the short-term and long-term effects of green building on affordability require careful assessments, and several methods to examine such trade-offs are introduced in the literature (Fulton et al., 2020; Mulliner et al., 2016). In practice, motivated LIHTC-allocating agencies have prioritized developers that go beyond the minimum set by building codes to conform to internal or third-party green building standards (Prum et al., 2012). For instance, nearly 100% of recently approved LIHTC projects in Virginia have pursued EarthCraft, a local green building rating system.

2.2.2. Models of policy innovation

There is a rich, yet growing body of scholarship describing mechanisms involved in governments' adoption of innovative public-sector policies as well as complementary structures, processes, products, and characteristics, which can help describe the formulation, implementation, and diffusion of innovative policies like green building in the context of affordable housing (Kammerer & Namhata, 2018; Karch, 2007). State policy innovation is often explained as the acquisition of policies or programs from others that are new to the state adopting them but are not necessarily altogether new ideas. The policy innovation mechanism is broadly defined as "the function of an interaction among the motivation to innovate, the strength of obstacles against innovation, and the availability of resources for overcoming such obstacles" (Mohr, 1969). Policy innovation researchers argue that as a result of having access to resources and information, public officials should take the initiative to recognize and deploy the utility of innovative policies and programs, whether or not such utilities are expressed wants of ordinary citizens. This moral standpoint reflects the significance of policy innovation literature and, simultaneously, the situation in which goods and services having societal benefits are inefficiently distributed in the free market (i.e., market failure).

Empirical models developed in the state policy innovation literature can help explain drivers of subnational environmental initiatives, including green building, sustainable development, and climate change (Krause, 2011a). Studies of policy innovation have explored innovation-driving forces to explain why some state or local governments adopt policies or programs while others do not. Major classic models of policy innovation that describe causal processes involved in the adoption of innovative policies are classified into the two categories of internal determinants models and diffusion models (Berry & Berry, 1999). Internal determinants models presume economic, environmental, political, and social characteristics of states – thus, not pressures created from other states – act as primary driving forces of innovation. Some internal determinants models include organization level (e.g., leadership, maturity, resources, structure) and individual level (e.g., attitudes, autonomy, entrepreneurship, motivations), and, in some cases, innovation level (e.g., compatibility, complexity, effectiveness) characteristics (Vries et al., 2016). For example, researchers have concluded that the perception of the severity of a crisis and a prior commitment to address a policy problem are positively associated with state environmental policy innovation (Sapat, 2004). On the other hand, diffusion models presume that innovation is communicated between state governments in a social system, through learning, competition, coercion, or other processes. Diffusion models include national interaction models, regional diffusion models, leader-laggard models, isomorphism models, and vertical influence models. In diffusion models, leading-edge US states (and the federal government in vertical influence models) regularly function as trendsetters, spreading new policies to follower states that search for solutions to potentially controversial or complicated issues and often want to reduce the cost of finding a solution (Berry & Berry, 1999; Boehmke & Witmer, 2004; Mooney, 2001; Obinger et al., 2013).

Policy innovation literature does not necessarily expand on complexities involved in decision-making processes by individuals within government organizations or degrees of success in the implementation of new policies. Organizational economists and theorists partially fill this gap by explaining various characteristics of organizations (e.g., birth, functioning, dynamics, progress, and impacts) and variables underlying decision-making (e.g., organizational culture, network structures, framing, and incentives) (Perrow, 2000). Of particular relevance to understanding drivers of policy innovation at the level of organizations are the notions of bounded rationality, optimization versus heuristics (i.e., finding the best solution to the problem versus relying on intuition, habit, or rules of thumb when resources are limited) and human systems properties (e.g., limited certainty, limited predictability, indeterminate causality, and evolutionary change) (Gigerenzer et al., 2011; Gsottbauer & Van den Bergh, 2011; Hjorth & Bagheri, 2006; Marsden et al., 2012; Nelson, 2012).

The classic models have inspired numerous empirical studies on policymaking. Nonetheless, more recent studies have started to criticize presumptions of single-explanation models, contending that such models do not have the required breadth to independently identify the causes of policy innovation. Some researchers, for instance, argue that government officials' interactions are complex and more selective than what the national interaction model suggests, and causal factors could be understood only if new studies integrate internal and regional diffusion determinants into a single discrete event history analysis (Berry, 1994; Berry & Berry, 1990). Contending the diffusion of innovation does not necessarily depend on geographical proximity, researchers criticize geographic proximity models for failing to account for the role of communication networks, overlapping media, and common attributes of proximate states (Karch, 2007). Some other researchers question the significance of early adoption, which is the focal point of the classic policy innovation scholarship, and argue that other considerations like the level of dedication and policy re-invention, could place late adopters in a superior position in solving local problems when compared to earlier adopters (Glick & Hays, 1991). There are also studies referring to specification issues and flaws in history analysis models regularly employed in empirical studies (Berry & Berry, 1990; Buckley & Westerland, 2004) and recent studies have proposed substitute models like directed dyadic analysis (Baldwin et al., 2019).

Highlighting the role of historical evolution, process innovation, and institutions, more recent theoretical works on innovation follows more comprehensive and interdisciplinary approaches to innovation, along with new analytical methods, thus augmenting earlier theories in policy studies (Kammerer & Namhata, 2018). A systematic review of the literature concludes past research has mostly focused on policy adoption and diffusion processes, and very few studies on policy innovation have identified the outcomes or explained questions like "What happens to innovative policies after adoption?" or, "Did those innovations make a change?" (Vries et al., 2016) Existing literature on affordable housing suggests that, in addition to environmental co-benefits, green affordable properties have generated considerable financial savings from efficiency for the occupants. Despite its significance as an opportunity to drive quality living conditions for U.S. residents and innovation in housing, green building in affordable housing has not received much attention in the literature. Chapter 4, therefore, expands on past research and explores: What components of green building are promoted in state QAPs? What happens to innovative green building criteria after adoption? Are all US states equally contributing to environmental sustainability through the LIHTC program? Why are some housing agencies more innovative than others in adopting and maintaining green building criteria?

2.3. Environmental Protection: Zero-Energy Affordable Housing

2.3.1. Energy-efficient affordable housing

In recent years, environmental concerns and rising energy prices have prompted a shift towards more energy-efficient residential units regardless of end-user finances. There are major reasons for decision-makers to consider energy-efficient affordable housing for low-income residents. First, sustainable development requires a balanced integration of economic, environmental, and societal goals, but environment and climate policy sectors alone are not capable of achieving all the objectives and thus must work with traditionally siloed policy sectors, such as affordable housing (Kivimaa & Mickwitz, 2006; Runhaar et al., 2014). Second, due to access to resources and information, public agencies are increasingly responsible for taking the initiative to recognize and deploy innovative, beneficial policies and programs, whether or not such utilities are expressed wants of all citizens (Mohr, 1969).

Empirical evidence suggests that energy and water efficiency throughout the building lifecycle significantly reduces the total cost of living for low-income households (Breysse et al., 2011; Singh et al., 2010). Lifecycle thinking is particularly consistent with the way LIHTC developments are financed, and research suggests, in the long term, energy-efficient LIHTC units built to high-performance building standards (e.g., ASHRAE 90.1, ASHRAE 90.2) and rating systems (e.g., Energy Star for Homes, LEED, EarthCraft) can be more cost-effective than conventional units for stakeholders and society (Bradshaw et al., 2005; Mueller & Tighe, 2007). LIHTC-financed residential units are charged a flat rent depending on the Area Median Income

(AMI), typically close to 30 percent of household income for gross housing costs, including utilities. Therefore, if a LIHTC tenant's income decreases, they will be spending more than 30 percent on the monthly rent. Resident behavior and rising energy prices can increase utility costs, and the extra amount deducted from residents' monthly income and spent on utilities impacts housing affordability and economic well-being (Lapsa et al., 2020; VCHR, 2015). Some LIHTC projects convert to market-rate units after the first 15-year compliance period due to a lack of resources and funding to replace building systems in need of repair. Lifecycle savings from the adoption of durable, energy-efficient building systems could help increase housing affordability, preserve affordable units, and prevent the relocation of residents at the end of the compliance period (Schwartz et al., 2018).

Despite benefits, energy-efficient affordable housing has positive externalities, meaning multiple factors, including split incentives, information lags, and asymmetries, risk aversion, skill shortages, and analytical failures can lead to underinvestment in these units in a free market. Thus, government intervention is needed for the efficient distribution of social benefits (Deng & Wu, 2014; Matisoff et al., 2016). Although the benefits of energy-efficient building for society as a whole are often larger than the average cost premium to obtain energy certifications, residential developers demand significant price premiums that are likely to affect affordability (Yeganeh, McCoy, & Hankey, 2019). For instance, researchers have reported up to 10 percent sales price premiums associated with energy-efficient, single-family units with green building certifications in U.S. cities (Walls et al., 2017). Empirical studies suggest that financing initiatives can affect the adoption of renewable energy generation systems in the residential sector by as much as 100 percent (Hughes & Podolefsky, 2015). Affordable housing legislation aimed at promoting sustainability and preserving affordability could balance energy-efficiency and renewable energy needs pending the careful assessment of incentives, financing mechanisms, and technical issues involved.

2.3.2. *Zero-energy buildings*

Built on low-energy building research, which dates to the 1940s, zero-energy buildings have received growing attention in recent years and are being incentivized and mandated in the residential sector to help developed countries, including the U.S., achieve carbon neutrality (Carrilho da Graça et al., 2012; Deng & Wu, 2014). Zero-energy residential buildings use renewable sources of energy to generate enough energy to offset the operation-phase energy demand, which normally includes heating, cooling, ventilation, domestic hot water, fixed lighting, plug loads, and elevators. An alternative and/or complementary to on-site renewable energy generation is a utility-scale renewable energy grid, which benefits from scale economies and equalizes local peaks.

In 2010, the European Union (EU) directive on the energy performance of buildings asserted that member states should ensure all new buildings are nearly zero-energy buildings by 2020 (EU, 2020). In 2008, California's long-term energy-efficiency strategic plan, which became a mandate in 2018, adopted energy efficiency goals, stating all new residential construction in California would be zero-energy by 2020 (CAPUC, 2008). Past research concludes that energy use in the operation phase roughly accounts for 70–90 percent of a building's life cycle energy use, showing the significance of zero-energy buildings in mitigating greenhouse gas emissions. Considering the embodied energy of electricity grids, energy savings achieved in the operation of zero-energy buildings is considerably larger than the increase in embodied energy when switching from passive to zero-energy houses (Berggren et al., 2013).

The US Department of Energy (DOE) recognizes builders for leadership in increasing energy efficiency, improving indoor air quality, and making homes zero-energy ready through the Zero Energy Ready Home program (DOE, 2020). The DOE defines a zero-energy building as "an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy" (DOE, 2017). Accordingly, delivered energy refers to "any type of energy that could be bought or sold for use as building energy", and exported energy is "on-site renewable energy supplied through the site boundary and used outside the site boundary" (DOE, 2017). In the DOE's definition, the source energy is composed of the delivered energy, plus the energy consumed in the extraction, processing, and transport of primary fuels plus energy losses in thermal combustion and power generation plants plus energy losses in transmission and distribution to the building site (D'Agostino & Mazzarella, 2019). An implicit assumption in this definition is that zero-energy buildings are not fully autonomous buildings and need to remain connected to existing energy grids that can exchange energy with buildings. According to this definition, the embodied energy of building materials, construction, and recycling, may or may not be considered in zero-energy building calculations.

The zero-energy building balance is a condition in which the sum of all generated energy is equal to or higher than the sum of all building energy loads over a period, nominally a month or a year. Load matching refers to the temporal match between load and generation and represents the building's ability to work dynamically, in synergy with the grid. Salom et al. (2011) reviews various load matching indicators. Equations 1 and 2 represent the zero-energy building balance condition, where e and d stand for exported and delivered energy, g and l stand for generation and load, and w and i stand for weighting factor and energy carrier. E, D, G, and L stand for weighted exported energy, weighted delivered energy, weighted generation, and weighted load, respectively. Equation 3 represents the load matching index, where f is the load matching index, t is the time interval used, e.g., hour, day, or month, and n stands for the number of data samples (12 for monthly and 8760 for hourly time interval). For guidance and information on the grid interaction index equation, see Sartori et al. (2012).

$$\sum_i e_i \times w_{e,i} - \sum_i d_i \times w_{d,i} = E - D \geq 0 \qquad \text{Equation 1}$$

$$\sum_i g_i \times w_{e,i} - \sum_i l_i \times w_{d,i} = G - L \geq 0 \qquad \text{Equation 2}$$

$$f_{load,i} = \frac{1}{n} \times \sum_{year} min\left[1, \frac{g_i(t)}{l_i(t)}\right] \qquad \text{Equation 3}$$

To maximize a zero-energy building's operation at the balance condition over time, the demand should be reduced by the means of energy efficiency, and the supply should be increased by the means of renewable energy systems. Although zero-energy buildings are often designed to achieve energy balance on an annual basis, increasing the generation-load match in smaller time scales using optimized energy storage systems reduces zero-energy buildings' stress on the existing grid, particularly at the times of peak energy demand, and reduces energy waste and carbon-related emissions (Guarino et al., 2015). Past research has examined different equations and weights to define the zero-energy building balance, including balances of primary energy, site energy, carbon emissions, and energy cost for different energy systems (Guarino et al., 2015; Mohamed et al., 2014). Data from the International Energy Agency suggest that the percentage of source energy that reaches the final end-user, which describes the overall energy efficiency in the U.S. supply sector, was 67.69 percent in 2010. The DOE definition of zero-energy buildings implies that these buildings should progress the restoration of the remaining 32.31 percent (loss) to the infrastructure system.

The surplus energy generation could be used as a basis to support asymmetric valuations of the energy exchanged between zero-energy buildings and energy grids, pricing the exported energy higher than that of the delivered energy. To export the equivalent of 32.31 percent of the annual load from multifamily buildings would require taking into account the need for large solar systems, installation of which may not currently be feasible based on design requirements and/or space availability in areas with low solar potential. For guidance and information on issues in zero-energy building, see D'Agostino & Mazzarella (2019).

2.3.3. Cost-benefit and simulation-based risk analyses

Researchers have examined the feasibility of utilizing renewable energy systems for residential and commercial purposes, while often in isolation (Aagreh & Al-Ghzawi, 2013; AlAjmi et al., 2016). The common approach is to evaluate the integration of one or more renewable energy systems like solar systems, wind turbines, heat pumps, district heating, and district cooling into new or existing developments using simulations and calculating the energy payback period or the levelized cost of energy in each scenario (Li et al., 2013).

Amasyali & El-Gohary (2018) reviews past research on data-driven building energy consumption prediction. Some studies have used simulation software, such as EnergyPlus, HOMER, and TRNSYS, in conjunction with daily or monthly load profile data obtained from study cases; most studies have focused on a single building; fewer studies have considered multiple developments with similarities and differences. Cost-benefit analyses include multiple non-financial criteria, such as the availability of technology, warranty period, ease of maintenance, required roof or ground area, avoided carbon emissions. Sensitivity analyses include the effect of changing key input variables for project outcomes, such as the effects of the cost of delivered energy, the value of exported energy, the introduction of a carbon tax, and the price of power generation technology. Few studies include an assessment of risk and uncertainty (e.g., the occurrence of alternative future events) into financial analysis, and most available studies are limited to simple financial analyses (Salci & Jenkins, 2016).

As a powerful tool for evaluating the effects of policy decisions, cost-benefit analysis relies on estimates about variables that are not accurately predictable, e.g., future prices, weather patterns, occupant behavior (Sartori et al., 2014). To effectively contribute to rational decision making, an analysis (e.g., scenario analysis, sensitivity analysis, Monte Carlo simulation) of risks and uncertainties associated with observed data and modeling errors that could change the project outcome and identify the range of possible outcomes should be an integral part of any cost-benefit analysis (Boardman et al., 2017; De Rus, 2010; Eeckhoudt et al., 2011; Salci & Jenkins, 2016). A conundrum about cost-benefit analysis is the choice of discount rate for future costs and benefits of projects. The U.S. Government recommends deterministic cost-benefit models followed by sensitivity analyses and Monte Carlo simulations to perform a full risk analysis of costs and benefits of policy interventions. The U.S. Government guidelines for cost-benefit analysis of federal programs have required a discount rate of 7 percent, which is supported by recent research, recommending discount rates in the range of 6-8 percent (Burgess & Zerbe, 2011; Management & Budget, 1992).

The National Renewable Energy Laboratory (NREL) benchmarks average U.S. solar photovoltaic (PV) system installed costs, weighted by state installed capacities and accounting for all system and project development costs incurred from the perspective of the developer/installer, including the cost of the hardware profit and installer/developer profit.

According to NREL, residential rooftop systems, ranging from 3-10 kW in size, cost $2.71 per watt DC (Wdc) or $3.11 per watt AC (Wac) in the first quarter of the year 2018. Figure 5.2.1 presents the NREL-estimated, inflation-adjusted national average rooftop system costs in 2018 dollars. The gradual decrease in the total cost results from various drivers working simultaneously, including increases in module efficiency, labor productivity, small installer market share, and decreases in supply chain cost, permitting cost, and structural and electrical balance of system commodity pricing. According to the benchmarking analysis, the total cost of residential PV systems has decreased by 4.91 percent, from 2017-2018, and it can be expected that in 2019 and 2020, the total cost per watt DC (Wdc) has decreased to ~$2.57 and ~$2.45, respectively. Since on-site electricity storage systems significantly increase the total cost of installation, the most common approach to zero-energy building, particularly where full retail net metering is not available, is to simply rely on the electricity grid (Ferrante & Cascella, 2011). Additional data and information on residential solar photovoltaics with energy storage systems are available in NREL's installed cost benchmarks (Ardani et al., 2016). Information on major trends in the U.S. solar industry can be found in the Solar Energy Industries Association's (SEIA) solar market insight reports (SEIA, 2020).

Despite its significance as an opportunity to drive innovative solutions to address environmental sustainability and economic development through affordable housing in the U.S., zero-energy affordable housing has received little attention in literature, policy, and practice. If proved to be cost-effective, zero-energy developments can benefit residents and society as a whole by increasing housing affordability, environmental sustainability, and efficient distribution of federal financial incentives. Therefore, Chapter 5 explores the existing gap to zero energy in the context of the LIHTC program: how much should state housing agencies raise energy efficiency and renewable energy requirements to bridge the gap to zero-energy LIHTC units?; how much does a zero-energy LIHTC building cost to developers at present?; is a zero-energy LIHTC building more cost-effective than a conventional building over its lifecycle?; and what types of additional support does the construction industry need to bridge the gap to zero energy?

2.4. Social Equity: Green Housing or Green Gentrification?

2.4.1. Environmental gentrification

In the 1920-1930s, studies of neighborhood change had a focus on inner-city neighborhoods' decline and disinvestment and relocation of higher-income residents (Hoyt, 1939). Since Ruth Glass first applied the term 'gentrification' in describing the displacement of London's working class in the 1960s, a massive body of scholarship on neighborhood change has evolved and investigated the class remake of the central city landscape (Davidson & Lees, 2005; Glass, 1964). As a form of neighborhood change, gentrification is the middle or upper-class colonization of urban property in poor or working-class neighborhoods, which can involve significant displacement of long-time, low-income residents after higher-income households purchase residential properties in the neighborhoods to inhabit, rebuild, upgrade, or rent out the properties at a higher rent (Landis, 2016). Due to having both costs and benefits, neighborhood change has been a complex, controversial, and hotly-debated planning topic (Mujahid et al., 2019).

The environmental gentrification field of research is the advanced capitalism era's iteration of old discourses about equitable urban development and the point of convergence of urban redevelopment, ecologically-minded initiatives, and environmental justice activism (Checker, 2011). The terms ecological, environmental, or green gentrification frequently apply to the process in which pro-environment policies, programs, or practices aimed at responding to the demand for livable urban environments and/or reduced suburbanization exclude, displace, and discriminate against existing, low-socioeconomic status residents (Rice et al., 2020). Ethnographic studies in the 2000s and a growing number of recent quantitative studies describe investments in large-scale environmental initiatives (e.g., green spaces, smart growth, mixed-use densification, and transit-oriented development) in brownfields and core urban areas, where the difference between the actual and potential ground rent is high, have replaced low-rent houses occupied by low-socioeconomic status residents with high-end real estate for higher-income, often white in-migrants (Anderson et al., 2012; Dong, 2017; Gould & Lewis, 2016; Loughran, 2014).

Sustainability thinking has long encouraged integrated, interdisciplinary approaches and policies that holistically address multiple contemporary problems and achieve a balanced integration of economic, environmental, and equity goals in traditionally siloed policy sectors, such as housing (Bowen et al., 2017; Briassoulis, 2017b; Tosun & Leininger, 2017). Substantive policy goals in broad and diverse sectors like energy, environment, and climate change, cannot be realized until incorporated into other sectors, such as housing, transport, and agriculture (Cejudo & Michel, 2017; Persson & Runhaar, 2018; Schmidt & Fleig, 2018), researchers have developed a wide array of approaches, strategies, and instruments that facilitate the integration of policy goals into development planning and address inherent conflicts involved in reaching sustainable development (Di Gregorio et al., 2017; Runhaar, 2016). Conflicts arise when achieving the goals of one pillar of sustainability, i.e., economy, environment, and society, is incompatible with achieving the goals of another pillar (Figure 6.2.1). Researchers have attributed environmental gentrification to the environment-equity conflict of sustainability, which is the economic conundrum of providing sustainable conditions for the natural environment and, simultaneously, a subsistence existence for low-socioeconomic status populations (Campbell, 1996).

Through the lens of distributive/distributional, procedural/participatory, or interactional/recognition justice, the environmental justice scholarship has highlighted disparities in environmental amenities (e.g., clean air and water, landscape, green transport infrastructure, public parks, beaches) that increasingly divide today's cities, informing activists to improve neighborhood conditions for low-socioeconomic-status groups by removing environmental burdens like air and water pollution, toxic and hazardous facilities, vehicle traffic, landfill sites, flood risk (Banzhaf et al., 2019; Kronenberg et al., 2020). Nonetheless, post-industrial cities' selective adoption of environmental sustainability as a redevelopment framework and corresponding efforts to improve existing neighborhoods have, in many cases, displaced existing long-term residents by attracting an inflow of affluent residents. This trend has captured the attention of a growing number of environmental justice researchers to study inequities involved when existing environmental burdens in cities are reinvested and transformed into environmental amenities (Anguelovski et al., 2019).

The net change in benefit for the city of selective adoption of environmental sustainability can be zero, or even negative. There is evidence that population migration due to gentrification is a cause of crime (Kirk & Laub, 2010). When a neighborhood is subject to gentrification, the cost-burdened, relocated, or displaced residents incur economic costs (e.g., job loss, falling wages, moving costs, housing costs, and transportation costs), social costs (e.g., crime increases, loss of community support, disruptions in the network of acquaintances), and health and well-being costs (e.g., damages to physical and mental health, disruptions in kids schooling), thus, requiring support from the host neighborhood and creating large negative externalities leading to welfare loss in the city. Figure 6.2.2 illustrates welfare gain from incentivizing actions to protect existing residents. In the free-market economy, residents underestimate the true social value of community protection actions. Introducing an incentive would increase the number of available resources for action (Q1) toward a socially optimal level (Q2), where the marginal cost of action to the community (MPC/MSC) is equal to the marginal social benefit of action (MSB). The upward shift in the marginal private benefit (MPB) curve creates the triangular grey area, representing the quantity of positive externality known as welfare gain from an action (Sheppard, 2012).

With substantial reductions to spending on public projects, private funders have become key players in environmental gentrification. Researchers contend that green gentrification is not always an unintended consequence of regulatory processes and procedures, rather, city governments, private funders, real estate developers, political, economic, and cultural elites work together in green business–government coalitions that exploit underserved neighborhoods with low property values to deliberately establish "neighborhood revitalization projects" that attract higher-income, college-educated, environmentally-minded professionals (Rigolon & Németh, 2018). This collaboration in neoliberal urbanism satisfies the needs of public agencies and private developers through increased property tax revenues and substantial price premiums at the cost of social equity. The influx of high-income residents after a greening initiative can disintegrate environmental and affordable housing goals, remove connections between public and non-for-profit actors, and increase housing costs by changing the class composition of the neighborhood.

2.4.2. *Green-building-induced gentrification*

Fueled with an ever-increasing interest in pro-environment real estate, numerous green building rating systems have emerged in the 2000s, which reward relative levels of compliance with certain construction requirements. An analysis of LEED and Energy Star-certified properties over the first decade of implementation in the US suggests improvements in the rate of adoption, the share of private developers, the share of buildings certified at higher certification levels, and certification standards (Fuerst, 2009a). Some rating systems like Energy Star for Homes have a single focus area; some like LEED cover multiple components (e.g., energy efficiency, smart growth, resource conservation, and health protection); advanced rating systems like the Living Building Challenge require expensive, cutting edge, innovative practices far beyond standard building codes. The economic, environmental, political, societal, and technological composition of cities to varying extents explains the growth in the proportion of green-certified properties in cities (Fuerst et al., 2014b; Rakha et al., 2018).

Since green-certified houses incur an extra upfront cost of compliance with green building certification requirements, builders may charge over 10% price premium for conventional green building certifications (U.S. Census Bureau, 2020; Walls et al., 2017). A 10% premium is an equivalent of $32,580 increase in the median new house transaction price in the first half of the year 2020 in the US, where the federal minimum wage for blue-collar jobs is only $7.25 per hour. Thus, real estate investors' confidence in the ability to recover upfront costs through sales or rent premiums significantly increases by favorable market conditions (e.g., high property values, high energy prices, low vacancy rates, and low days on market), supportive political regulations and incentives, and the presence of higher income, well-educated professionals whose environmental desires align with green building components (Dippold et al., 2014).

Researchers have criticized private-sector-led urban intensification projects that involve the construction of green-certified houses for a lack of engagement with social justice or ecological principles. The production of green-certified houses in low-income neighborhoods where the difference between the actual and potential ground rent is high helps developers recoup cost premiums by attracting higher-income households who prefer to live in a compact, mixed-use neighborhood and drive less. Incoming households may observe savings from energy efficiency, but the level of consumption of incoming high-income residents, the rebound effect, and the high embodied energy of green-certified houses lead to significantly higher carbon emissions (Copiello, 2017). In fact, low-income households with limited access to modern energy and technology often cause very low carbon emissions but are disproportionately exposed to indoor air pollution, the world's largest single environmental health risk (Roser, 2020). Cidell (2009) argues that the development of LEED has been primarily motivated by economic considerations, and, to smaller degrees, environmental considerations, with a disregard for social processes that shape urban environments. For instance, LEED rewards occupant health promotion largely aimed at improving worker productivity and accredits environmental impact reduction without mandating a specific scientific benchmark.

While et al. (2004) conceptualizes recent forms of local economy-environment relations through the notion of "urban sustainability fix", or the selective incorporation of ecological goals in urban governance to safeguard post-industrial urban growth in response to the global ecological crisis and the rise of popular environmentalism. In this approach, the politics of urban development support environmental and social goals only so long as economic goals are not diminished. Bunce (2009) describes the high-density, mixed-use redevelopment of public lands on Toronto's waterfront where a process of policy-led gentrification that supports middle-to-high-income-oriented property development at the expense of housing affordability. Toronto's financial and educational incentives for LEED-certified structures drive the development of the "revitalization project" by large, globally-financed, private development corporations that have the capital to absorb the upfront costs of developing, publicizing, and marketing Gold-level LEED-certified properties. Goodling et al. (2015) describes Portland's investment in urban growth boundary, transit-oriented development, and infill construction, which has contributed to Portland's reputation for commitment to livability and sustainability by transforming vacant lots into stylish, LEED-certified condos and retail hubs, but, at the same time, has multiplied housing costs and displaced long-term, low-socioeconomic status residents.

2.4.3. Measuring gentrification

There is no best indicator, operationalization method, analysis unit, or degrees of change to measure gentrification. Neighborhoods may change both physically and socially. Therefore, quantitative studies track physical changes using physical, occupancy, and financial indicators of the building stock and track social changes using aggregate socioeconomic indicators of inhabitants and businesses. A significant increase in renovated buildings, rents, prices, taxes, and ownership rates and a significant increase in the percentage of White, young, college-educated, middle- or high-income households are both used to indicate gentrification (Dong, 2017). Some studies have also tracked the number of incoming residents and the flow of physical and capital investment into and out of neighborhoods (Landis, 2016).

Most researchers operationalize neighborhoods using administrative units of analysis due to convenience and data availability, whereas these units do not necessarily possess a single area with a distinct identity (Kirk & Laub, 2010). Mujahid et al., (2019) compares three census-based, quantitative gentrification classification methods to examine the impact of the choice of method on potential health decisions at the Census Tract level. Census tracts generally have a population size between 1,200 and 8,000 people, and Block Groups are statistical divisions of census tracts, are generally defined to contain between 600 and 3,000 people. Landis (2016) tracks significant changes in the deciles of tract-level median household income within a metropolitan area and categorizes tracts as gentrifying, declining, or stable depending on the severity of changes in the income decile often within a one-to-two-decade timeframe. Freeman (2005) uses the ACS data to track tract-level changes in household income, housing stock, urbanization, house prices, and educational attainment relative to the corresponding metro-level over a predefined period to designate gentrifying and stable tracts. Urban Displacement Project (2020) defines eight categories for gentrification and displacement to capture a more nuanced understanding of gentrification stages using several indicators on socioeconomic and housing indicators from multiple datasets. Hwang (2015) uses Google Street View imagery to capture stages of gentrification and overcome limitations in the use of census-defined boundaries as the unit of analysis. Comparative studies suggest that the choice of the method has a large impact on neighborhood categorization but the results share similarities across the studies (Barton, 2016).

Quantifying the gentrification impacts of pro-environmental redevelopment projects is a recent trend in urban studies. Immergluck & Balan (2018) examines the effect of the Atlanta Beltline – a transit-oriented redevelopment of historic railroad corridors, providing a network of public parks and multi-use trails – on value and tax appreciation of houses located within one-half mile of the project over five years. The study finds significant evidence on the creation of exclusionary housing patterns near the project, where economically advantaged households enjoy new, typically subsidized new amenities, whereas lower-income households are forced to live in less attractive neighborhoods. Dong (2017) explores gentrification effects of rail transit development in suburban Portland, Oregon, employing tract-level data on the demographic composition, housing characteristics, and location in a longitudinal quasi-experimental design. The study uses propensity score matching to designate treatment and control neighborhoods and applies several statistical t-tests to identify changes at multiple observation points and timeframes, but the author does not find statistically significant evidence of transit-induced gentrification.

A review of quantitative studies on gentrification suggests researchers' decisions have greatly impacted study outcomes in several ways. First, the choice of definition, unit, data, operationalization, location, and timeframe greatly impacts neighborhood characterization. Second, case studies are context-specific and there are biased comparisons, e.g., some neighborhoods are already very different from other ones before the introduction of a pro-environmental project. In the latter case, researchers have used matching methods to guarantee "apple-to-apple" comparisons. Third, reliance on administrative units and aggregated census data – for instance to measure housing affordability without differentiating households of different income levels – may mask underlying nuances and reduce accuracy.

Literature has documented the presence of contradictory linkages between economic, environmental, and equity goals of development policy and planning in large-scale, smart-growth, mixed-use, and transit-oriented redevelopment initiatives but limited studies have made progress on the links between gentrification and the new construction of green-certified houses to help craft more efficient and equitable housing policies. Chapter 6 contributes to the growing body of scholarship on urban sustainability governance by quantifying price premiums, price spillovers, and neighborhood changes connected with the new construction of private-market-led, green-certified single-family houses. We explore whether the construction of these houses can trigger a process of neighborhood change by increasing the value of nearby properties and displacing existing long-term residents. We examine four interrelated questions: Do green-certified houses have transaction price premiums? Do green-certified houses cause positive spillover effects? Do green-certified houses cause neighborhood change and gentrification? Has the willingness to pay for green-certified houses decreased over time?

2.5. Economic Development: Incentivizing Green Affordable Housing

2.5.1. Costs and benefits of green building and affordable housing

The US Green Building Council (USGBC) defines green building as a comprehensive approach to planning, design, construction, operations, and, ultimately, end-of-life recycling or renewal of structures with several central considerations, including energy use, water use, indoor environmental quality, material selection and the building's effects on its site (USGBC, 2019a). There are several green building rating programs that encourage the development of green buildings and energy-efficient products and appliances in the US, of which LEED and EnergyStar are often cited as the two most prominent. USGBC, a private, membership-based, non-profit organization, developed LEED in 1999, and the Environmental Protection Agency and the Department of Energy jointly developed EnergyStar in 1992, extended it to buildings in 1995, and initiated the EnergyStar labeling program for buildings in 1999 (USGBC, 2019a). In a parallel effort, and at the regional level, Greater Atlanta Home Builders Association and Southface established EarthCraft jointly in 1999, which was extended to Virginia in 2006 as EarthCraft VA, and named Viridiant since 2018, whose certification standards are similar to or higher than EarthCraft's (EarthCraft, 2019). To become certified, an EarthCraft project must meet or exceed the local International Energy Conservation Code (IECC), requirements for the energy code for energy and water efficiency, and meet certain required standards and optional points in a series of categories, determining Certified, Gold, or Platinum levels of certification (i.e., the expected levels of environmental performance). An analysis of LEED and Energy Star-certified properties suggests several trends over the first decade after the programs' inception: increases in the rate of adoption, improvements in certification standards, decreases in the share of buildings certified at the lowest level, growth of the share of private, versus public, developers (Fuerst, 2009b). Previous research has compared the costs and benefits of green buildings to those of conventional buildings (e.g., in terms of energy and water efficiency, indoor environmental quality, health and productivity), using a variety of indicators, but construction costs and price premiums are among the most concrete indicators to reflect total costs and total benefits for the purpose of policy and planning (Zuo & Zhao, 2014).

During the last decade, a growing body of empirical research has tracked the economic performance of green buildings, based on reported construction costs, rent, sale prices, and occupancy rates. So far, there is little evidence on the magnitude of upfront green construction cost premiums in the residential sector in the US, and available studies in the commercial sector provide no conclusive answers. Two recent reviews, covering a variety of geographies, building types, and rating systems, Dwaikat & Ali (2016) and Zhang et al., (2018) report that the majority of incremental costs for all levels of certification fall within the range of -0.4%–21% and -0.4%–11%, respectively. Large-sample statistical studies of new constructions, however, have reported narrower ranges. For instance, Matthiessen & Morris (2004) and Matthiessen & Morris (2007) did not find a statistically significant upfront cost premium from an analysis of the actual cost of green buildings when compared to conventional ones. Based on anecdotal evidence from homebuilders, EarthCraft reports an upfront cost premium of 0.5%–3%, which is consistent with a hypothesis by Fischer & Lyon (2014), suggesting that entry-level certification standards and costs are often kept loose and low to attract stakeholders with low willingness to pay for environmental labels (Earth Craft, 2019). In addition to the impacts of confounding variables that could explain the variability of results (e.g., stage of involvement with the program, choice of program and the magnitude of its requirements, builders' level of experience, building characteristics, the choice of research methodology), some variability is attributed to the nature of green building programs (e.g., the availability of optional easy or hard credits, and interactions of project-specific issues and program credits) (GSA, 2004).

Although empirical cost estimates are often based on industry reports, more comparable systematic studies have emerged on estimated rents and sale price premiums of green certification on office properties in the US, based on commercial real estate databases (Eichholtz et al., 2010, 2013; Fuerst & McAllister, 2011a, 2011b; Robinson & McAllister, 2015; Wiley et al., 2010). According to these studies, average sale price premiums for EnergyStar and for LEED-certified buildings could fall between 5.1%–31% and 11.7%–28.4%, respectively. In some cases, results are not statistically significant, and contrasting results have been found on the incremental premiums associated with different levels of certification. In the residential sector, there is comparatively less research available on both construction costs and price premiums. In a study of three US metropolitan areas between 2005 and 2011 Walls et al., (2017) finds 2% and 4%–9% sale price premiums associated with single-family units with EnergyStar and local green building certifications, respectively. Kahn & Kok (2014) finds EnergyStar certified single-family dwellings in California transacted at an average premium of 4.7% between 2005 and 2012, with higher premiums for GreenPointRated and LEED certifications, although these differences were insignificant. Stephenson (2012) estimated a sale price premium of 8.3% for EarthCraft certified houses in Atlanta. Using American Community Survey 2007 data, Koirala et al., (2014) estimated that energy efficiency codes IECC 2003-06 resulted in an increase of 23.25% in house rents. Based on contingent valuation analysis, Robinson et al., (2016) estimated that the aggregate stated willingness to pay for green features was 9.3%. A general conclusion from the past analyses is that green buildings can have small upfront cost premiums, but price premiums often offset the cost of certification.

The US Department of Housing and Urban Development (HUD) broadly defines affordable housing as "housing for which the occupant(s) is/are paying no more than 30% of his or her income for gross housing costs, including *utilities*" (Ezennia & Hoskara, 2019; HUD, 2019a). While helpful, this definition combines all the potential reasons for lack of affordability (e.g., housing prices, housing quality, household income, household choices, public policies), thus, making affordability difficult to understand (Quigley & Raphael, 2004). A voluntary inclusionary housing program—used interchangeably with an affordable housing program—places a rent or price control on a percentage of new developments to keep its units affordable to very low-, low-, or moderate-income households for a pre-determined period of time, and in return, offers economic or zoning benefits to builders to offset the imposed costs (Powell & Stringham, 2005). Many program-specific studies on the costs and benefits of affordable housing have explored diverse effects of housing conditions (e.g., affordability, stability, quality, location) on program participants (e.g., residential mobility, residents' satisfaction, health outcomes, labor market outcomes, educational outcomes, criminal offenses, parenting behavior, etc.) and stakeholders (e.g., origin communities, host communities, taxpayers, and government agencies) but the most common method has been quantifying the value impact of locating near affordable housing properties (Baum-Snow & Marion, 2009; Johnson et al., 2002; Mueller & Tighe, 2007). A general conclusion from existing value impact analyses is that conventional affordable housing properties can have negative but small spillover effects, which should be addressed by planning and policy instruments (Nguyen, 2005). However, there is also evidence that the construction of well-maintained affordable housing properties can appreciate property values in neighborhoods containing abandoned or physically deteriorating housing units (Santiago et al., 2001).

Since the inception of green building rating systems in the early 2000s, state and local governments have provided incentives to promote the integration of green building with affordable housing (Yeganeh et al., 2020). Many researchers have seen the integration of environmental principles into traditionally single-purpose policy sectors, such as affordable housing, as a goal of governance to reduce policy conflicts and inefficiencies (Kivimaa & Mickwitz, 2006; Runhaar et al., 2014). As affordable housing advocates increasingly demand the inclusion of affordable housing in locations beyond central cities, this integration could make affordable housing developments more acceptable for host neighborhoods in the suburbs, and more cost-effective for low-income occupants on a life-cycle basis, thus helping to achieve multiple policy goals (Bradshaw et al., 2005; Foy, 2012; Mueller & Tighe, 2007). Nonetheless, costs and benefits of green affordable housing have rarely been investigated, despite the fact that low-income households are often exposed to low quality housing conditions and thus bear disproportionate costs of energy, transport, healthcare, safety, etc. (Chegut et al., 2016; Zhao et al., 2018). Except for a few recent studies in the EU, available evidence on green building cost premiums is from the gray literature on the commercial sector, thus leaving little information for public and private entities considering green building certifications in the housing sector (Chegut et al., 2019; Zhang et al., 2018).

2.5.2. *Incentivizing the supply of green affordable housing*

Focused on quantifying the relationships between local characteristics and the market penetration of green buildings, a number of previous studies have recognized the importance of economic, political, environmental, and social composition of urban areas to the market penetration of green building. For instance, Eichholtz et al. (2016) concluded that some industry types (e.g., the financial services industry) are more likely than others to choose to locate in green buildings, thus, cities with a high concentration of those industries are more likely to have a higher number of green buildings per capita. The work of Fuerst et al. (2014a) concluded that large, growing, and wealthy cities with a highly educated workforce are more likely to have a higher adoption of green buildings. Financial benefits of green buildings and features (e.g., solar panels, green roofs, etc.) increase where more energy savings can be achieved due to the scarcity of water reserves (i.e., higher water costs) or frequency of heating or cooling degree days (Kahn & Kok, 2014; Simons et al., 2009). Such economic, political, environmental, and social drivers could help to explain the reasons behind the slow market penetration of green buildings, despite documented tangible benefits. Therefore, municipal policy measures—whether regulatory policies or incentives—should be seen as a small fraction of all drivers of green building (Choi, 2010; Simcoe & Toffel, 2014).

Besides findings on the effective real-world performance and economic viability of green buildings, states and local governments have increasingly developed policies and programs that require or encourage public–private partnerships to internalize life-cycle externalities associated with conventional buildings (e.g., construction waste, water run-off, energy inefficiency) (DSIRE, 2019; IEA, 2019; Olubunmi et al., 2016; USGBC, 2019b). These policy instruments include a blend of energy price increases (e.g., by introducing an ecological tax), mandatory energy-efficiency standards, and incentives for new construction and rehabilitation projects (Alberini & Filippini, 2011). Mandatory green building standards often apply to publicly owned or funded projects, and voluntary economic instruments (e.g., loans, tax-based incentives, soft-cost assistance, technical assistance, information provision) and zoning instruments (e.g., height and/or density incentives, parking incentives, flexible lot sizes) influence the incorporation of green standards in both public and private sectors (Circo, 2007). Assuming other drivers of green building are, to some extent, present, the goal of an incentive is to help local builders to supply an efficient quantity of green affordable housing when the free market fails to provide a socially optimal level of such benefits for the society. Previous research considers a variety of factors that could lead to underinvestment in green building, including but not limited to, split incentives, information asymmetries, risk aversion, skill shortages, and analytical failures (Deng & Wu, 2014; Fuerst et al., 2014a; Matisoff et al., 2016).

The rationale for inclusionary housing programs (i.e., incentivizing private developers to incorporate affordable housing into market-driven developments) is the historic shortage of housing units for low-income households (Sirmans & Macpherson, 2003). Underinvestment in affordable housing has been historically exacerbated by local opposition from host neighborhoods to equitable affordable housing siting. For instance, in a survey of 74 not-for-profit and for-profit developers, Scally & Tighe (2015) found that 70% of developers experienced local opposition to affordable housing developments, leading to construction delays, delays in leasing or selling units, denied building permits, reduction in the number of units, changes in project location, or cancellation of the entire development. The positive externalities graph (Figure 7.2.1) illustrates the effect of introducing a per square foot incentive correcting the under-provision of green affordable housing in free market. A supply incentive would increase the free market supply quantity (Q_1) toward a socially optimal level (Q_2), where the marginal private/social cost of production (MPC/MSC) is equal to the marginal social benefit of consumption (MSB). The upward shift in the marginal private benefit (MPB) curve creates the triangular grey area, which represents the quantity of positive externality known as welfare gain. Marginal private cost (MPC), also known as marginal cost of production, is the change in the producer's total cost, resulting from the production of an additional unit, and marginal private cost (MPC) could be considered equal to marginal social cost (MSC), as there is no external cost from the production of green housing relative to conventional housing.

While aiming for socially efficient green affordable housing, incentives are often linked to other urban planning goals, to further address market failures in environmental sustainability and economic development. For instance, urban planners strategically use density incentive programs to direct development to areas with locational and temporal priorities and common challenges. In addition, green building programs could provide opportunities to fund or realize long-term community benefits (e.g., open space preservation, historic preservation, pedestrian and bicycle connectivity, compliance with urban design guidelines) in new construction projects. These programs could work towards a more efficient use of existing infrastructure (e.g., higher transit ridership, reduction in road construction) and penalize goods with negative externalities (e.g., congestion, pollution) (Deng & Wu, 2014; Matisoff et al., 2016). Incentives, however, have limited power to induce general growth and increase affordability by reducing housing prices in markets with a low price-elasticity of supply or demand. In fact, any changes in supply (e.g., associated with regulations, approval delays or growth management) or demand (e.g., associated with changes in income, demographics, mortgage mechanisms) might not be feasible without major regulatory reforms (Eicher, 2008; Ganong & Shoag, 2017; Malpezzi & Vandell, 2002). Figure 7.2.2 illustrates such inefficient markets. On the left graph, S_1, D_1, Q_1, and P_0 are supply curve (marginal cost), demand curve (marginal benefit), supply quantity, and equilibrium price in the existing housing market, respectively. The introduction of a per-square-foot subsidy would create a new equilibrium, in which Q_2, P_p, and P_c are the new supply quantity, the unit price for firms, and the unit price for costumers, respectively. The right graph represents a market with a low-price elasticity of supply, in which introducing the same amount of subsidy ($P_p - P_c = P'_p - P'_c$) would have a little impact on supply quantity (Q'_2), while giving more benefits to producers than consumers. Similar mechanisms are in place for introducing new residential energy efficiency policies that depend on the price elasticity of demand for energy (Alberini & Filippini, 2011). For guidance and more information, see Varian (2014).

The integration of environmental principles in an affordable housing program requires innovative policymakers to monetize and evaluate the private and public costs and benefits of the program, based on local demographic and housing market data. The extant literature suggests that certified offices and houses have higher rents and/or prices that can come from energy efficiency, water efficiency, improved air quality, and occupant productivity. Nonetheless, evaluation of public benefits (i.e., positive externalities, such as eco-system protection, and waste and carbon dioxide emission reduction) associated with green building against environmental damages caused by conventional buildings has been documented with insufficient attention and consensus in the literature (Chegut et al., 2014; Zhang et al., 2018). Simulation-based life-cycle analyses have provided valuable insight into the environmental impacts of green buildings

(Cabeza et al., 2014), but little, if any, research has been performed to date to analyze the spillover effects of green buildings, e.g., in terms of the impact of the presence or density of green buildings on prices of nearby non-green buildings. Such analyses would have provided more details on price dynamics and the social benefits of green buildings, and consequences for local sustainability and climate change policy (Yeganeh et al., 2020). The need for monetary analyses is reinforced by the fact that construction cost data, performance data (e.g., energy use, water use) and outcome data (e.g., on health, pollution, congestion) are generally confidential, limited, or simply unavailable, and engineering simulation studies could be hard to compare or have restricted generalizability, due to heterogeneities involved in the operation stage. Monetizing all the impacts of green affordable housing could reduce uncertainties associated with forecasts, and allow policy analysts to obtain systematic and context-driven conclusions about the social benefits of such programs, based on cost benefit analysis (Fuguitt & Wilcox, 1999; Kats & Alevantis, 2003).

In Chapter 7, we address the lack of attention in the existing literature to the residential sector in smaller urban areas, through a cost analysis of EarthCraft VA certified LIHTC developments, a price analysis of market-rate EarthCraft VA certified single-family houses, and an analysis of spillover effects associated with market-rate certified houses and affordable non-certified houses in Montgomery County, VA. As previous research has documented large associations between the presence of density incentives and a higher production of green residential buildings in a state or county, we apply our findings on costs and prices to the design of a county-wide voluntary density incentive program, to explore how much additional floor area could compensate local builders for investment in the construction of green affordable housing units in for-sale and for-rent scenarios (Choi, 2010; Kontokosta, 2011; Sanderford et al., 2018; Sauer & Siddiqi, 2009; Simons et al., 2009).

CHAPTER THREE: CLIMATE AND SUSTAINABILITY POLICY ADOPTION

Chapter Summary

Recent studies have taken different approaches to explore how climate change policies are shaped by city characteristics in the U.S. Yet, there is clearly a need for integration of policy adoption literature since there is not a comprehensive synthesis currently available, and the average effect of any associations between local conditions and different policy formulations is unknown. The objective of this study is to present such a synthesis of frequently quantified associations described in the body of empirical research on climate policy adoption. We use average elasticities (i.e., the ratio of the percentage change in the dependent variable associated with the percentage change in an independent variable) to explore the magnitude of associations between various characteristics of local environments and the adoption of climate policies in US cities. Elasticities are best "estimates" as currently possible and should be refined as more individual studies become available. This study finds that public support for climate policy has the largest positive impact on policy adoption. Differences in policy benefits (e.g., local versus global) and approach (e.g., mitigation versus adaptation) should be distinguished when encouraging local governments to confront climate change. Given deficiencies in the empirical literature, critical review essays are needed for integration.

3.1. Introduction

Despite worldwide attention to climate change, national leadership in the US has played a marginal role in creating strong collaborative networks to confront climate change (Bedsworth & Hanak, 2013; Gerber, 2013). Some state governments have been more active, but the level of engagement and leadership has been mixed (Shi et al., 2015); thus, leaving a great deal of responsibility in the hands of municipal governments. Since local governments are in a unique position to understand local problems and develop effective responses, decentralization of decision-making and taking a bottom-up approach to climate change can be advantageous (Hughes, Runfola, & Cormier, 2018; Lutsey & Sperling, 2008). However, the lack of involvement on the part of federal and sometimes state governments combined with limitations and opposition at the local level can create challenges for efforts and the ultimate achievement of environmental targets (Patterson et al., 2018).

Scholars have identified several barriers local governments face when dealing with climate change (Betsill, 2001; Wheeler, 2008). First, climate change mitigation policies are public goods with positive spillover effects (i.e., have concentrated costs for the local community and dispersed benefits to all cities and regions). In addition, the positive impacts of climate policies – mitigation and adaptation – are hard to measure and expected to accrue over the long term. Thus, there are powerful incentives favoring nonaction, particularly in areas where there are competing local or regional policy priorities. Policy adoption is often constrained by opposition group pressure (e.g., lobbying from manufacturing and extractive industries), limited policy windows (i.e., influence) in areas with high potential for reductions in emissions (e.g., utilities and transportation, both of which involve various levels of government, consumer choice, and other actors), high up-front costs associated with policy implementation and limited financial resources, and low visibility of adverse effects to the public – particularly in small communities (Hughes et al., 2018; Hultquist et al., 2017; Yeganeh et al., 2018). Voluntary and fragmented investments, particularly in mitigation, neither insulate proactive communities from the global risks of climate change nor exclude passive communities from receiving their benefits (Brody et al., 2008). In practice, many local governments have not yet established substantive climate-related programs or have sometimes abandoned prior commitments due to existing barriers or perceived program ineffectiveness (Krause et al., 2016).

In spite of these challenges, hundreds of cities have committed themselves to manage and reduce greenhouse gas emissions and engage in adaptative measures to increase resilience given the local nature of risks (e.g., to infrastructures, coastal communities, economic activities, etc.) (Miao, 2019). Hultquist et al. (2017) distinguish three waves of municipal activities in response to climate change in the US: the first wave – in the mid-1990s – was focused on reducing greenhouse gas emissions in large cities albeit in an ad hoc manner with limited coordination; the second wave – in the early-2000s – was facilitated through network organizations, such as the US Conference of Mayors Climate Protection Agreement (MCPA) and International Council for Local Environmental Initiatives (ICLEI); the third wave – in the mid-2010s – emphasized long-term sustainability and adaptation.

There is a growing body of climate change scholarship exploring why some localities increasingly act as pioneers in confronting climate change, how others learn and follow, what differences exist in adopted policies, and what processes and conditions enable policy change in different contexts (Dilling et al., 2017; Wood et al., 2014). For example, case studies suggest that proximity to ambitious pioneers with sophisticated policies is associated with the spread of climate actions to neighboring jurisdictions (Kalafatis & Lemos, 2017; Wheeler, 2008). However, there is hitherto no systematic review and meta-analysis that draws from and seeks to learn across the various case studies that test different explanations for local climate change policy adoption. In addition, the scholarship is this area has generally been non-cumulative because design and measurement have been carried out in ad-hoc ways. Swann & Deslatte (2019) critique the overall body of empirical literature developed in this area for being "non-nested", i.e., similarly aimed models omit different sets of variables or theoretical explanations. Given the deficiencies of the empirical literature, critical review essays are needed for integration. Nonetheless, narrative reviews could be largely subjective, i.e., different experts can come to different conclusions, and impossibly difficult when there are more than few studies involved. Meta-analysis, by contrast, applies objective formulas to the large number of currently available studies to summarize the existing body of evidence. Therefore, this study presents a systematic review and meta-analysis of quantitative research published before the end of 2018 on drivers of climate change policy adoption in US cities, marshaling lessons learned from various studies to draw synthesized conclusions. It aims to contribute to the literature by analyzing what we know so far and proposing a foundation for more systematic and cumulative assessment going forward.

3.2. Systematic Literature Review

3.2.1. Review protocol

Qualitative and quantitative reviews in urban and environmental studies have synthesized individual studies on climate change risk measurement (Chapman et al., 2017; Tonmoy et al., 2014), adaptation policy adoption (Biesbroek et al., 2018; S. Hughes, 2015), and policy intervention assessment (Dulal et al., 2011; Lwasa et al., 2015; Rose & Dormady, 2011). However, no work has been performed to summarize previously quantified associations between characteristics of urban areas and policy response to climate change in the context of US cities. In order to consistently aggregate and synthesize findings from individual studies, we followed the PRISMA statement (Moher et al., 2010) to establish a pool of studies from any published peer-reviewed English journal papers in urban affairs and public policy and administration areas that applied regression analyses to explain climate policy adoption by local governments. Following the steps described in Figure 3.2.1, we used Google Scholar to inspect 123 international journals that focus on current urban and environmental studies, finding thousands of research articles relating to climate change. We read the title and abstracts of about 1250 papers looking for those that explicitly reference the adoption of climate policies in US cities. We then reviewed the references and citations of the 37 papers that met the established criteria and identified a few more relevant studies, resulting in a total of 53 papers included for analysis.

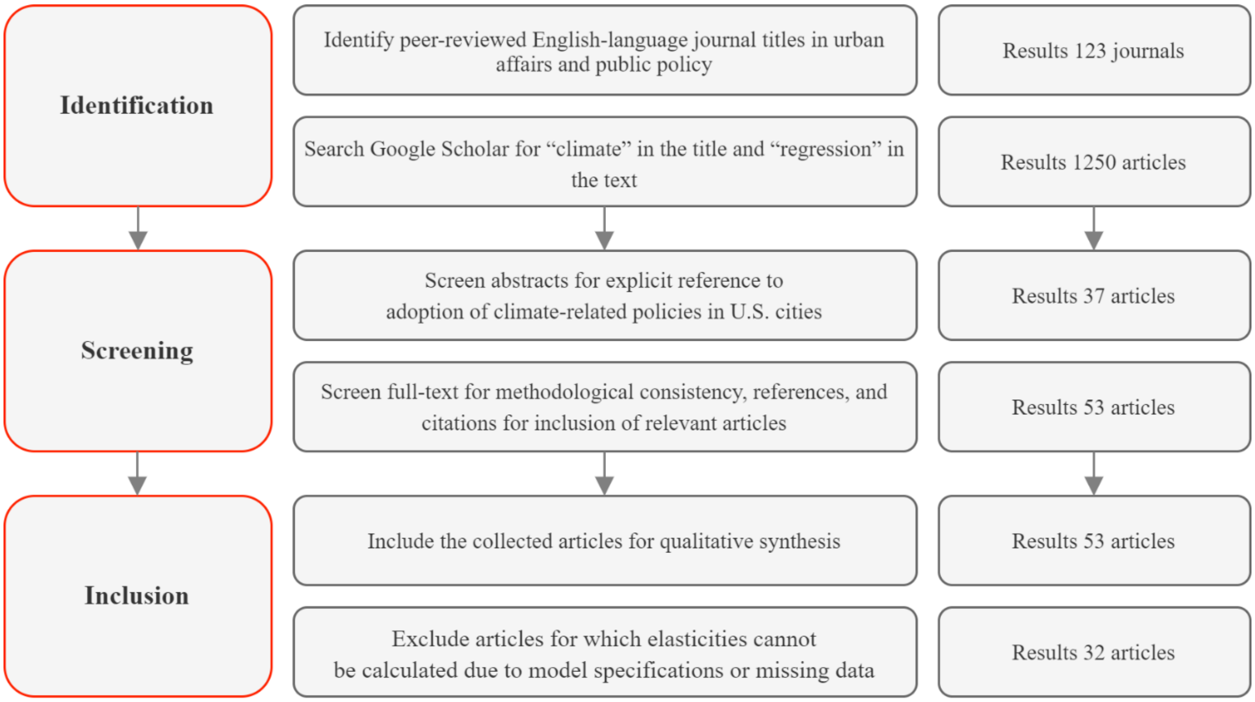


Figure 3.2.1 Steps taken in this systematic review adapted from (Moher et al., 2010)

3.2.2. Characteristics of individual studies

Table 3.2.1 summarizes the specifications of the studies that meet the inclusion criteria described in Figure 3.2.1. We sought individual studies with dependent variable data as either adoption (i.e., a binary variable) or quantity (i.e., a continuous variable) of climate policies. Nonetheless, included studies have used different types of dependent variables (e.g., inventories, plans, policies) individually or in combination to explain the same construct (i.e., confronting climate change). Although a combination of sustainability tools (e.g., green building, alternative transportation) could represent some levels of commitment to greenhouse gas reduction, local support for sustainability – which often has local benefits – does not necessarily influence the adoption of climate change mitigation tools that impose costs on the city but have global benefits (Bedsworth & Hanak, 2013; Deslatte & Swann, 2016). Thus, when synthesizing the results, there is a need to distinguish between studies that use a distinct climate-specific policy with global benefits (e.g., greenhouse gas targets) as the dependent variable and studies that apply a bundle of integrated policies with primarily local benefits often under the overarching term *sustainability*. Also, policies that intend to mitigate the causes of climate change should be distinguished from those that aim to adapt to its consequences. The Dependent Variable (DV) column in Table 3.2.1 describes the type of dependent variables as used in the individual studies. Authors have often created different models depending on sets of policies analyzed. For instance, Deslatte & Swann (2016) have distinct models for greenhouse gas (GHG) targets, sustainability, and adaptation. Based on the DV column, such variations in individual studies were considered when creating sub-groups for this meta-analysis.

Table 3.2.1 Specifications of the included studies

Study	M[1]	S[2]	R[3]	DV[4]	L[5]	C[6]	IV[7]	I[8]
1) (Bae & Feiock, 2013)	1	477	PSR	Sustainability & GHG inventory (C)	N	SE	CI, CS, GC, GS	Y
	2	479	PSR	Sustainability & GHG inventory (G)				
2) (Bedsworth & Hanak, 2013)	1	302	LGR	CAP (2008)	Y	SE	CI, CS, GC, GI, GS	Y
	2	327	LGR	CAP (2010)				
	3	296	LGR	GHG inventory (2008) (C)				
	4	330	LGR	GHG inventory (2010) (C)				
	5	295	LGR	GHG inventory (2008) (G)				
	6	328	LGR	GHG inventory (2010) (G)				
3) (Brody et al., 2008)	3	3101	LGR	CCP program adoption	N	ST	CI, CS, ER	N
4) (Daley et al., 2013)	1	89	OLS	Sustainability & GHG inventory (CM)	N	GV	CI, CS, GC, GS, IG	Y
	2	58	OLS	Sustainability & GHG inventory (MC)				
5) (Deslatte & Swann, 2016)	1	362	LGR	GHG targets	N	TY	CI, CS, GC, GI, GS	Y
	2	317	ZNB	Sustainability				
6) (Dilling et al., 2017)	8	60	PSR	Adaptation	N	-	CS, ER, IG, GC, GI	Y
7) (Feiock & Bae, 2011)	1	540	PBR	GHG inventory	N	SE	CI, CS, GI, GS	Y
	2	540	PBR	GHG inventory (C)				
	3	540	PBR	GHG inventory (G)				
8) (Feiock et al., 2017)	1	214	NBR	Sustainability & climate policy	N	-	CS, CI, GC, GS, IG	Y
9) (Gerber, 2013)	1	1000	LGR	Sustainability & climate policy (C)	N	SE	CI, CS, GI, GS	N
	2	1000	LGR	Sustainability & climate policy (G)				
	3	1000	LGR	CC program adoption				
	4	1000	LGR	MCPA program adoption				
10) (Hawkins et al., 2016)	1	539	LGR	Budget dedicated to sustainability	N	-	CI, CS, ER, GC, GS, IG	Y
	2	537	LGR	Staff dedicated to sustainability				
	3	524	LGR	Full commitment to sustainability				
11) (Hawkins et al., 2018)	1	683	OLS	Sustainability & climate policy	N	-	CI, CS, GC, GI, IG	Y
12) (Hawkins & Wang, 2013)	1	263	ZPS	Sustainability & climate policy	N	-	CI, CS, GS	N
13) (Homsy, 2016)	1	861	NBR	Sustainability & climate policy (C)	N	SE	CI, CS, GC, GI, GS, IG	Y
	2	861	NBR	Sustainability & climate policy (G)				
14) (Homsy, 2018)	1	1839	PSR	Sustainability & climate policy (C)	N	SE	CS, GC, GI, GS, IG	Y
	2	1839	PSR	Sustainability & climate policy (G)				
15) (Homsy & Warner, 2015)	1	1497	MLR	Sustainability & climate policy	N	SI	CI, CS, ER, GC, GI, GS, IG	N
	2	246	MLR	Sustainability & climate policy (L)				
	3	1251	MLR	Sustainability & climate policy (S)				
16) (Hughes et al., 2018)	1	1253	OLS	GHG inventory & targets	N	SC	CI, CS, ER, GS, IG	Y
17) (Hultquist et al., 2017)	1	211	NBR	Climate policy	Y	TY	CI, CS, GC, GI, GS, IG	Y
	2	211	NBR	Adaptation				
	3	211	NBR	GHG inventory & targets				
18) (Kalafatis, 2017)	1	287	LGR	Climate policy	N	SC	CI, CS, ER, GC, GI, GS	N
19) (Kalafatis, 2018)	1	287	LGR	Adaptation	N	TY	CI, CS, ER, GC, GI, GS, IG	Y
	2	287	LGR	Sustainability				
	3	287	PSR	Adaptation				
	4	287	PSR	Sustainability				
20) (Kalafatis & Lemos, 2017)	1	371	LGR	Climate change entrepreneur	Y	-	CI, CS, ER, GC, GI, GS	Y

Table 3.2.1 (continued) Specifications of the included studies

Study	M[1]	S[2]	R[3]	DV[4]	L[5]	C[6]	IV[7]	I[8]
21) (Kalesnikaite, 2018)	1	130	OLR	Adaptation (outputs)	N	-	CI, CS, ER, GC, GS, IG	Y
	2	94	OLS	Adaptation (outcomes)				
22) (Koski & Siulagi, 2016)	1	98	OLG	Adaptation	N	TY	CI, CS, ER, GC, GS, IG	Y
23) (Krause, 2011b)	1	50	MLG	MCPA program adoption	N	ST	CI, CS, ER, GC, GS, IG	N
24) (Krause, 2011c)	1	52	OLS	Sustainability & climate policy	N	ST	CI, CS, ER, GC, GI	N
25) (Krause, 2012a)	1	329	OLS	Sustainability & climate policy	N	SC	CI, CS, GC, GI, IG	N
	2	329	PBR	ICLEI membership				
	3	329	PBR	MCPA program adoption				
26) (Krause, 2012b)	1	329	OLS	Sustainability & climate policy	N	TY	CI, CS, ER, GC, GI, GS, IG	Y
27) (Krause, 2013)	1	245	LGR	CAP & GHG inventory (C)	N	SE	CI, CS, ER, GC, GI, GS, IG	N
	2	245	LGR	CAP & GHG inventory (G)				
	3	245	LGR	Resource commitment				
28) (Krause et al., 2016)	1	526	LGR	ICLEI termination	N	ST	CI, CS, ER, GC, GI	Y
29) (Kwon et al., 2014)	1	156	PSR	Climate policy	N	SC	CI, CS, ER, GC, GI, GS, IG	N
	2	156	PSR	Sustainability				
30) (Kwon et al., 2018)	1	128	LGR	Sustainability & climate policy	N	TY	CI, CS, GC, GI, GS, IG	Y
	2	114	OLG	Climate policy				
31) (Lee & Koski, 2012)	1	591	MLR	Green building activity	N	SC	CI, CS, ER, GI, GS, IG	N
32) (Lee & Koski, 2015)	1	591	MLG	Climate policy	N	SC	CI, CS, GI, GS, IG	N
33) (Mason & Fragkias, 2018)	1	73	LGR	Climate policy	N	-	CI, CS, ER, GC, GI, IG	Y
	2	84	LGR	Climate policy				
	3	71	LGR	Climate policy				
34) (Millard-Ball, 2012)	1	7383	PBR	Climate policy	Y	ST	CI, CS	Y
35) (Pitt, 2010)	1	255	OLS	Climate policy	N	SC	CI, CS, ER, GI, GS, IG	Y
	2	255	OLS	Sustainability & climate policy				
36) (Romsdahl et al., 2015)	1	633	MNL	Adaptation	N	ST	CI, CS, ER, GC, GI, GS, IG	Y
	2	633	MNL	Adaptation				
37) (Rosenthal et al., 2015)	1	812	MLR	Sustainability & climate policy	N	SC	CI, CS, GC, GI, GS, IG	Y
	2	812	OLS	Sustainability & climate policy				
38) (Sharp et al., 2011)	1	46	LGR	ICLEI membership	N	ST	CI, CS, ER, GC, GS	N
	2	46	LGR	ICLEI membership				
	3	72	LGR	ICLEI membership				
	4	72	LGR	ICLEI membership				
39) (Shi et al., 2015)	1	156	LGR	Adaptation	N	ST	CI, CS, ER, GC, GI	Y
40) (Svara et al., 2013)	1	1612	OLS	Sustainability & climate policy	N	TY	CS, GI, GS, IG	Y
	2	1519	OLS	Sustainability & climate policy			CS, GI, GS, IG	
41) (Swann, 2017)	1	315	ZNB	Sustain. & climate policy (C)	N	SE	CI, CS, GC, GI, IG	N
	2	315	ZNB	Sustain. & climate policy (C)				
	3	315	ZNB	Sustain. & climate policy (G)				
	4	315	ZNB	Sustain. & climate policy (G)				
42) (Swann & Deslatte, 2019)	1	419	MRS	GHG reduction	N	TY	CI, CS, ER, GC, GI, GS, IG	N
	2	419	MRS	Sustainability & GHG targets				
43) (Tang et al., 2011)	1	133	OLS	Climate policy	N	-	CS, ER	Y
44) (Tang et al., 2010)	1	40	OLS	Climate plan quality	N	ST	CS, ER, GC, GI, IG	N

Table 3.2.1 (continued) Specifications of the included studies

Study	M[1]	S[2]	R[3]	DV[4]	L[5]	C[6]	IV[7]	I[8]
45) (Tang et al., 2012)	1	53	OLS	Climate policy	N	ST	ER	Y
	2	53	OLS	Climate policy			GI, IG	
	3	53	OLS	Climate policy			GC	
	4	53	OLS	Climate policy			CS	
46) (Wang, 2012)	1	197	PHR	MCPA program adoption	N	SC	CI, CS, ER, GC, GS, IG	N
47) (Wang, 2013)	1	174	PBR	Adaptation (2008)	Y	TY	CI, CS, ER, GC, GI, GS, IG	Y
	2	174	PBR	GHG calculation (2008)				
	3	185	PBR	GHG calculation (2009)				
	4	174	PBR	GHG target (2008)				
	5	185	PBR	GHG target (2009)				
	6	174	PBR	Mitigation analysis (2008)				
	7	174	PBR	Mitigation policies (2008)				
	8	174	PBR	Plan language (2008)				
	9	185	PBR	Plan language (2009)				
	10	174	PBR	Policy / program (2008)				
	11	185	PBR	Policy / program (2009)				
48) (Weible & Elgin, 2013)	1	272	OLS	Sustainability & climate policy	N	SC	GC, GI, IG	N
	2	272	OLS	Sustainability & climate policy				
49) (Wood et al., 2014)	1	211	OLS	Climate policy	N	TY	CI, CS, ER, GI, GS, IG	N
	2	211	OLS	Adaptation				
	3	211	OLS	Mitigation				
50) (Woodruff, 2018)	1	418	LGR	Network membership	N	SC	CI, CS, GS, IG	N
51) (Yi et al., 2017)	1	376	LGR	MCPA program adoption	Y	ST	CI, CS, ER, GC, GS, IG	Y
52) (Zahran, Brody, et al., 2008)	1	3071	LGR	CCP program adoption	N	ST	CI, CS, ER	Y
53) (Zahran, Grover, et al., 2008)	1	306	OLS	CCP program adoption	N	ST	CS, ER	N

Note:

1-Regression model code: partial or specified models are not included.
2-Sample size: count of observations (i.e., counties, cities, or towns)
3-Regression specifications as follows:
- BYR: Bayesian regression
- LGR: Logistic regression
- MLG: Multi-level logistic regression
- MLR: Multi-level regression
- MRS: Multi-variate adaptive regression
- NBR: Negative binomial regression
- OLG: Ordinal logistic regression
- OLS: Ordinary least squares regression
- PBR: Probit regression
- PHR: Proportional hazards regression
- PSR: Poisson regression
- TBT: Tobit regression
- ZNB: Zero-inflated negative binomial regression
- ZPS: Zero-inflated poisson regression

4- Dependent variable:
- C: Community-wide operations
- CAP: Climate action plan
- CC: Cool Cities
- CCP: Cities for Climate Protection
- CM: Council-manager government
- EE: Energy efficiency
- G: Government-wide operations
- ICLEI: International Council for Local Environmental Initiatives
- MC: Mayor-council government
- MCPA: Mayors Climate Protection Agreement

5-Longitudinal: “Y”: Yes, “N”: No.
6-Comparative policy analysis (if developed):
- GV: Government-based
- SC: Scale-based
- SE: Sector-based
- SI: Size-based
- ST: Status-based
- TY: Type-based

7-Independent variable specifications:
- CI: Community interest
- ER: Environmental risk
- GC: Government capacity
- GI: Government interest
- GS: Government structure
- IG: Inter-governmental collaboration
- SE: Socio-economic characteristics

8- Inclusion in the meta-analysis (decided based on whether means of the variables are reported or elasticities can be estimated using the regression model specifications): “Y”: Yes, “N”: No.

Studies examined often tested policy adoption theories (e.g., theories of local political decision making, political entrepreneurship, multiple streams) or hypotheses based on the study objective (Hultquist et al., 2017; Krause, 2012b; Zahran, Brody, et al., 2008). In addition, authors developed statistical models to compare differences by city size (e.g., small versus large), government structure (e.g., council-manager versus mayor-council), issue scale (e.g., local versus global), policy sector (e.g., government versus community), policy status (e.g., adoption versus implementation), and policy type (e.g., mitigation versus adaptation) to investigate how these changes might impact the distribution of policy benefits (Rosenthal et al., 2015). This section highlights a number of these comparisons as these relate to the study results. For further description of broad emerging themes (e.g., Democratic responsiveness, organizational capacity, environmental conditions, and governance institutions), see, Swann & Deslatte (2019).

Previous studies have found that the adoption of internal government programs (e.g., planning initiatives, green municipal purchasing programs) is generally higher than of community-oriented and climate-specific programs (e.g., recycling programs, rebates for purchasing environmentally-friendly products) (Bedsworth & Hanak, 2013; Gerber, 2013). Since developing climate action plans for internal government operations requires less fiscal and staff capacity than developing similar plans for household and private sector operations (Krause, 2013) and governments have much more control over their own operations, they may initially focus on their own emissions before starting community initiatives (Feiock & Bae, 2011). In addition to economic drivers, Gerber (2013) suggests that the adoption of community- and government-focused policies is also associated with resident and elected official partisanship, respectively.

Few studies in the sample set focused on climate adaptation (i.e., risk management) or have compared and contrasted it with climate mitigation (i.e., risk protection) (Kalafatis, 2018). Gerber (2013) argues that mitigating the causes of climate change (e.g., through a reduction in emissions and reliance on renewable energy) is in contrast with adapting to its consequences (e.g., through emergency preparedness planning). According to Hultquist et al. (2017), mitigation is, in essence, a global problem, whereas adaptation policies are intended to reduce vulnerability at the local level; thus adaptation policies are easier to justify without the need to acknowledge the causes of climate change. In contrast to the collective action problem associated with mitigation policies, adaptation policies can be more self-serving. Models developed by Wang (2013) and Wood et al. (2014) link local adaptation actions to the presence of risk factors (e.g., coastal location and weather-related incidents, respectively). Koski and Siulagi (2016) contend that framing climate change as an environmental hazard – rather than an environmental harm – could lead to greater community support. However, once local restrictions on climate adaptation planning are surmounted, continuous success requires institutional capacity (Pitt & Bassett, 2014) and support from state and federal government (Romsdahl et al., 2015). Existing state policies do not currently seem strong enough to support local adaptation planning (Shi et al., 2015).

A notable discussion in the literature relates to the ways in which commitment to substantial climate protection is represented; is it through membership in climate networks, implementation of climate change related activities, or something else (Koski & Siulagi, 2016)? Several studies find that participation in a climate-related network alone might not be the best indicator of confronting climate change (Kalafatis, 2018). In fact, network membership could represent the *intention* to adopt climate change mitigation measures more than their *actual* adoption (Pitt &

Bassett, 2014). Krause (2012a) finds ICLEI membership is associated with small to moderate increases in mitigation activities, whereas adoption of the MCPA has no such effect. Moreover, Hughes et al. (2018) argue that choosing a single type of policy in isolation (e.g., ICLEI membership) or aggregate indexes of policy adoption could obscure the motivations behind the adoption of policies as there are many contextual factors that determine the prioritization of specific actions.

With regard to the scale of the impact of policy on adoption, Hughes et al. (2018) suggests that responses to highly local, regional, and global problems are most likely to be influenced by problem severity, the actions of external jurisdictions, and local political leaning, respectively. In other words, strong bi-partisan support for climate policy at the local level is associated with the perception of salient local impacts. Interestingly, Dilling et al. (2017) finds that the influence of state support on policy adoption is lower in areas with higher risk perception and more in areas with lower risk perception, suggesting that high-risk areas have acted more proactively whether assisted by state governments or not. Some studies have controlled for such multi-level governance effects using simple and hierarchical regression analyses (Hughes et al., 2018; Lee & Koski, 2012, 2015). The few studies that use cluster analysis to account for spatial autocorrelation found that a significant amount of variation in policy adoption is explained by the characteristics of neighbors (Brody et al., 2008). Gerber (2013) finds that the inclusion of a local government in a democratic partisan cluster with its neighbors can explain policy adoption even better than support group pressure existing within its own jurisdiction. Table 3.2.2 summarizes and suggests categories for all variables included in reviewed studies. Although sample sizes are often large – between 40 and 7383 geographical areas with an average of 500 observations – several individual studies contained low statistical power and restricted generalizability.

Therefore, narrative reviews for synthesizing data across these studies could lead to largely subjective interpretations. Applying objective formulas through a meta-analysis – which is the objective of this study – could help inform decisions about the utility of policy interventions or the validity of the frequently tested hypotheses (Borenstein et al., 2009b).

Table 3.2.2 Independent variables used in climate adoption models

Government capacity (GC)	*Government interests (GI)*	*Government structure (GS)*
1. Budgetary conflict	1. Attitude or motivation	1. Adaptability to change
2. Budget surplus or shortfall	2. Civic or development entrepreneurship	2. Administrative structure
3. Debt burden	3. Collaboration or partnership	3. Age of the organization
4. Expenditure	4. Dedicated sustainability unit	4. Central or capital city
5. General revenue or change in revenue	5. Elected official support	5. Charter city
6. Intergovernmental dependence	6. Environmental entrepreneurship	6. County government
7. Overall capacity or change in capacity	7. Interdepartmental leadership	7. Directly elected district quantity
8. Reliance on property tax	8. Issue salience to government staff	8. Form of government
9. Staff education, expertise, training, etc.	9. Policy priorities	9. Fragmentation (e.g., districts in the area)
10. Staff quantity	10. Political orientation	10. Mayor years of service
11. Stakeholder involvement	11. Political or bureaucratic entrepreneurship	11. Municipalities in the area
12. Technical capacity (e.g., access to data)	12. Staff support	12. Utility ownership
Community interests (CI)	*Community structure (CS)*	
1. Attitude towards climate change	1. Age or change in age	
2. Business association support	2. College education	
3. Carbon or manufacturing dependence	3. Education change	
4. College town or local university presence	4. Employment	
5. Democratic-leaning	5. Foreclosure or home ownership	
6. Environmental association support	6. Income, poverty, or wealth	
7. Green party activity	7. Income change	
8. Homeownership association support	8. Ph.D. degree holders	
9. Issue salience to the public	9. Population	
10.Neighborhood association support	10. Population change	
11.NGO strength	11. Population density	
12. Public support	12. Population proportion under 16	
13. Real estate employment	13. Racial diversity	
14. Tea Party events or PAC support	14. Social vulnerability	
15. Voter turnout		
Environmental risk, stress, & opportunity (ER)	*Intergovernmental characteristics (IG)*	
1. Commute time	1. County climate protection plan	
2. Coastal area, mileage, or proximity	2. ICLEI, MCPA, and length of membership	
3. Cost of electricity	3. Influence of neighboring cities	
4. Drought or change in drought	4. Level of involvement	
5. Energy use	5. State action plan or GHG target	
6. Expected change in temperature	6. State carbon or manufacturing dependence	
7. Extreme event frequency or type	7. State climate advisory board	
8. GHG emissions or unhealthy air	8. State climate-related policies	
9. Heating or cooling degree days	9. State energy or green initiatives	
10. Open space or wildlife vulnerability	10. State energy agency	
11. Precipitation quantity	11. State energy consumption	
12. Severity of events or FEMA assistance	12. State environmental groups	
13. Solar energy use	13. State GHG reporting system	
14. Traffic injuries	14. State park visitors	
15. Transportation mode	15. State political leaning	
16. Vulnerability or FEMA disaster area	16. State support / opposition	
17. Water footprint	17. State tourism spending	
18. Water quality	18. State urbanization	

Note: The variables have been categorized in many ways depending on the purpose of individual studies.

3.3. Methodology

Since studies with higher statistical significance are more likely to be published, selecting individual studies from the published literature may increase the magnitude of summary effect sizes in meta-analysis. Thus, publication bias is considered as a potential source of type I error in meta-analysis as well as a threat to other areas of research. Nonetheless, others have reported mixed results when comparing meta-analyses of published and unpublished literature. Several researchers concluded that the results of unpublished studies are not necessarily different from those of published studies (Schmidt & Hunter, 2014). Others also considered publication bias beyond a hypothetical problem and suggested that an analysis of publication bias should always be included in the results (Borenstein et al., 2009a). Conference papers, archived manuscripts, and white papers were subsequently examined to reduce the possibility of bias. We identified a limited quantity of unpublished studies, but they did not include the required information for calculating the effect size for the purposes of this analysis. Another potential source of weakness in meta-analysis is the combination of studies with varying levels of sophistication (e.g., modeling techniques, variables, and sampling units) (Ewing & Cervero, 2010). Individual studies have often described that climate policy adoption is driven by complex dynamics of contextual factors resulting in a relatively low coefficient of determination in the obtained models; thus, each study seems to capture a part of the policy formation process from a specific perspective. A potential solution to avoid the weakness resulting from combining strong and weak studies is to create sub-groups that could decrease between-study heterogeneity – on the condition that each sub-group includes the minimum acceptable sample size. After creating sub-groups, we did not find significant differences in the level of methodological strength that could be used as a criterion for exclusion or separation of the collected studies.

In combining results from the included studies, we use elasticities to compute the average effect size. The first reason is that elasticities have been frequently used in previous meta-analyses in urban policy and planning and are easy to apply and interpret for planning and policy purposes (Ewing & Cervero, 2010; Stevens, 2017). The second reason is the suitability of elasticities for this analysis as they could be estimated and combined from a variety of regression models (linear, logit, etc.) with the statistics that are often reported (coefficients, means, etc.) in the climate policy adoption literature. Elasticity is the ratio of the percentage change in the dependent variable (i.e., policy adoption) associated with the percentage change in an independent variable. For binary variables (e.g., presence of the council-manager form of government), however, semi-elasticity seems to be a more meaningful measure, which is the percent change in the dependent variable when the binary independent variable changes from 0 to 1. In this analysis, we calculate the sample-size-weighted-average of the elasticities with respect to the seven constructs introduced in Table 3.2.2, namely, community interests, community structure, government interest, government capacity, government structure, intergovernmental relationship, and environmental risk. The corresponding variables for which elasticities are calculated are introduced in Table 3.3.1. Elasticities for the full list of variables cannot be generated due to the limited number of available studies.

Table 3.3.1 Independent variables for which average elasticities are estimated

Variable	Description
Community interest	
Democratic-leaning	Percentage of city population who voted for a Democratic or green party candidate
Business group support	Perceived salience of climate issues or support for climate policy among business groups
Environmental group support	Perceived salience of climate issues or support for climate policy among environmental groups
Manufacturing dependence	Value added in city economy of the manufacturing sector
Public support	Perceived salience of climate issues or support for climate policy among the general public
Community structure	
Density	City population per area unit
Education	Percentage of city population who have attained at least a bachelor's degree
Income	Mean or median annual personal or household income in US dollars
Population	City population
White population	Percentage of White population in the city
Government capacity	
Fiscal capacity	Average of all measures of fiscal capacity including budget, expenditure, and revenue
Intergovernmental dependence	Percentage of city revenue from intergovernmental transfers
Staff capacity	Count of planners
Government structure	
Council-manager form (*b*)	Binary variable: 1 if the City has a council-manager form of government and 0 if otherwise
Utility ownership (*b*)	Binary variable: 1 if the City owns the utility (power or water) and 0 if otherwise
Wards	Number of wards that directly elect council members
Government interests	
Dedicated sustainability unit (*b*)	Binary variable: 1 if the City has a dedicated sustainability office and 0 if otherwise
Policy entrepreneurship (*b*)	Binary variable: 1 if the City has a sustainability policy entrepreneur and 0 if otherwise
Staff support	Perceived salience of climate issues or support for climate policy among the City staff
Environmental risk	
Air quality	Average of all measures of air quality in individual studies
Coastal location (*b*)	Binary variable: 1 if the city is in a coastal location and 0 if otherwise
Vulnerability	Average of all measures of physical vulnerability in individual studies
Intergovernmental	
Active state (*b*)	Binary variable: 1 if the city is in a state with GHG emission goals and 0 if otherwise
ICLEI/MCPA membership (*b*)	Binary variable: 1 if the City is a member of ICLEI or MCPA and 0 if otherwise

We then estimated elasticities using the formulas proposed by Ewing and Cervero (2010) and Stevens (2017) (Table 3.3.2) for which the average values of dependent and independent variables were often needed. Where nonstandard coefficients were reported in terms of marginal effect, odds ratio, hazard ratio, etc., we converted the coefficients to beta coefficients where possible. Where the average values were missing, we contacted corresponding authors to seek information – as well as to seek potential studies in the publication process – before excluding the studies from the analysis. In many cases, the data were several years old, and the authors did not have immediate access to data to provide the averages. Nonetheless, many studies included more than one dependent variable or regression model, which increased the total number of elasticities from the final models to about 750.

Table 3.3.2 Elasticity estimation formulas adapted from Ewing and Cervero (2010)

Linear	Linear-log	Log-linear	Log-log	Logistic	Negative binomial	Poisson	Tobit
$\beta * \frac{\bar{x}}{\bar{y}}$	$\frac{\beta}{\bar{y}}$	$\beta * \bar{x}$	β	$\beta * \bar{x}\left(1 - \left(\frac{\bar{y}}{n}\right)\right)$	$\beta * \bar{x}$	$\beta * \bar{x}$	$\beta * \left(\frac{\bar{x}}{\bar{y}}\right)$

Notes: β is the regression coefficient on the independent variable of interest, $\bar{y}$ is the mean value of the dependent variable of interest, $\bar{x}$ is the mean value of the independent variable of interest, and $\left(\frac{y}{n}\right)$ is the mean predicted probability of occurrence.

3.4. Results

The results presented in Table 3.4.1 describe the average magnitude of effect for the continuous and binary variables that studies suggest influence the adoption and implementation of local climate policies as previously described. The acceptable minimum number of individual effect sizes to calculate average elasticities is attributed to the field and the quantity of available studies for analysis (Ewing & Cervero, 2010). Empty cells in the following tables indicate variables for which less than three effect sizes are currently available.

Table 3.4.1 Elasticity of policy adoption with respect to local characteristics

Variable[1]	All studies						
	E[2]	M[3]	SD[4]	Min[5]	Max[6]	C[7]	S[8]
Community interest							
Democratic leaning	0.267	0.403	0.580	-1.390	2.091	53	16
Business group support	0.278	0.231	0.324	-0.521	1.104	18	7
Environmental group support	0.089	0.049	0.302	-0.559	0.631	14	9
Manufacturing dependence	-0.399	-0.104	0.243	-0.572	0.267	8	4
Public support	0.914	0.512	0.486	0.031	1.925	17	7
Community structure							
Density	0.481	0.401	0.692	-0.054	2.385	13	8
Education	0.317	0.313	0.356	-0.186	1.611	27	17
Income	0.094	0.282	0.692	-0.853	2.010	40	16
Population	0.623	0.250	0.321	-0.190	1.244	57	27
White population	0.290	0.078	0.386	-0.550	0.886	12	6
Government capacity							
Fiscal capacity	0.042	0.052	0.997	-2.019	2.783	19	9
Intergovernmental dependence	-0.632	-0.569	0.582	-1.353	-0.077	4	3
Staff capacity	-0.036	-0.055	0.528	-1.298	0.550	20	6
Government structure							
Council-manager form (*b*)	-0.008	0.024	0.464	-2.148	0.420	28	14
Utility ownership (*b*)	0.067	0.046	0.069	-0.004	0.295	17	4
Wards	0.019	0.098	0.257	-0.274	0.444	6	3
Government interests							
Dedicated sustainability unit (*b*)	0.682	0.567	0.880	-0.041	2.583	9	4
Policy entrepreneurship (*b*)	0.386	0.413	0.738	-0.162	3.190	27	7
Staff support	0.179	0.174	0.201	-0.058	0.691	21	7
Environmental risk							
Air quality	0.137	0.072	0.564	-0.450	1.613	18	6
Coastal location (*b*)	0.346	0.194	0.166	0.019	0.403	5	5
Vulnerability	0.051	0.066	0.126	-0.232	0.312	21	6
Intergovernmental							
Active county / state (*b*)	0.100	0.049	0.388	-0.446	0.808	9	4
ICLEI/MCPA membership (*b*)	0.338	0.372	0.360	0.090	1.745	19	7

Notes:

1- Binary (b) variables are based on semi-elasticity values.
2- Sample-size-weighted-average elasticities
3- Simple mean of elasticities
4- Standard deviation of elasticities
5- Minimum elasticity value
6- Maximum elasticity value
7- Count of elasticities
8- Count of studies

Within the community interest category, all variables are continuous and *public support*, which is measured by the expressed support for environmental activism, has the largest positive impact on policy adoption. On average, a one percent increase in public support is associated with a 0.914% increase in local government engagement in policy adoption. In the same category, *manufacturing dependence* has the largest negative impact on policy adoption among all the variables. On average, a one percent increase in dependence on manufacturing is associated with a 0.399% decrease in local government engagement in policy adoption. In the community structure category (i.e., socioeconomic characteristics), all the included variables are continuous, and *population size* has the largest positive impact on policy adoption (a 1% increase in population is associated with a 0.623% increase in local government engagement), followed by *population density*.

Increased government capacity is generally associated with an increase in climate policy adoption. A 1% increase in *fiscal capacity* is associated with a 0.042% increase in government engagement. And in terms of independence, a 0.632% decrease in government engagement is associated with a 1% increase in *intergovernmental dependence*. Nonetheless, there is small evidence that operationalization of government capacity in the form of the number of planners leads to positive results as responsibility for climate initiatives is not always or necessarily located in planning departments but just as often located in departments like public works, environmental services, or city manager or mayor offices.

Tables 3.4.2 and 3.4.3 disaggregate the magnitude of effect size of these local characteristics into separate categories based on policy integration (distinct/climate-specific versus integrated/sustainability) and approach (mitigation versus adaptation) as described in Table

3.2.1. These sub-analyses could help reduce heterogeneity or reveal new patterns, which could be different than what is observed in the aggregated analysis. As might be expected, climate-specific policies (e.g., greenhouse gas targets) – that often impose concentrated costs on the local community and dispersed benefits to all cities – are strongly associated with public support (a one percent increase in public support is associated with a 1.123 increase in local government engagement in climate-specific policy adoption). There is also a high association with ICLEI and/or MCPA membership. Local government engagement on climate-specific policy adoption is negatively associated with the manufacturing groups, whereas policies with local benefits generally receive greater support. This latter group of policies encompasses all dependent variables that are associated with the term *sustainability*. The former group (i.e., climate-specific policies) combines effect sizes from the rest of individual studies. The plethora of empty columns on the 'adaptation' side of Table 3.4.3 underscores that most of the existing empirical studies in the sample set focused on mitigation and there is currently a gap in the quantification of factors influencing climate adaptation policies, which impose local costs and yield mostly local benefits by reducing risks of climate change. The mitigation subgroup includes all effect sizes from studies described in Table 3.2.1 excluding those which use climate adaptation as the dependent variable. Therefore, Tables 3.4.2 and 3.4.3 are not mutually exclusive.

Table 3.4.2 Elasticity of climate (mitigation and adaptation) and "sustainability" policies

Variable[1]	Climate-specific							Sustainability						
	E[2]	M[3]	SD[4]	Min[5]	Max[6]	C[7]	S[8]	E[2]	M[3]	SD[4]	Min[5]	Max[6]	C[7]	S[8]
Community interest														
Democratic leaning	0.282	0.434	0.607	-1.390	2.091	46	14	0.138	0.198	0.302	-0.029	0.798	7	6
Business group support	0.316	0.303	0.398	-0.038	1.104	7	3	0.253	0.186	0.278	-0.521	0.578	11	5
Environmental group support	0.143	0.197	0.260	-0.039	0.631	5	5	-0.075	-0.032	0.305	-0.559	0.343	9	5
Manufacturing dependence								-0.032	0.006	0.154	-0.114	0.267	5	3
Public support	1.123	0.654	0.541	0.036	1.925	11	6	0.284	0.250	0.209	0.031	0.546	6	3
Community structure														
Density								0.415	0.257	0.378	-0.054	1.000	11	6
Education	0.398	0.455	0.475	-0.186	1.611	12	11	0.220	0.199	0.164	0.007	0.575	15	9
Income	0.131	0.305	0.689	-0.853	2.010	31	13	-0.019	0.205	0.740	-0.445	1.896	9	6
Population	0.636	0.222	0.288	-0.190	1.244	41	20	0.598	0.321	0.397	-0.178	1.157	16	14
White population								0.339	0.162	0.354	-0.346	0.886	10	5
Government capacity														
Fiscal capacity	0.171	0.131	1.168	-2.019	2.783	12	7	-0.094	-0.083	0.669	-1.508	0.631	7	4
Staff capacity	-0.134	-0.097	0.536	-1.298	0.537	18	4							
Government structure														
Council-manager form (*b*)	0.012	0.070	0.235	-0.438	0.397	13	8	-0.020	-0.016	0.603	-2.148	0.420	15	9
Utility ownership (*b*)								0.126	0.085	0.140	0.003	0.295	4	3
Wards	0.066	0.064	0.297	-0.274	0.444	4	3							
Government interests														
Dedicated sustainability unit (*b*)								0.777	0.638	0.990	0.000	2.583	6	4
Policy entrepreneurship (*b*)	0.376	0.404	0.732	-0.162	3.190	20	6							
Staff support	0.217	0.193	0.201	-0.027	0.691	19	6							
Environmental risk														
Air quality	-0.063	-0.124	0.216	-0.451	0.248	15	5							
Coastal location (*b*)	0.368	0.235	0.162	0.019	0.403	4	4							
Vulnerability	0.051	0.066	0.126	-0.232	0.312	21	6							
Intergovernmental														
Active state (*b*)	0.100	0.049	0.388	-0.446	0.808	9	4							
ICLEI/MCPA membership (*b*)	0.522	0.487	0.566	0.090	1.745	7	4	0.282	0.305	0.157	0.101	0.643	12	5

Notes:

1- Binary (b) variables are based on semi-elasticity values.
2- Sample-size-weighted-average elasticities
3- Simple mean of elasticities
4- Standard deviation of elasticities
5- Minimum elasticity value
6- Maximum elasticity value
7- Count of elasticities
8- Count of studies

Table 3.4.3 Elasticity of mitigation and adaptation policy with respect to local characteristics

Variable[1]	Mitigation							Adaptation						
	E[2]	M[3]	SD[4]	Min[5]	Max[6]	C[7]	S[8]	E[2]	M[3]	SD[4]	Min[5]	Max[6]	C[7]	S[8]
Community interest														
Democratic leaning	0.435	0.452	0.596	-1.390	2.091	47	14	0.008	0.015	0.139	-0.153	0.188	6	4
Business group support	0.283	0.243	0.330	-0.521	1.104	17	10							
Environmental group support	0.089	0.049	0.302	-0.559	0.631	14	9							
Manufacturing dependence	-0.434	-0.091	0.273	-0.572	0.267	6	4							
Public support	1.019	0.483	0.538	0.031	1.925	13	6							
Community structure														
Density	0.481	0.401	0.692	-0.054	2.385	13	8							
Education	0.318	0.308	0.352	0.007	1.611	24	16							
Income	0.094	0.334	0.697	-0.776	2.010	35	14	0.109	-0.080	0.592	-0.853	0.784	5	4
Population	0.665	0.277	0.337	-0.190	1.244	47	22	0.129	0.122	0.203	-0.179	0.491	10	8
White population	0.067	-0.327	1.151	-3.448	0.886	12	6							
Government capacity														
Fiscal capacity	0.296	0.295	1.029	-1.508	2.783	12	6	-0.646	-0.364	0.849	-2.019	0.626	7	4
Intergovernmental dependence														
Staff capacity	0.041	0.029	0.457	-1.199	0.550	18	5							
Government structure														
Council-manager form (*b*)	-0.016	0.011	0.497	-2.148	0.420	24	13	0.107	0.101	0.167	-0.092	0.252	4	3
Utility ownership (*b*)	0.067	0.046	0.069	-0.004	0.295	17	4							
Wards	0.118	0.125	0.325	-0.274	0.444	4	3							
Government interests														
Dedicated sustainability unit (*b*)	0.693	0.547	0.936	0.000	2.583	7	3							
Policy entrepreneurship (*b*)	0.316	0.332	0.523	-0.130	2.235	22	6							
Staff support	0.193	0.163	0.168	-0.058	0.457	18	6							
Environmental risk														
Air quality	0.137	0.072	0.564	-0.451	1.613	18	5							
Coastal location (*b*)	0.346	0.194	0.166	0.019	0.403	5	5							
Vulnerability	0.082	0.044	0.126	-0.232	0.209	11	3	0.034	0.091	0.128	-0.159	0.312	10	4
Intergovernmental														
ICLEI/MCPA membership (*b*)	0.338	0.689	0.917	0.090	1.745	3	7							

Notes:

1- Binary (b) variables are based on semi-elasticity values.
2- Sample-size-weighted-average elasticities
3- Simple mean of elasticities
4- Standard deviation of elasticities
5- Minimum elasticity value
6- Maximum elasticity value
7- Count of elasticities
8- Count of studies

3.5. Discussion and conclusion

3.5.1. Key results and comparison with previous research

This analysis suggests that climate policy adoption is primarily driven by internal factors, including the level of public support and the presence of dedicated sustainability staff. Leadership from higher levels of government (i.e., state and federal) is not strongly associated with policy adoption at the local level. The results suggest that there is a strong relationship between community support and climate policy adoption, which is in general accordance with many reviewed studies. However, there are nuances in how public support might impact policy adoption, as it might have stronger influences on community-focused rather than internal government-focused programs (Bae & Feiock, 2013). Government-focused programs are likely to be strongly driven by local government environmental awareness or the presence of environmental entrepreneurs (Pitt, 2010). We find that policy adoption has been more frequent in populated and dense cities, particularly where residents have higher education (E = 0.317) and lean Democratic politically (E = 0.267). These policy drivers are strongly associated with climate-specific and mitigation actions with primarily global benefits rather than adaptation actions and other policies with primarily local benefits. Figure 3.5.1 is a visual representation of policy adoption with respect to local characteristics as described in Table 3.4.1. In Figure 3.5.1, bars represent the minimum and maximum effect sizes, and "N" is the number of studies. Although the presence of manufacturing jobs has a relatively large negative relationship with policy adoption (E = -0.399), previous studies have shown environmental protection and economic development are not mutually exclusive (Kalafatis, 2018; Yi et al., 2017). Also, many studies have explored where improvements in one area could positively enhance efforts related to the other (Kalafatis, 2017).

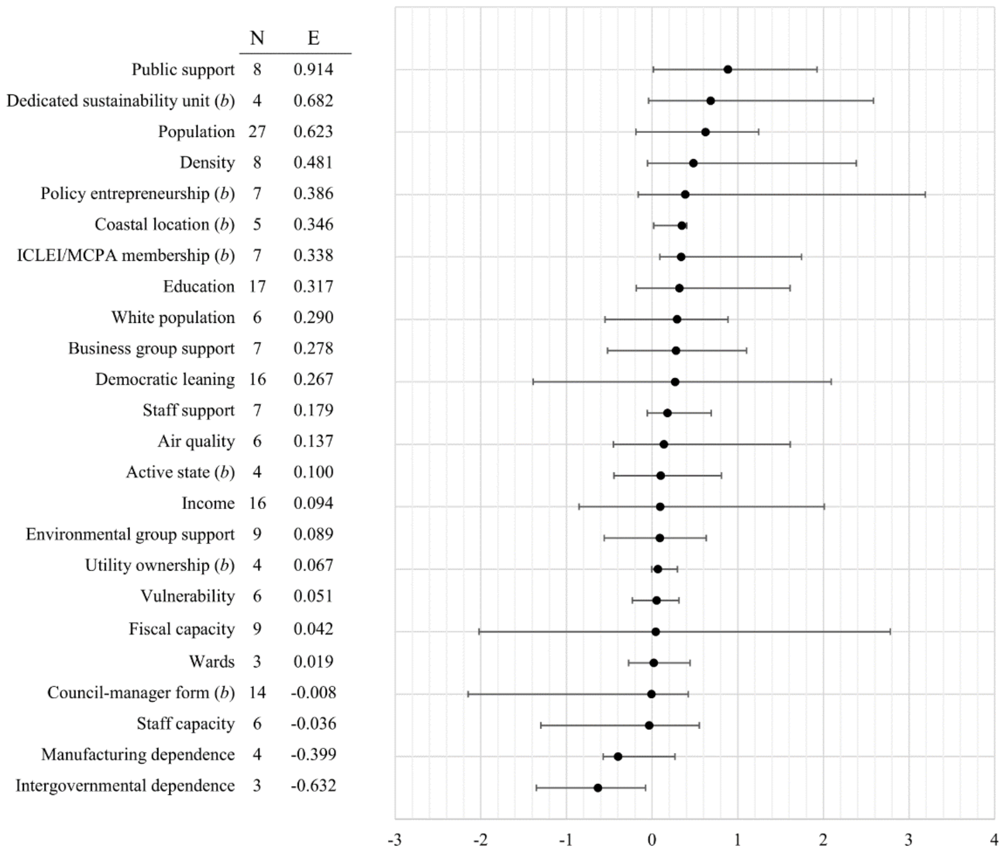


Figure 3.5.1 Average elasticity of policy adoption with respect to local characteristics

Developing climate action plans requires fiscal health and staff capabilities. Governments that heavily rely on intergovernmental funding have been far less active (E = -0.632) than governments that are relatively fiscally independent. Kalafatis and Lemos (2017) argue that the emergence of climate change policy entrepreneurs might also be negatively influenced by intergovernmental dependence, which leaves less incentive for action if policy decisions are dominated by higher levels of government. Among fiscally independent governments, policy adoption seems to be relatively inelastic to local government capacity. Rather, it seems to be primarily driven by the presence of political will. This will often manifest as dedicated sustainability units, environmental entrepreneurship, and staff support for climate initiatives.

Previous research has tested whether the council-manager form of government directly influences climate policy adoption, as this form is differently influenced by political impacts than the mayor-council form. Hultquist et al. (2017) found that cities with the council-manager form adopt on average of 2.79 more climate policies, including mitigation and adaptation. Bae and Feiock (2013) reported statistically significant results and concluded that council-manager governments tend to improve government-focused policies but undermine community-focused sustainability policies. Kalafatis (2018) found that the relationship between government form and climate mitigation or adaptation policy adoption is not statistically significant. In general, there is some evidence of a relationship between government form and climate-specific and sustainability policy adoption and the choice of different but closely related dependent and independent variables could have changed the direction and significance of regression coefficients. On average, however, results from this study suggest that the absolute effect of the form of government on policy adoption is negligible (for guidance and more information see Carr (2015)).

As expected, the results of this study indicate a relationship between coastal location and climate policy adoption (E = 0.368). The salience of consequences of climate change (e.g, rising sea levels) to the public and the need to develop mitigation and adaptation measures likely encourage governments to take a pro-active role and insulate vulnerable communities. Previous studies have found that climate network membership (e.g., Cities for Climate Protection) is higher among coastal communities, which are more frequently affected by extreme weather events and risks of inundation (Zahran, Brody, et al., 2008).

3.5.2. Strengths and limitations

The value of the insight that can be drawn from a meta-analysis is highly dependent on the studies estimating the same phenomena. Although the included studies have often used nationally representative survey data, many individual models have examined a relatively small number of variables and achieved a relatively small coefficient of determination (i.e., R-squared). Scholarship in the climate policy adoption area has generally been non-cumulative and analytical models in this area require further improvement (Swann & Deslatte, 2019). This analysis is an early effort to improve the generalizability of previous studies and reduce subjective judgments by accumulating many studies that are distinguished by focus area. In addition, this study for the first time collects and synthesizes all the previously fragmented variables to provide a theoretical foundation for future research, which is critical to the integration of the extant literature.

We acknowledge three main limitations of this meta-analysis of climate policy adoption. First, this analysis examines climate action primarily based on the adoption of greenhouse gas reduction goals, climate network membership, and count of adopted policies, which may not fully represent the effectiveness of and commitment to climate actions. In fact, joining a climate network and making progress in achieving greenhouse gas reduction targets over time are fundamentally different phenomena (Sharp et al., 2011). Few recent studies have tried to measure climate action based on more substantial factors, including but not limited to investment of staff and fiscal resources, financing climate initiatives, stakeholder engagement, and collaboration for climate protection and sustainability (Hawkins et al., 2016; Wang, Hawkins, & Berman, 2014). Using greenhouse gas emissions as the dependent variable could be an ideal outcome measure, but it is subject to the availability of data from all observations (Millard-Ball, 2012). The second limitation is that this analysis is cross-sectional; thus, it does not detail the dynamics of the studied communities, policy adoption, and causal relationships (e.g., whether policy adoption increased after network membership or vice versa). Since the number of existing studies is currently limited, it is not yet practical to categorize these studies based on the time of study to see how the quantified associations might have changed over time. Third, the calculated elasticities contain unknown errors and confidence intervals due to methodological limitations and should be refined in the future as more studies become available.

3.5.3. Implications for future research and local climate actions

The problems, solutions, and politics of climate change policies are shifting over time and tend to have long-term impacts. Bedsworth & Hanak (2013) show some driving forces (e.g., partisan effect) lose their initial magnitude when adoption of climate policies becomes more widespread. Hultquist et al., (2017) explore climate change policy adoption as a series of responses to local socioeconomic, political, and environmental changes during the decade before the adoption period. Similarly, the emergence of climate policy entrepreneurs could be influenced by disruptive social changes (e.g., population change) or extreme climatic events as such changes often raise public awareness (Kalafatis & Lemos, 2017; Schneider et al., 2011). Thus, by taking a longitudinal approach, future studies could reveal more details of policy adoption in this area. In addition, it is suggested that nationally representative survey data control for geographic location (e.g., state, region), contextual effects (e.g., type of climate-related hazard), and effects of neighboring areas. The costs associated with climate change are not evenly distributed in space, leaving some areas (e.g., the Southeast) more vulnerable than others (e.g., the Northeast) (Brody et al., 2008). Also, future empirical studies should investigate adaptation policies, as there are fewer studies available on adaptation than mitigation as indicated by this sample. Given existing deficiencies of the empirical literature, ad-hoc design and measurement methods, and differences in conclusions (e.g., on the form of government), there is clearly a need for integration of the scholarship is this area. More critical review essays are needed for this purpose are needed as recent studies, e.g., Swann & Deslatte (2019) have started to reveal competing explanations for urban sustainability in the literature. As described in this study, previous empirical research has described associations between city characteristics and bundles of sustainability and climate change policies. Critical reviews and event history analyses could help address distinctions between causal mechanisms leading to distinct, rather than bundled, climate and sustainability-related policies (Miao, 2019).

The importance of local support and awareness to climate policy adoption necessitates the development of public outreach, education, and engagement activities based on scientific projections and objective risk assessments, particularly in communities that are more vulnerable to environmental risks. Climate change has generally been framed and perceived as a global phenomenon without a local dimension, which makes it harder for local governments to build strong community support (Betsill, 2001). Since conservative communities are relatively less receptive to such policies, a proposed solution is creating effective alignment of climate change issues with a wider set of environmental (e.g., higher density developments, reuse of brownfields), economical (e.g., clean technologies, green jobs) and public health goals (e.g., clean air, clean water) that are associated with cost savings and community benefits through participatory processes that facilitate consensus among stakeholders (Kalafatis, 2017). There is a growing awareness among local governments of the co-benefits associated with sustainability (e.g., cost savings, growth management, and political recognition) (Svara et al., 2013). Hence, small communities, with proportionally less capacity — and total emissions — could potentially benefit from partnerships with utilities, community groups, and regional initiatives to save costs, obtain expertise, and increase individual advantage by participation in a group (Bedsworth & Hanak, 2013).

CHAPTER FOUR: GREEN BUILDING AND AFFORDABLE HOUSING POLICY

Chapter Summary

This chapter analyzes the integration of green building with the largest low-income housing production program in the US and the innovativeness of state housing agencies. Drawing on policy innovation literature, panel data and regression analysis are employed to quantify associations between state-level characteristics and the adoption of green building criteria into the Low-Income Housing Tax Credit (LIHTC) program. Results show that housing agencies have increasingly adopted green building criteria, and most have identified co-benefits from energy-efficient buildings and smart growth. Despite overall progress, the rate of adoption of green building criteria has decreased, few US states have comprehensive criteria, and many have dropped important criteria, such as on-site renewable energy generation, often due to perceived additional costs to developers and, in some cases, due to perceived progress in building codes. Results suggest that the integration of green building with the LIHTC program is significantly associated with the states' internal factors, such as public housing agencies' motivations and resources, and external factors like regional policy diffusion from other states. Future research should explore organization-level factors that affect environmental policy innovation. It is recommended that housing agencies require compliance with regional green building rating systems that periodically reconfigure green building criteria based on planned evolutionary change, data-driven strategies, and life-cycle analyses towards zero-energy building.

4.1. Introduction

While renewable energy is rapidly growing in worldwide adoption, approximately 89% of the energy consumed in the US in 2019 still came from non-renewable sources like coal, gas, and nuclear power (USDOE, 2019). Of that energy produced, the residential sector accounted for about 21% of consumption. Simultaneously, almost half of all renter households are cost-burdened, often due to poverty and, in large metro areas, rapidly rising housing prices (JCHS, 2019). The residential sector in the US is clearly in need of comprehensive policymaking reforms that concurrently address affordability and environmental sustainability, thus, reducing uncertainties around the national economy, energy security, declining natural resources, and climate change.

In the spirit of sustainability, environmental and climate change policy integration have been established as key strategies to increase organizational effectiveness in policy coordination and achieve equal weighting of sectorial and environmental policies (Adelle & Russel, 2013; Jordan & Lenschow, 2010). Since the 1980s, the US federal government's environmental preeminence has dwindled and many state governments have taken environmental and climate leadership roles. For instance, many state governments have integrated green building (i.e., building with higher than basic standards based on a holistic attitude toward the planning, design, construction, operation, and recycling or renewal of buildings) into low-income housing programs to achieve co-benefits like reductions in the life-cycle cost of homeownership, increases in energy and water efficiency, indoor environmental quality, health, safety, productivity, and environmental stewardship (Pearce et al., 2007; USGBC, 2019c). Along with consistent increases in urbanization, housing shortage, and development cost in the US, policy integration has become of critical importance for many state housing finance agencies who need to allocate their limited financial resources more efficiently through the selection of projects that best promote the states' visions of a good society.

In 1986, the US Congress enacted the Low Income Housing Tax Credit (LIHTC) program, providing state and local LIHTC-allocating agencies an equivalent of $8 billion per year to issue tax credits for the acquisition, rehabilitation, or new construction of rental housing for low-income households by private investors (Deng, 2011; HUD, 2019). With more than 2.4 million active units, the LIHTC program is the principal federal affordable housing production program, which incentivizes the production of a significant portion of below-market-rate multifamily rental units for extremely low-income to low-income households based on an indirect federal subsidy (HUD, 2020b). Residents that qualify to live in a LIHTC unit receive income and quality benefits, depending on their certified annual income and the maximum rent set by the project (Novogradac, 2020). For detailed information about the basics of the LIHTC program, see Deng 2011; Dewar et al., 2020; McClure, 2019.

Low-income housing in the US has been historically associated with sub-standard indoor and outdoor environmental conditions, characterized by the presence of toxic waste sites, polluting industries, vehicle traffic, and lead air and water pollution, among others (Bailey et al., 2017). Experimental studies report significant improvements in overall health and respiratory conditions of adults and children once existing low-income housing units are rehabilitated to meet green standards (Allen et al., 2015; Diaz Lozano Patino & Siegel, 2018; Willand et al., 2015). To address state environmental concerns, climate targets, and the living conditions of low-income families, green building standards are increasingly considered important in LIHTC Qualified

Allocation Plans (QAPs), which outline the criteria based on which state housing agencies allocate financial incentives in the form of tax credits to multi-family residential developers. The basic federal criteria included in QAPs do not mandate green building standards, but additional criteria that support state housing policy goals may include specific energy efficiency or other requirements. Previous studies show QAPs have significant impacts on the location and quality of LIHTC developments (Ellen et al., 2015). Existing literature on the LIHTC program suggests that, in addition to environmental co-benefits, green LIHTC properties have generated considerable financial savings from efficiency for the occupants (Zhao et al., 2018). Despite its significance as an opportunity to drive quality living conditions for US residents and innovation in housing, green building in the LIHTC program has not received much attention in the literature.

The US states have deployed resources to better meet their population and housing needs through the expansion of policies like inclusionary zoning and such programs as housing assistance, technical assistance for nonprofits, housing trust funds, housing tax credit, affordable housing preservation (Scally, 2012). After the devolution and retrenchment of federal housing support, the increased engagement of state governments in housing policy has followed an innovation process that involves the adoption of new policies not previously implemented (Basolo & Scally, 2008). This study aims to explain this low-income housing activism through the lens of policy innovation, which "involves the formulation, implementation, and diffusion of new visions of what a good society is, concrete goals inspired by these visions, and strategies for moving society in the desired direction" (Ansell & Torfing, 2014). The rationale for undertaking this study is twofold: First, there is no systematic study exploring green building in the US housing production policies, and the literature in this area is both nascent and ad-hoc (Basolo &

Scally, 2008); Second, many US states have sometimes reduced or abandoned the adoption of green building criteria despite revealed public health-, economic development-, and local environmental improvement co-benefits, due to perceived additional costs to developers and, in some cases, due to perceived progress in state-level building codes. To provide a better understanding of state-led housing policy innovation, this article explores the following questions about the LIHTC program: What components of green building are promoted in state QAPs? What happens to innovative green building criteria after adoption? Are all US states contributing equally to environmental sustainability through the LIHTC program? Why are some LIHTC-allocating agencies more innovative than others in adopting and maintaining green building criteria? The next section sets forth a concise review of the literature on green building and policy innovation. Following descriptive analyses, an empirical framework is introduced to investigate the extent to which interstate variations in the adoption of green building criteria are associated with certain economic, environmental, political, societal, and regional state characteristics. The article concludes with a discussion on research and policy implications.

4.2. Literature Review

4.2.1. The need for green LIHTC developments

Sustainability thinking has long encouraged integrated, interdisciplinary approaches and policies that holistically address multiple contemporary problems (Briassoulis, 2017a). Sustainable development requires a balanced integration of economic, environmental, and social goals with traditionally siloed policy sectors, such as low-income housing, as a goal of governance (Kivimaa & Mickwitz, 2006; Runhaar et al., 2014). Policy integration is deemed necessary because some policy sectors – like environment and climate – alone are not capable of achieving all of the objectives and, thus, must work with other sectors (Lafferty & Hovden, 2003). Despite the importance of sustainability to the future of the planet, there are inherent economic, environmental, and social justice conflicts involved in reaching sustainable development, and conflict resolution has not been easy (Campbell, 1996; Wolch et al., 2014).

In light of rapid urbanization and the need for improving the living conditions of low-income households, policy integration has been challenging to implement in the federal political system (Jordan & Lenschow, 2010; Patterson et al., 2018). Historically, low-income households and racial minorities in the US have lived in proximity to toxic waste sites, suffered from air and water pollution, and experienced disproportionate costs of energy, transport, healthcare, and safety (Bullard, 2018; Chegut et al., 2016). Even access to green space, recreation, and civic services has been dependent upon income and race and become an environmental justice issue (Wolch et al., 2014). Affordable housing is often defined solely based on house price to household income ratio, thus, discounting transportation, healthcare, education, and other trade-offs low-income households should make to survive (Mulliner et al., 2016). Siting and building LIHTC developments according to green building standards have the potential to reduce operating costs, increase the assisted families' access to education and employment, promote the residents' health and safety, and mitigate negative environmental impacts of LIHTC developments (HUD, 2020a).

At the neighborhood level, LIHTC properties built to green building standards can help further revitalize distressed neighborhoods (i.e., the place-based approach) or improve the quality of life of low-income households by moving them to high-opportunity neighborhoods (i.e., the people-based approach) (Davidson, 2009). An increase in the diffusion and clustering of green buildings is associated with positive spillover effects on neighboring buildings, thus reducing the risk of investment in LIHTC developments, improving neighborhood characteristics, and encouraging further sustainability (Chegut et al., 2014). As social justice advocates increasingly demand the siting of low-income housing beyond central cities, improved building quality could make developments more acceptable to the host suburban communities. Recently built LIHTC units are increasingly located in suburban areas with low poverty rates and are associated with positive price impacts both in high-income and low-income neighborhoods when developed and managed well (Deng, 2011; McClure, 2019).

At the building level, there is empirical evidence that green building codes and standards bring a range of co-benefits, such as energy and water efficiency, improved health, safety, productivity, and indoor environmental quality, which significantly reduce the total cost of living throughout the building life-cycle (Breysse et al., 2011; Singh et al., 2010). Life-cycle thinking is particularly consistent with the finance of LIHTC developments, and empirical evidence suggests green LIHTC units can be more cost-effective than non-green units for stakeholders and society as a whole in the long term (Bradshaw et al., 2005; Mueller & Tighe, 2007).

Despite large benefits, affordable housing and green building have positive externalities, thus, multiple factors can lead to underinvestment in these goods in the free market (e.g., split incentives, information asymmetries, risk aversion, skill shortages, and analytical failures) and government intervention is required for an efficient distribution of benefits (Matisoff et al., 2016). Using hedonic modeling of construction costs, rents, and occupancy rates, previous research on the economic performance of green buildings suggests that building to green standards can increase upfront costs but generate sufficient savings that benefit green building owners and operators within an acceptable payback period (Chegut et al., 2019; Matthiessen & Morris, 2004, 2007).

Although the benefits of green building for society as a whole are often larger than the average cost premium to obtain green building certifications, residential developers demand significant price premiums that are likely to affect affordability (Yeganeh, McCoy, & Hankey, 2019). Researchers have often reported up to 10 percent sales price premiums associated with single-family units with green building certifications in US cities (Walls et al., 2017). Therefore, the LIHTC program regulations demanding sustainable construction features like on-site renewable energy generation should include considerations such as rigorous cost-benefit analyses, higher levels of LIHTC subsidy, or other financing mechanisms to preserve affordability. Empirical studies suggest that financing initiatives can have as high as 100% impact on the adoption of green building technologies in the residential sector (Hughes & Podolefsky, 2015). Therefore, short-term and long-term effects of green building on affordability require careful assessments, and several methods to examine such trade-offs are introduced in the literature (Fulton et al., 2020; Mulliner et al., 2016). In practice, motivated LIHTC-allocating agencies have prioritized developers that go beyond the minimum set by building codes to conform to internal or third-party green building standards (Prum et al., 2012). For instance, nearly 100% of recently approved LIHTC projects in Virginia have pursued EarthCraft, a local green building rating system.

4.2.2. Models of policy innovation

There is a rich, yet growing body of scholarship describing mechanisms involved in governments' adoption of innovative public-sector policies as well as complementary structures, processes, products, and characteristics, which can help describe the formulation, implementation, and diffusion of innovative policies like green building in the context of affordable housing (Kammerer & Namhata, 2018; Karch, 2007). State policy innovation is often explained as the acquisition of policies or programs from others that are new to the state adopting them but are not necessarily altogether new ideas. The policy innovation mechanism is broadly defined as "the function of an interaction among the motivation to innovate, the strength of obstacles against innovation, and the availability of resources for overcoming such obstacles" (Mohr, 1969). Policy innovation researchers argue that as a result of having access to resources and information, public officials should take the initiative to recognize and deploy the utility of innovative policies and programs, whether or not such utilities are expressed wants of ordinary citizens. This moral standpoint reflects the significance of policy innovation literature and, simultaneously, the situation in which goods and services having societal benefits are inefficiently distributed in the free market (i.e., market failure).

Empirical models developed in the state policy innovation literature can help explain drivers of subnational environmental initiatives, including green building, sustainable development, and climate change (Krause, 2011a). Studies of policy innovation have explored innovation-driving forces to explain why some state or local governments adopt policies or programs while others do not. Major classic models of policy innovation that describe causal processes involved in the adoption of innovative policies are classified into the two categories of internal determinants models and diffusion models (Berry & Berry, 1999). Internal determinants models presume economic, environmental, political, and social characteristics of states – thus, not pressures created from other states – act as primary driving forces of innovation. Some internal determinants models include organization level (e.g., leadership, maturity, resources, structure) and individual level (e.g., attitudes, autonomy, entrepreneurship, motivations), and, in some cases, innovation level (e.g., compatibility, complexity, effectiveness) characteristics (Vries et al., 2016). For example, researchers have concluded that the perception of the severity of a crisis and a prior commitment to address a policy problem are positively associated with state environmental policy innovation (Sapat, 2004). On the other hand, diffusion models presume that innovation is communicated between state governments in a social system, through learning, competition, coercion, or other processes. Diffusion models include national interaction models, regional diffusion models, leader-laggard models, isomorphism models, and vertical influence models. In diffusion models, leading-edge US states (and the federal government in vertical influence models) regularly function as trendsetters, spreading new policies to follower states that search for solutions to potentially controversial or complicated issues and often want to reduce the cost of finding a solution (Berry & Berry, 1999; Boehmke & Witmer, 2004; Mooney, 2001; Obinger et al., 2013).

Policy innovation literature does not necessarily expand on complexities involved in decision-making processes by individuals within government organizations or degrees of success in the implementation of new policies. Organizational economists and theorists partially fill this gap by explaining various characteristics of organizations (e.g., birth, functioning, dynamics, progress, and impacts) and variables underlying decision-making (e.g., organizational culture, network structures, framing, and incentives) (Perrow, 2000). Of particular relevance to understanding drivers of policy innovation at the level of organizations are the notions of bounded rationality, optimization versus heuristics (i.e., finding the best solution to the problem versus relying on intuition, habit, or rules of thumb when resources are limited) and human systems properties (e.g., limited certainty, limited predictability, indeterminate causality, and evolutionary change) (Gigerenzer et al., 2011; Gsottbauer & Van den Bergh, 2011; Hjorth & Bagheri, 2006; Marsden et al., 2012; Nelson, 2012).

The classic models have inspired numerous empirical studies on policymaking. Nonetheless, more recent studies have started to criticize presumptions of single-explanation models, contending that such models do not have the required breadth to independently identify the causes of policy innovation. Some researchers, for instance, argue that government officials' interactions are complex and more selective than what the national interaction model suggests, and causal factors could be understood only if new studies integrate internal and regional diffusion determinants into a single discrete event history analysis (Berry, 1994; Berry & Berry, 1990). Contending the diffusion of innovation does not necessarily depend on geographical proximity, researchers criticize geographic proximity models for failing to account for the role of communication networks, overlapping media, and common attributes of proximate states (Karch, 2007). Some other researchers question the significance of early adoption, which is the focal point of the classic policy innovation scholarship, and argue that other considerations like the level of dedication and policy re-invention, could place late adopters in a superior position in solving local problems when compared to earlier adopters (Glick & Hays, 1991). There are also studies referring to specification issues and flaws in history analysis models regularly employed in empirical studies (Berry & Berry, 1990; Buckley & Westerland, 2004) and recent studies have proposed substitute models like directed dyadic analysis (Baldwin et al., 2019).

Highlighting the role of historical evolution, process innovation, and institutions, more recent theoretical works on innovation follows more comprehensive and interdisciplinary approaches to innovation, along with new analytical methods, thus augmenting earlier theories in policy studies

(Kammerer & Namhata, 2018). A systematic review of the literature concludes past research has mostly focused on policy adoption and diffusion processes, and very few studies on policy innovation have identified the outcomes or explained questions like "What happens to innovative policies after adoption?" or, "Did those innovations make a change?" (Vries et al., 2016) This longitudinal study, therefore, expands on past research and explores: What components of green building are promoted in state QAPs? What happens to innovative green building criteria after adoption? Are all US states equally contributing to environmental sustainability through the LIHTC program? Why are some housing agencies more innovative than others in adopting and maintaining green building criteria? The next section describes the development of hypotheses of an empirical model informed by a set of internal and regional correlates to explore policy innovation in the LIHTC program.

4.3. Methodology

4.3.1. Research hypotheses

To respond to this article's first three questions (i.e., What components of green building are being promoted? Are all US states contributing equally to environmental sustainability? What happens to innovative green building criteria after adoption?) we use descriptive statistics of data obtained from longitudinal questionnaire surveys of state housing finance agencies. To explore why some housing agencies are more innovative than others in adopting and maintaining green building criteria, we develop five hypotheses based on theoretical models of policy innovation discussed in the previous section. The hypotheses are then tested using the data in a conceptual multiple regression model framework. Multiple regression models are the mainstay of econometrics and provide mathematical solutions to help quantify the extent changes in one variable affect the dependent variable (i.e., policy innovation), to check whether the relationships have remained stable over time, to make measurable predictions, and to evaluate the accuracy and significance of all such inferences. For guidance and more information on econometric models, see Gelman & Hill, 2006; Stock & Watson, 2015; Wooldridge, 2016. The description of results is triangulated with Global Green's reports on LIHTC housing agencies.

This article's hypotheses examine the impact of internal characteristics of the US states and the horizontal diffusion of policy from neighboring states within identical climate regions on the innovativeness of LIHTC-allocating agencies. The adapted model (Equation 1) reflects Mohr's conceptualization of policy innovation as the sum of motivation to innovate (MOT), the strength of obstacles against innovation (OBS), and the availability of resources (RES) for overcoming the obstacles. Furthermore, the model includes the effect of complementary policies (POL) and external effects (EXT) that have implications for the likelihood that the state will adopt green building criteria.

$$ADOPT_{i,t} = MOT_{i,t} + RES_{i,t} + OBS_{i,t} + POL_{i,t} + EXT_{i,t} \qquad \text{Equation 1}$$

Motivation has two different dictionary definitions: a) enthusiasm for doing something, and b) the need or reason for doing something (Cambridge English Dictionary, 2020). Mohr argues that activism and ideology are both important indicators of the motivation of organizations to innovate. According to Mohr, activism is represented by "the … officer's perception of the extent to which the role of … the officer requires interaction with others … to obtain ideas, support, approval, and resources for departmental programs" and ideology is represented by "the … officer's opinion regarding the scope of services that should properly be offered by the local public … agency in non-traditional … program areas." (Mohr, 1969). Resources, according to Mohr, are "not only money and skills to overcome obstacles of expense, but also resources such as a position of authority, a charismatic effect, the support of prestigious individuals and self-confidence to overcome obstacles presented in terms of human forces." Therefore, resources and obstacles that impact innovation can take a variety of forms, e.g., economic, environmental, political, and societal.

Hypothesis (1): There is a positive association between the availability of economic resources and the innovativeness of LIHTC-allocating agencies. The successful adoption, maintenance, and development of green building criteria in the long term require financial resources to cover direct and indirect program evaluation and implementation expenses, and housing agencies in US states with high rates of debt are less likely to take such initiatives. Not only do economic resources affect policymakers' decisions in adopting innovative policies, but also the financial capacity of affordable housing developers in meeting green building standards depends on the strength of the states' economic performance (Dewar et al., 2020). Obstacles like dependency on traditional construction methods, resistance to change, and realtors' lobbying against stringent energy efficiency standards should be surmounted. Where carbon-intensive industries constitute a substantial portion of the state economy, opposition group demand (e.g., lobbying from manufacturing and extractive industries) and general pro-industry sentiments may constrain policy innovation. To understand the impact of economic resources, we adopt state GDP per capita and the rate of state sales tax to represent housing agencies' access to economic resources. Intergovernmental revenue and value-added by manufacturing are adopted to represent economic obstacles affecting green building policy innovation.

Hypothesis (2): There is a positive association between the availability of environmental resources and the innovativeness of LIHTC-allocating agencies. In geographical areas where abundant natural resources facilitate the supply of renewable energy (e.g., wind, solar, geothermal, or biomass) or high numbers of degree days increase residential energy demand, strict energy efficiency requirements result in more financial savings in the long term. Urbanizing economies with a high concentration of population often have a high energy demand, high urban pollution, and high density to advance efficient transit services, mixed land use, smart growth, and transit-oriented development, which all align well with green building standards. On the contrary, in areas where energy generation has historically relied on the presence of ample state fossil fuel resources, there could be obstacles to promoting renewable energy infrastructure. Also, policymakers are likely to divert resources to immediate rather than long-term environmental policy solutions in states frequently experience extreme climatic events, natural disasters, and other environmental obstacles. To understand the impact of environmental resources, we adopt heating degree days and population density. Disaster frequency and fossil fuel reliance are adopted to represent obstacles affecting green building policy innovation.

Hypothesis (3): There is a positive association between the availability of political motivations and resources and the innovativeness of LIHTC-allocating agencies. The presence of environmental attitudes and ideologies among state policymakers could increase the agencies' motivation to promote green building in LIHTC developments (Carley, 2011). Furthermore, complementary and supportive environmental and/or climate standards, energy codes, and advanced building regulations and incentives can promote innovation in the LIHTC program or, at least, increase the baseline LIHTC development requirements (Shipan & Volden, 2006). To understand the impact of political motivations and resources, we adopt the state government ideology index to represent the motivation for innovation, and we adopt the presence of energy-efficiency and renewable energy incentives and regulations to represent the presence of complementary policy resources affecting policy innovation.

Hypothesis (4): There is a positive association between the availability of societal resources and the innovativeness of LIHTC-allocating agencies. Since the supply of LIHTC units results from a synthesis of public sector and private sector actions, market demand – and therefore policymakers' resources – for improved green practices is likely to grow in urbanized US states where highly educated citizens with high skills and environmentalist awareness and attitudes reside (Kahn & Morris, 2009). Those communities are also more likely to be willing to pay higher upfront costs of building to green codes compared to less educated communities. We adopt the percentage of the population living in urban areas, workers holding post-professional degrees in the workforce, and the age of housing stock to represent societal resources affecting housing agency innovativeness.

Hypothesis (5): There is a positive association between the availability of regional motivations and resources and the innovativeness of LIHTC-allocating agencies. Policy innovation in the LIHTC program is likely to accelerate in states located in regional policy innovation clusters where housing agencies experience pressures from other agencies in the region, learn from others by receiving information, training, and expertise, or simply want to remain competitive with other agencies (Bushnell et al., 2007; Kahn & Vaughn, 2009). To understand the impact of regional effects, we adopt the average green building score of each state's neighbors and the fixed location effects of the US climate regions as defined by the National Oceanic and Atmospheric Administration (NOAA), controlling for mediating impacts of climatic factors.

4.3.2. Data collection and description of variables

Global Green is an organization that “works to create green cities, neighborhoods, affordable housing, and schools to protect environmental health, improve livability, and support our planet's natural systems to address climate change and create resilient and sustainable communities” (Global Green, 2019). Since 2006, Global Green has published reports and national performance rankings of state LIHTC QAPs on an annual basis and has invited all state housing agencies to review the reports and include any comments or further information before the final scores are released. Upon the receipt of questionnaire surveys, yearly scores are assigned to all QAPs based on a 45-point scale composed of the four components of energy efficiency, smart growth, resource conservation, and health protection (Table 4.3.1). The final QAP score represents the total number of green building points that housing agencies use to help prioritize projects to allocate tax credits.

Table 4.3.1 QAP scoring structure and scores achieved by 50 states in 7 years

Component	Mean	S.D.	Min	Max	Component	Mean	S.D.	Min	Max
Energy Efficiency					*Resource Conservation*				
Energy Codes	1.59	0.79	0	2	Construction & Demolition Recycling	0.47	0.50	0	1
Energy Star Homes	1.77	1.48	0	3	Maintenance Free Standard	0.74	0.44	0	1
Energy Star Appliances	1.77	0.61	0	2	Preserve Existing Flora	0.46	0.50	0	1
HVAC Performance	1.79	0.56	0	2	Recycled Content Materials	0.45	0.50	0	1
Insulation Standards	0.86	0.34	0	1	Renewable Materials	0.32	0.47	0	1
Photovoltaics (PV)	0.47	0.50	0	1	Reused Materials	0.39	0.49	0	1
Specified Efficient Products	0.95	0.22	0	1	Stormwater Protection	0.57	0.50	0	1
Total Energy Efficiency	9.20	2.61	0	12	Water Conservation	3.62	1.73	0	5
					Total Resource Conservation	7.01	3.55	0	12
Smart Growth					*Health Protection*				
Adaptive Reuse	0.85	0.36	0	1	Carpet Quality	0.59	0.49	0	1
Brownfields Redevelopment	0.32	0.47	0	1	Environmental Assessment	0.82	0.38	0	1
Floodplain Preservation	0.69	0.46	0	1	Formaldehyde Free	0.52	0.50	0	1
Habitat Preservation	0.46	0.50	0	1	Hazard Abatement	2.30	1.79	0	5
Proximity to Public Transit	0.85	0.35	0	1	Hazard Proximity	0.66	0.47	0	1
Proximity to Services	0.87	0.33	0	1	Paint Quality	0.65	0.48	0	1
Rehabilitate Existing Housing	1.00	0.05	0	1	Ventilation Quality	0.78	0.42	0	1
Revitalization Plans	0.98	0.14	0	1	Total Health Protection	6.31	2.94	0	11
Urban Infill	0.56	0.50	0	1					
Wetland Preservation	0.62	0.49	0	1					
Total Smart Growth	7.12	2.08	1	10					

The main dependent variable we use to measure policy innovation among LIHTC-allocating agencies is the QAP score, which is the sum of the individual scores of all green building criteria as described in Table 4.3.1. Furthermore, we develop models to explain the sum of scores in each of the four green building components. Table 4.3.2 describes the independent variables of interest for hypothesis testing, representing housing agency motivations, obstacles, and resources, as well as operationalization methods and the sources of the applied database. We choose these variables based on their relevance to the study hypotheses, the extant literature on environmental and climate policy adoption (Yeganeh et al., 2020), and the availability of historic data for the seven-year study period. Since Global Green did not collect QAP data in 2011 – for reasons that are not clear to the authors – this analysis covers the year 2010 plus the 2012-16 timeframe. The regression models include the control variables of income, population, and time.

Table 4.3.2 Description of independent variables

Construct and variables	Type[1]	Definition	Source
Economic characteristics			
GDP per capita	(r)	GDP per capita in 1,000 USD in 2017 (Q4) dollars	US BEA
Intergovernmental revenue	(o)	Ratio of revenue from the federal government to general revenue in percentage	US Census ACS-1
Manufacturing value added	(o)	Percentage of state GDP that is manufacturing GDP	US BEA
Sales tax	(r)	State general sales tax in percentage	Tax Policy Center
Unemployment rate	(r)	Percentage of unemployed population in workforce	US Census
Environmental characteristics			
Degree days of heating	(r)	Heating degree days weighted by population in 100 degrees	US NOAA
Density	(r)	Population per square mile state area	US Census ACS-1
Disaster frequency	(o)	Number of federal disaster declarations by state	FEMA
Fossil fuel reliance	(o)	Electricity generated from natural gas in MCF per capita	US DOE
Political characteristics			
Energy code status	(r)	Status of state energy code based on 1-8 ordinal score	US DOE
Government ideology[2]	(m)	State government ideology index. Higher scores are more liberal.	R. Fording
RE incentive policy[3]	(r)	Number of state-wide renewable energy incentives	DSIRE
RE portfolio standard	(r)	Presence of Renewable Energy Portfolio Standard (RPS)	DSIRE
RE regulatory policy	(r)	Number of state-wide renewable energy regulatory policies	DSIRE
Societal characteristics			
Higher education	(r)	Percentage of the workforce population holding master's or Ph.D. degrees	US Census ACS-1
Housing stock year built	(r)	Median year house was built	US Census ACS-1
Urbanization	(r)	Percentage of urban population	US Census ACS-1
Regional characteristics			
Neighbors' score[4]	(m)	The average QAP score for green building in neighboring states	Global Green
Climate region	(m)	The 9 climate regions in which US states are located	US NOAA
Control variables			
Median household income		Median household income in 1,000 USD	US Census ACS-1
Total population		Total population in 1M persons	US Census ACS-1
Time		Year	

Notes:

1- Motivations (m), obstacles (o), resources (r). For example, GDP is a resource because larger GDP values imply more accessible resources. Intergovernmental revenue is an obstacle because larger shares of intergovernmental revenue imply more debt.
2- Compared to frequently used measures suitable for cross-sectional single-state studies (e.g., the share of liberal candidate vote in an election) the citizen and government ideology data better capture temporal and geographical variations (Berry et al., 1998).
3- For a concise review and synthesis of the literature on regulatory policies and energy incentives see Carley (2011)
4- Policy diffusion in a region can be explained by the public choice / economic competition (m) theory or the social learning theory (r) (Boehmke & Witmer, 2004).

4.3.3. Statistical analysis

We use multivariate regression analysis with climate region fixed effects to describe the correlates of policy innovation, treating time as a linear independent variable and assuming that ordinary least squares regression analysis is an admissible estimate. Based on the maximum number of independent variables included in this analysis, a priori power analysis using G*Power 3.1.9.4 suggests that a minimum sample size of 218 is required to detect the effect size (f^2) of 0.05 (where 0.15 and 0.02 are f^2 conventions for medium and small effect sizes) with a statistical power of 0.95 at an alpha level of 0.05 (Faul et al., 2009). This analysis – performed in Stata 14.0 of StataCorp LLC – is based on data from all the 50 US states in 7 years. Therefore, the primary sample size is 350, except where independent variable data are not applicable (e.g., Alaska and Hawaii). A Shapiro–Wilk test and standardized normal probability plot are applied to inspect the normal distribution of residuals, and the Breusch-Pagan / Cook-Weisberg test is used to ensure that heteroskedasticity levels are not significant. To prioritize the independent variables for inclusion in the final regression analysis and to avoid overfitting, we rely on the magnitude of the Pearson correlation coefficient and statistical significance. To prevent multicollinearity, the use of highly correlated variables in regression models is avoided based on the assumption that the presence of zero-order Pearson coefficients above 0.80 (e.g., between education and income) denotes multicollinearity (Gujarati, 2009). We use robust standard errors, Variance Inflation Factors (VIFs), and the residuals graph to reduce heteroskedasticity and control multicollinearity. The US Census estimates are at the state level; thus, error margins are negligible when assessed against the coefficient of variation.

4.4. Results

4.4.1. Description of green building criteria in QAPs

Figure 4.4.1 (top) presents the box plot of QAP scores achieved by the green building component since the year data collection started. The Y-axes represent the scores achieved as the percentage of the maximum score available for each component (top) or construction option (bottom). The level of initiative state housing agencies take toward green building in the LIHTC program varies considerably, particularly in resource conservation and health protection. The energy efficiency component has the highest total score, followed by smart growth, resource conservation, and health protection. There is also a notable upward trend in the median scores of all four categories. Table 4.4.1 ranks the state housing agencies based on mean QAP scores achieved from 2006-17 and categorizes them into role-model, strongly-committed, committed, moderately-committed, and weakly-committed (i.e., least innovative) housing agencies (Rogers, 1995). The role-model states, namely, Massachusetts and Connecticut, achieved mean scores above two standard errors from the mean of all states. Strongly-committed states achieved scores between one and two standard errors above the mean and so on. Figure 4.4.1 (bottom) compares the mean scores role-model, strongly-committed, committed, moderately-committed, and weakly-committed housing agencies achieved within each component as a percentage of the total score.

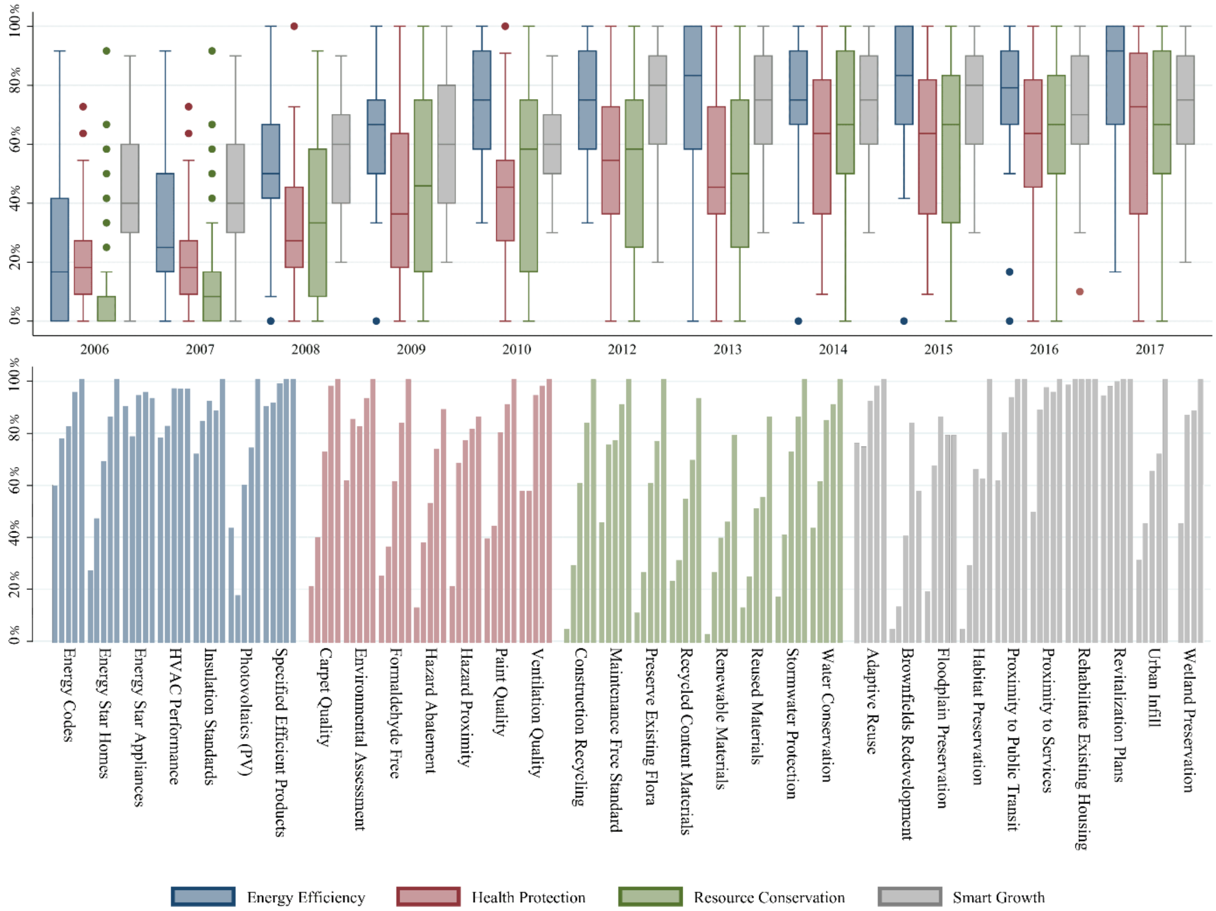


Figure 4.4.1 Top: box plot of QAP scores achieved by component. Bottom: mean score achieved by the role model, strongly committed, committed, moderately committed, and weakly committed state housing agencies within each component.

Table 4.4.1 State QAP scores ranked by mean QAP values

	Rank	State	2006	2007	2008	2009	2010	2012	2013	2014	2015	2016	2017	Mean	SD
Role model	1	Massachusetts	33	33	35	38	36	41	45	40	43	41	41	38.73	4.03
	2	Connecticut	6	14	43	45	44	45	45	45	45	45	44	38.27	14.11
Strongly	3	Maryland	25	25	27	38	37	45	45	45	45	39	39	37.27	8.08
	4	Georgia	32	34	33	40	39	34	31	35	35	35	36	34.91	2.70
Committed	5	Pennsylvania	26	26	29	29	27	40	38	40	40	44	43	34.73	7.25
	6	Maine	21	22	32	32	34	33	39	37	37	37	34	32.55	5.92
	7	New Jersey	13	15	32	34	35	38	19	41	41	43	44	32.27	11.38
	8	Minnesota	2	12	19	35	36	36	45	45	45	37	38	31.82	14.41
Committed	9	Washington	3	3	3	39	38	41	44	42	42	42	42	30.82	17.94
	10	New York	5	6	23	35	36	35	34	37	39	40	44	30.36	13.36
	11	Vermont	6	12	26	29	28	39	37	41	39	35	41	30.27	11.82
	12	California	30	28	28	28	30	31	23	30	31	29	40	29.82	4.05
	13	Rhode Island	6	6	11	29	38	36	40	35	36	44	41	29.27	14.44
	14	Nevada	24	23	24	25	27	28	36	34	28	33	35	28.82	4.83
	15	Delaware	6	9	24	26	32	32	33	36	38	40	40	28.73	11.70
	16	Michigan	5	5	27	27	36	34	32	34	35	35	45	28.64	12.63
	17	North Dakota	3	3	28	27	24	27	33	41	39	42	40	27.91	13.87
	18	Arizona	14	16	16	20	22	26	36	35	39	40	33	27.00	9.90
	19	Wyoming	17	17	21	24	18	29	28	37	34	32	38	26.82	7.91
	20	North Carolina	13	13	23	24	24	31	29	34	34	34	33	26.55	7.92
	21	New Hampshire	7	7	19	30	29	31	36	36	29	33	33	26.36	10.61
	22	Illinois	6	6	23	22	30	29	37	32	34	35	35	26.27	11.10
	23	Montana	9	14	29	28	28	29	32	28	29	30	30	26.00	7.35
	24	Iowa	15	15	12	27	31	31	28	33	30	30	33	25.91	7.89
	25	Indiana	17	18	21	27	29	28	28	31	31	26	28	25.82	4.92
	26	Colorado	8	8	8	14	35	33	19	34	34	41	45	25.36	14.16
	27	West Virginia	8	8	14	16	23	18	40	39	37	37	36	25.09	12.90
Moderately	28	Ohio	6	9	13	16	15	35	6	41	44	43	45	24.82	16.56
	29	Alabama	19	20	21	20	21	23	19	25	23	28	32	22.82	4.09
Committed	30	Kentucky	5	7	16	24	24	31	35	26	32	28	23	22.82	9.77
	31	Louisiana	10	15	14	27	26	21	22	23	22	32	34	22.36	7.37
	32	Kansas	13	17	19	21	20	23	26	29	25	24	28	22.27	4.84
	33	South Dakota	11	11	17	19	20	23	23	32	28	30	30	22.18	7.39
	34	New Mexico	8	15	20	23	25	26	27	15	28	29	24	21.82	6.62
	35	Arkansas	14	18	21	21	23	22	23	21	25	28	22	21.64	3.59
	36	Idaho	5	5	6	19	24	24	25	32	33	30	32	21.36	11.14
	37	South Carolina	13	13	16	18	15	23	24	29	23	27	31	21.09	6.44
	38	Utah	12	12	13	14	15	18	19	40	35	21	21	20.00	9.33
	39	Florida	4	4	19	19	20	28	17	25	27	25	28	19.64	8.65
	40	Oregon	7	7	21	6	22	25	14	26	26	31	31	19.64	9.55
	41	Texas	12	12	22	31	29	30	26	9	6	6	31	19.45	10.49
	42	Missouri	15	15	19	21	23	22	25	17	19	16	20	19.27	3.32
	43	Nebraska	2	2	26	14	14	19	29	27	23	26	26	18.91	9.77
Weakly	44	Hawaii			4	19	19	27	28	11	28	11	13	17.78	8.67
	45	Virginia	10	10	12	12	22	21	17	19	22	22	20	17.00	5.02
Committed	46	Mississippi	7	9	15	11	14	17	16	21	20	24	23	16.09	5.61
	47	Tennessee	4	5	7	11	13	15	16	21	20	27	27	15.09	8.09
	48	Wisconsin	5	5	4	14	15	20	22	35	16	5	9	13.64	9.55
	49	Alaska	6	6	10	8	17	12	16	14	16	14	13	12.00	3.97
	50	Oklahoma	6	6	12	12	11	13	13	19	12	12	15	11.91	3.65
		Mean	11.31	12.67	19.54	23.76	25.86	28.36	28.44	31.08	30.84	30.76	32.18		
		SD	7.94	7.70	8.65	8.91	8.13	7.97	9.65	9.16	9.07	9.87	9.23		

4.4.2. Policy innovation motivations, resources, and obstacles

Table 4.4.2 introduces the summary of the dataset. The primary dependent variable, QAP score, is reported in the original scoring format, but the secondary dependent variables (i.e., component scores) are transformed to the percentage of the maximum score available for each component to become comparable in models and figures. The right-most column contains the uncontrolled Pearson correlation coefficients, suggesting that most of the independent variables have statistically significant correlations with QAP score. Among the economic correlates, there is a moderate (± 0.30 and ± 0.49) correlation between GDP per capita (i.e., the per capita total value of goods and services in a state in a year) and QAP score (R=0.317). Among the environmental correlates, QAP score is moderately correlated with heating degree days and population density. Also, QAP score is significantly correlated with all the political, societal, and regional characteristics independent variables.

Table 4.4.2 Descriptive statistics and correlation analysis (n = 350)

Construct and variables	Type	Mean	SD	Minimum	Maximum	Correlation w/ QAP
Green building						
QAP score	Contin.	29.65	9.18	5.00	45.00	
Energy efficiency	Contin.	76.64	21.75	0	100	
Health protection	Contin.	57.35	26.71	0	100	
Resource conservation	Contin.	58.43	29.61	0	100	
Smart growth	Contin.	71.23	20.77	10	100	
Economic characteristics						
GDP per capita	Contin.	53.04	10.60	32.49	82.49	0.317***
Intergovernmental revenue	Percent.	33.56	5.71	17.33	50.69	-0.191***
Manufacturing value-added	Percent.	11.96	5.65	1.83	29.89	-0.115
Sales tax	Percent.	5.07	1.98	0.00	8.25	0.156***
Unemployment rate	Percent.	7.04	2.31	2.60	15.10	-0.141***
Environmental characteristics						
Degree days of heating (n = 336)	Contin.	49.56	19.97	3.41	98.45	0.302***
Density	Contin.	167.76	205.38	1.07	1032.40	0.412***
Disaster frequency	Contin.	2.00	2.82	0.00	31.00	-0.034
Fossil fuel reliance	Contin.	11.36	11.96	0.01	81.13	-0.100*
Political characteristics						
Energy code status	Contin.	4.44	2.20	1.00	8.00	0.281***
Government ideology	Contin.	42.40	17.53	17.51	73.62	0.355***
RE incentive policy	Contin.	5.12	4.23	0	24	0.256***
RE portfolio standard	Binary	0.55	0.50	0	1	0.374***
RE regulatory policy	Contin.	4.47	1.89	0	9	0.321***
Societal characteristics						
Higher education	Percent.	9.05	2.26	5.16	16.41	0.476***
Housing stock year built	Contin.	1976.43	8.23	1955	1994	-0.337***
Urbanization	Percent.	73.58	14.44	38.66	94.95	0.178***
Regional characteristics						
Neighbors' score (n = 336)	Contin.	34.57	6.08	17.00	47.33	0.419***
Control variables						
Median household income	Contin.	54.58	9.50	36.85	80.78	0.351***
Total population	Contin.	6.35	7.07	0.56	39.54	0.035
Year	Binary	0.1667	0.373	0	1	0.210***

Note: *** p < 0.01 ** p < 0.05 * p < 0.10

Table 4.4.3 presents regression analyses based on the block-wise forward selection method controlling for state population, household income, time, and fixed effects of climate regions. We develop five partial (Table 4.4.4) and one full (Table 6) regression models for the primary dependent variable. These models describe the sample after 8 data points are removed as outliers after the initial regression's residuals are obtained. These data points represent states and years in which the greatest radical changes occurred to QAPs (including GA 2010, NJ 2013, OH 2013, TX 2014, TX 2015, TX 2016, WI 2016, and WI 2017). Robust standard errors are utilized to increase the validity of the inferences valid despite minor levels of heteroskedasticity. Only those independent variables that are statistically significant and describe a greater amount of variance in the dependent variable are included in the full model.

Table 4.4.3 Partial OLS regression analysis of QAP score

Construct and variables	Model 1		Model 2		Model 3		Model 4		Model 5	
	Economy		Environment		Policy		Society		Region	
	Coef.	R.S.E.	Coef.	R.S.E.	Coef.	R.S.E.	Coef.	R.S.E.	Coef.	R.S.E.
Economic characteristics										
GDP per capita	0.209***	0.074								
Int.gov. revenue	0.088	0.100								
Manufacturing value-added	0.046	0.066								
Sales tax	1.205***	0.246								
Unemployment rate	0.289	0.306								
Environmental characteristics										
Degree days of heating			0.144***	0.023						
Density			0.014***	0.002						
Disaster frequency			-0.052	0.142						
Fossil fuel reliance			0.001	0.027						
Political characteristics										
Energy code status					0.973***	0.230				
RE incentive policy					-0.042	0.434				
RE portfolio standard					5.375***	1.099				
RE regulatory policy					0.296	0.268				
Societal characteristics										
Higher education							1.342***	0.333		
Housing stock year built							-0.257***	0.051		
Urbanization							0.027	0.036		
Regional characteristics										
Neighbor's score									0.030	0.093
East North Central									3.773**	1.831
Northeast									7.793***	1.450
Northwest									2.595	1.900
South									-5.407***	1.680
Southeast									-2.749	1.436
Southwest									0.019	1.826
West									-0.557	1.812
West North Central									0.545	1.477
Control variables										
Median household income	0.224***	0.086	0.166**	0.069	0.130	0.069	-0.017	0.087	0.162***	0.053
Total population	-0.050**	0.061	0.130**	0.051	-0.110	0.057	0.016	0.049	0.118**	0.049
Year	0.625**	0.279	0.911***	0.180	0.764***	0.171	0.819***	0.187	0.838***	0.163
Constant	-1263.239	563.921	-1823.557	360.469	-1524.010	344.306	-1126.011	359.574	-1669.579	325.469
Observations	342		328		328		342		328	
R-squared	0.244		0.442		0.334		0.319		0.495	
Root MSE	7.685		6.343		7.200		7.273		6.080	

Note: *** $p < 0.01$ ** $p < 0.05$

Table 4.4.4 includes the full QAP score model and three models of the green building components. Most independent variables in the full model are statistically significant (at p <

0.05) and corroborate Mohr's motivation-resource-obstacle hypothesis. The effect sizes (i.e., partial degrees of associations) of the independent variable in the full model are indicated by the Omega squared statistic ("estat esize, omega" in Stata). As expected, the availability of economic resources, represented by sales tax revenue (ω^2 = 9.2%) and GDP per capita (ω^2 = 4.5%), is significantly associated with the housing agencies' adoption of green building criteria in the LIHTC program and, to some extent, explain the total variability in QAP score. All other variables held constant, on average, each one percent increase in state sales tax is associated with a 1.225 unit increase in QAP score. Environmental characteristics that increase the utility of improved building practices, such as heating degree days (ω^2 = 1.8%) and density (ω^2 = 0.4%), appear to create statistically significant resources for policy innovation in the LIHTC program. Each one hundred degrees increase in heating degree days is associated with a 0.094 unit increase in QAP score. Government ideology (i.e., motivation) explains a small percentage (ω^2 = 0.8%) of the total variability of the QAP score. There is also statistically significant evidence of associations between QAP score and complementary environmental legislation, in this case, renewable portfolio standards (ω^2 = 5.9%), which suggests the presence of a renewable portfolio standard is, on average, associated with 4.282 unit increase in QAP score. The age of housing stock is inversely related to the QAP score and explains 2.3 percent of the total QAP score variability. The effect sizes of individual dependent variables are small, but together, the full model explains nearly 60 percent of the total variability of green building criteria in QAPs. The US states that are in the Northeast climate region score, on average, 7.705 units more than other states.

Since 2010, most housing agencies have received high scores with low variability on the energy efficiency component (Mean = 76.64, SD = 21.75). Therefore, the energy efficiency component model is not included. The scores of the three included components are transferred to percentages for consistency. Models in Table 4.4.4 suggest that the rate of state sales tax, existing environmental legislation, and regional characteristics are significantly associated with health protection, resource conservation, and smart growth components. For instance, each one percent increase in state sales tax revenue is associated with a 3.67 unit increase in health protection score, a 2.95 unit increase in resource conservation score, and a 1.90 unit increase in smart growth score.

Table 4.4.4 Full analysis of QAP Score (0-45) and green building components (0-100)

Construct and variables	Full Model[1]			Health Protection[2]		Resource Conservation[2]		Smart Growth[2]	
	Coef.	R.S.E.	ω^2	Coef.	R.S.E.	Coef.	R.S.E.	Coef.	R.S.E.
Economic characteristics									
GDP per capita	0.238***	0.049	4.5%	0.0632***	0.173	0.124	0.167	0.956***	0.130
Sales tax	1.225***	0.188	9.1%	3.673***	0.671	2.953***	0.615	1.901***	0.531
Unemployment rate	-	-		3.814***	0.932	1.714**	0.855	1.977**	0.835
Environmental characteristics									
Degree days of heating	0.094**	0.036	1.8%	0.203	0.108	0.207	0.125	0.365***	0.096
Density	0.005**	0.002	0.4%	0.003	0.009	0.009	0.009	-0.001	0.008
Political characteristics									
Government ideology	0.051	0.030	0.8%	0.033	0.099	0.416***	0.100	-0.045	0.082
RE portfolio standard	4.282***	0.979	5.9%	14.197***	2,915	9.539**	3.707	10.150***	2.530
Societal characteristics									
Housing stock year built	0.221***	0.066	2.3%	0.440	0.233	0.824***	0.213	0.257	0.200
Regional characteristics									
East North Central	1.381	1.991	0.00%	7.458	5.972	13.497**	6.500	-7.694	4.931
Northeast	7.705***	1.502	8.2%	16.568***	4.701	33.792***	5.327	11.159***	3.908
Northwest	2.880	1.545	0.7%	5.200	5.113	21.789***	5.279	-5.001	4.254
South	-2.488	1.564	0.6%	-9.359	5.045	-4.527	5.035	-3.405	4.769
Southeast	1.018	1.650	0.0%	2.607	6.274	-3.302	5.303	-0.661	4.026
Southwest	0.874	2.009	0.0%	-8.359	6.270	16.557**	7.060	-1.900	4.248
West	-3.135	1.998	0.3%	-12.502	6.628	-27.039***	7.568	-13.261**	5.728
West North Central	1.773	1.657	0.1%	8.930	5.411	35.412***	5.786	-13.948***	4.674
Control variables									
Median household income	-0.182**	0.077	1.2%	-0.040	0.275	-0.367	0.246	-0.635***	0.227
Total population	0.092	0.052	0.3%	-0.145	0.169	1.378***	0.196	-0.182	0.157
Year	1.013***	0.161	9.6%	5.084***	0.738	5.156***	0.726	2.717***	0.699
Constant	-2466.766	338.977		-11147.410	1555.900	-12022.660	1542.679	-5966.493	1513.867
Observations	328			328		328		328	
R-squared	0.586			0.508		0.588		0.432	
Root MSE	5.566			18.46		18.33		15.46	

*** $p < 0.01$ ** $p < 0.05$

4.5. Discussion

4.5.1. Key results and comparison with previous research

Starting from the first research question, the first finding from the descriptive analysis is that state housing agencies increasingly incorporated green building into QAP criteria in the 2000s, but the adoption momentum has decreased since 2010 and now is on a slight upward trajectory. Energy efficiency has received the most attention, followed by smart growth, resource conservation, and health protection criteria. Since the cost of development is often a major determinant of innovation in low-income housing, a potential explanation for prioritizing energy efficiency and smart growth criteria is that benefits from enhancing such practices often manifest themselves in the form of immediate financial savings, making it easier for housing stakeholders to accept the upfront cost, whereas benefits from enhancing resource conservation and health protection criteria are not as instant and tangible as those of savings from reduced energy consumption. Also, many smart growth criteria, such as proximity to services, could already be satisfied in the urban context of most LIHTC projects without extra costs to developers. Even though green building components have become mainstream in the industry, health protection and resource conservation have received little attention as project selection criteria.

Corresponding to the second research question, the next finding from the descriptive analysis is that state housing agencies that adopt a set of green building criteria, do not always maintain the adopted criteria in the long term. Some agencies (e.g., Kentucky, Missouri, and Wisconsin) that scored high on green building criteria at the outset relinquished green construction policy options. Some agencies have reported the adoption of limited green building criteria to make them more attainable for developers, and some others seem to have adopted green building criteria as efficient instruments in the short term until stringent state-wide standards are evolved. Consequently, anticipating the development of strict state-specific standards, some agencies dropped third-party certification requirements. In some states, meeting Home Energy Rating System (HERS) ratings were mandated as a substitution for more expensive rating systems, which decreased the states' QAP score (Global Green, 2019). Agencies in Texas, Florida, and some other states pursued a different path by abandoning sub-components at the start and re-adopting them in the following years. These variations suggest that there are trials and errors involved in adopting and maintaining new policies, allowing agencies to experiment with various methods of dealing with environmental concerns until the agencies find the most practical solution.

The third finding from this analysis is that state housing agencies do not equally contribute to environmental sustainability and climate protection through low-income housing. The LIHTC housing agencies can be divided into role-model, strongly committed, committed, moderately committed, and weakly committed (i.e., least innovative) organizations. The fact that even less innovative or weakly committed agencies have frequently adopted energy efficiency and smart growth criteria suggests that most decisionmakers have recognized immediate co-benefits (e.g., cost savings, pollution reduction, fuel cost reduction) associated with these criteria. Most states that rank high on the policy innovation list are in the Northeast innovation cluster, where annual heating energy loads are among the highest in the country and fuel poverty is an issue. On the other hand, states in the West and South often appear at the bottom of the list. Together, these findings suggest that while cost-benefit analysis has a strong role in prioritizing green building criteria by housing agencies, there is an innovation cluster effect, explaining significant between-region variations in the state adoption of energy-saving criteria despite the presence of similar climatic characteristics between regions. In other words, all else being equal, housing agencies are more likely to emulate green building policies of innovative agencies of nearby agencies, rather than those of innovative agencies in remote locations.

Lastly, this analysis finds that the role-model (i.e., most innovative) state housing agencies often have more motivation and resources than weakly-committed ones do to overcome existing obstacles and adopt green building policies and commercialize the technologies. We accept the five hypotheses examined since positive and statistically significant relationships exist between policy innovation and the presence of economic resources (represented by sales tax and GDP per capita), environmental resources (represented by heating degree days and population density), political motivations and resources (represented by liberal ideology and complementary environmental standards), and societal resources (represented by the presence of highly educated workforce and newly built housing stock). In addition to the presence of statistically significant internal determinants, most role-model and strongly committed agencies are in the Northeast innovation cluster, where the role-model state agencies function as regional trendsetters spreading new policies through imitation, emulation, competition, or other mechanisms to the followers that share characteristics like those of the role-models.

4.5.2. Limitations and future research and policy recommendations

The independent variables employed in the regression models collectively explain up to approximately 60 percent of the variance in the QAP score, which raises the question about what other factors should be included in the model to explain the remaining variance. This analysis and previous research on social and psychological barriers to green building suggest policymaking for sustainable development in public organizations has not always followed pure rationality. Rather, individual-, organization-, and industry-level factors, e.g., attitudes, autonomy, entrepreneurship, motivations, leadership, maturity, resources, structures, have been involved in driving sub-optimal outcomes. The literature on organizations and environment broadly identifies and articulates how such factors may affect organizations' interaction with complex social and environmental issues (Etzion, 2007; Garud et al., 2013). Institutional barriers, such as adherence to rigid building codes and standards, standard operating procedures, and unquestioned biases, that impede rationality, innovativeness, and responses to societal interests regarding complex problems are very common in the construction industry and should be accounted for in future research on policy innovation (see, e.g., Hoffman & Henn, 2008). This analysis shows many housing agencies tend to adopt a set of innovative green building criteria but radically change the initial decisions within only a few years. Such organization-level decisions affect the linear trajectory of policy adoption and, thus, reduce the predictability of future outcomes.

This study shows that factors that are external to housing agencies – such as the state economy, environment, policy, regional effect, and pressure from the society – provide partial explanations regarding the adoption of green building practices. At the same time, the change in the environmental performance of LIHTC units has been slow and unsteady in coming. Thus, future studies may follow two lines of research. First, to explore how role-model housing agencies like Massachusetts and Connecticut overcome organizational inertia, approach environmental problems, and set strategies for action (Bloch & Bugge, 2013; Kankanhalli et al., 2017; Kaplan & Henderson, 2005). Second, to study what other barriers affect the integration of environmental targets into LIHTC developments. Past research on the role of organizational culture and subculture suggests that the adoption of new practices is easier when framed as a positive and attractive option, and this analysis supports this by showing green building options having immediate financial savings are more likely to be adopted and commercialized (Howard-Grenville, 2006). This line of research should account for the increased availability of green products, technological advances, federal and state subsidies, integrated design-build practices, and professional workforce, and determine what is needed to close the gap towards zero energy housing. Data-driven analyses showing a long-term reduction in LIHTC development and maintenance expenses can motivate all stakeholders to be receptive to reducing existing barriers to high environmental performance.

This study finds that, all else equal, housing agencies located in a regional innovation cluster have been more successful than others in overcoming obstacles to innovation in the LIHTC context. The LIHTC housing agencies' cooperation with inter- and intrastate organizations and professional networks to exchange information, training, and expertise can increase the diffusion of innovative housing policy solutions. Creating and maintaining effective partnerships with local third-party green building rating systems that are focused on the development of practical high-performance building solutions can help maintain green building in the LIHTC program. Reducing frequent changes to green building requirements would increase transparency, predictability, and the development of data-driven long-term contracting and financing solutions. Past research shows that effective alignments of state tax credit allocation and local government incentives have reduced construction costs and resulted in the development of a large number of high-quality LIHTC projects (Deng, 2011). With recent decreases in the cost of green construction options, adopting such cost reduction strategies can significantly reduce the cost of compliance with third-party green building rating systems.

4.6. Conclusion

This article explored residential policy innovation in the context of the largest federal low-income housing production program in the US. Using panel data and information from seven years of collaboration between Global Green and LIHTC-allocating agencies, the authors developed an empirical framework, showing interstate variations in the adoption of green building criteria are, to a large extent, explained by state-level data of housing agency resources, motivations, and obstacles. The adoption momentum of green building criteria has decreased since 2010 and now is on a slight upward trajectory. Significant between-state differences in policy innovation in LIHTC persist. The LIHTC housing agencies can be divided into role-model, strongly committed, committed, moderately committed, and weakly committed organizations. This study shows that agencies that adopt a set of green building criteria do not always maintain the adopted criteria in the long term. Apart from a cost-benefit analysis, there are trials and errors involved in adopting new policies, allowing agencies to experiment with various methods of dealing with environmental concerns until the agencies find the most practical solution. The empirical model examined here corroborates Mohr’s motivation-resource-obstacle hypothesis, showing positive and statistically significant relationships exist between policy innovation and the presence of economic, environmental, political, and societal resources and motivations. The results suggest that the determinants influencing the propensity of LIHTC-allocating agencies to require green construction options can include organization-level factors. Future policy innovation research should explore factors that impact the utility of policy innovation and barriers the environmental sustainability movement faces at the organization level and beyond. Since QAPs have significant impacts on the location and quality of LIHTC developments, housing agencies can use QAPs as effective policy tools to drive planned evolutionary change to residential developments. Since buildings represent up to 40 percent of global energy use and 30 percent of greenhouse gas emissions, the LIHTC program can provide considerable opportunities for national and subnational governments to promote global environmental sustainability and climate change mitigation through policy interventions (Edenhofer, 2015).

CHAPTER FIVE: FEASIBILITY OF ZERO-ENERGY AFFORDABLE HOUSING

Chapter Summary

The United States needs comprehensive policymaking reforms that address sustainable residential development. This study investigates the feasibility of statewide zero-energy affordable housing by analyzing historical data on climate, energy use, and solar system costs in the Commonwealth of Virginia. The hypothesis examined is that the net present cost of implementation of rooftop residential solar systems to achieve zero-energy, multifamily buildings in the U.S. Low Income Housing Tax Credit (LIHTC) program is lower than the discounted present cost of energy of otherwise identical buildings that run without renewable energy generation systems. We propose a generalizable framework for analyzing the feasibility of achieving regionwide or statewide zero-energy affordable housing. To validate the framework, we employ a longitudinal sample of monthly energy use data from 2013-2016, obtained from 310 residential units of 15 LIHTC developments across Virginia. Based on statistical regression analysis, energy simulation, and simulation-based risk analysis, we find that the net present value of investments in zero-energy affordable housing can be positive with low risk. The investment value varies often depending on the zero-energy building definition, weather characteristics, retail price of electricity, and incentive rate. The results suggest that many other southern states can accrue benefits from zero-energy affordable housing.

5.1. Introduction

While renewable energy is rapidly growing in worldwide adoption, approximately 89 percent of the energy consumed in the United States in 2019 still came from non-renewable sources like coal, gas, and nuclear power (USDOE, 2020). Of that energy produced, the residential sector accounted for approximately 21 percent of consumption. Simultaneously, almost half of all renter households are cost-burdened, often due to poverty and rapidly rising housing prices in large metro areas (JCHS, 2019). The residential sector in the U.S. is clearly in need of comprehensive policymaking reforms that address sustainable residential development to reduce risks and uncertainties around the national economy, energy security, declining natural resources, and climate change.

In 1986, the U.S. Congress enacted the Low Income Housing Tax Credit (LIHTC) program, which provides state LIHTC-allocating agencies with approximately $8 billion per year to issue tax credits for the acquisition, rehabilitation, or new construction of rental housing for low-income households (HUD, 2019b). With more than 2.4 million active units (HUD, 2020b), LIHTC is the principal federal housing production program, which incentivizes the production of a significant portion of below-market-rate multifamily rental units for extremely-low-income to low-income households based on an indirect federal subsidy. Residents who qualify to live in a LIHTC unit receive housing benefits depending on their certified annual income and the maximum rent set by the project (Novogradac, 2020). McClure (2019) describes the basics of the LIHTC program (McClure, 2019).

Energy efficiency is increasingly considered important in LIHTC Qualified Allocation Plans (QAPs), which outline the criteria based on which state housing agencies allocate financial incentives in the form of tax credits to multifamily residential developers (Yeganeh et al., 2020). The basic federal criteria included in QAPs do not mandate specific energy efficiency standards, but additional criteria that support state housing policy goals often include energy efficiency incentives. Previous studies show QAPs have significant impacts on the location and quality of LIHTC developments (Ellen et al., 2015). As a result, QAPs could either promote or inhibit the application of innovative designs and technologies in affordable housing. Existing literature on the LIHTC program suggests that, among other co-benefits, energy-efficient LIHTC properties have generated considerable financial savings for the occupants (Zhao et al., 2018). Despite its significance as an opportunity to drive innovative solutions to address environmental sustainability and economic development through affordable housing in the U.S., zero-energy affordable housing has received little attention in literature, policy, and practice. If proved to be cost-effective, zero-energy developments can benefit residents and society as a whole by increasing housing affordability, environmental sustainability, and efficient distribution of federal financial incentives.

This article explores the existing gap to zero energy in the context of the LIHTC program: how much should state housing agencies raise energy efficiency and renewable energy requirements to bridge the gap to zero-energy LIHTC units?; how much does a zero-energy LIHTC building cost to developers at present?; is a zero-energy LIHTC building more cost-effective than a conventional building over its lifecycle?; and what types of additional support does the construction industry need to bridge the gap to zero energy? The main hypothesis examined is that the net present cost of the implementation of rooftop solar systems to achieve zero-energy affordable housing is lower than the discounted present cost of energy of otherwise identical buildings that run without renewable energy generation systems. The authors propose a generalizable framework for analyzing the feasibility of achieving regionwide or statewide zero-energy affordable housing. The framework is then validated using empirical data in a proof-of-concept case study focused on the rooftop grid-connected photovoltaic (PV) system as the only source of harvesting renewable energy to offset 100 percent of a multifamily residential building's annual energy demand in Virginia. This research addresses the knowledge gap in the literature and contributes to the body of knowledge through the examination of generalizable statistical energy load prediction methods and simulation-based risk analysis, which have essential applications in planning and policy analysis but have received little attention in existing feasibility studies (Rai et al., 2016).

The article opens with a concise review of literature on the need for energy-efficient affordable housing, the zero-energy building concept, and previous research on costs and benefits of zero-energy residential developments. Following the description of the analysis framework, we describe the study case, including the context, specifications, and related assumptions. Following steps were taken to test the research hypothesis and answer the research questions: (1) Collecting data of LIHTC units' energy loads, energy prices, and state climatic divisions; (2) Predicting the total energy load of the study case in the climatic divisions of Virginia; (3) Designing a rooftop solar energy system using simulation; (4) Estimating the system's lifecycle cost; (5) Performing a deterministic and simulation-based feasibility analysis. Results suggest that the net present value of zero-energy LIHTC units can be positive at low risk. The investment value varies often depending on the zero-energy building definition, project location, the retail price of electricity, and the rate of incentives available for solar systems. The article concludes with a discussion on implications and recommendations for affordable housing research, policy, and practice.

5.2. Literature Review

5.2.1. Energy-efficient affordable housing

In recent years, environmental concerns and rising energy prices have prompted a shift towards more energy-efficient residential units regardless of end-user finances. There are major reasons for decision-makers to consider energy-efficient affordable housing for low-income residents. First, sustainable development requires a balanced integration of economic, environmental, and societal goals, but environment and climate policy sectors alone are not capable of achieving all the objectives and thus must work with traditionally siloed policy sectors, such as affordable housing (Kivimaa & Mickwitz, 2006; Runhaar et al., 2014). Second, due to access to resources and information, public agencies are increasingly responsible for taking the initiative to recognize and deploy innovative, beneficial policies and programs, whether or not such utilities are expressed wants of all citizens (Mohr, 1969).

Empirical evidence suggests that energy and water efficiency throughout the building lifecycle significantly reduces the total cost of living for low-income households (Breysse et al., 2011; Singh et al., 2010). Lifecycle thinking is particularly consistent with the way LIHTC developments are financed, and research suggests, in the long term, energy-efficient LIHTC units built to high-performance building standards (e.g., ASHRAE 90.1, ASHRAE 90.2) and rating systems (e.g., Energy Star for Homes, LEED, EarthCraft) can be more cost-effective than conventional units for stakeholders and society (Bradshaw et al., 2005; Mueller & Tighe, 2007). LIHTC-financed residential units are charged a flat rent depending on the Area Median Income (AMI), typically close to 30 percent of household income for gross housing costs, including utilities. Therefore, if a LIHTC tenant's income decreases, they will be spending more than 30 percent on the monthly rent. Resident behavior and rising energy prices can increase utility costs, and the extra amount deducted from residents' monthly income and spent on utilities impacts housing affordability and economic well-being (Lapsa et al., 2020; VCHR, 2015). Some LIHTC projects convert to market-rate units after the first 15-year compliance period due to a lack of resources and funding to replace building systems in need of repair. Lifecycle savings from the adoption of durable, energy-efficient building systems could help increase housing affordability, preserve affordable units, and prevent the relocation of residents at the end of the compliance period (Schwartz et al., 2018).

Despite benefits, energy-efficient affordable housing has positive externalities, meaning multiple factors, including split incentives, information lags, and asymmetries, risk aversion, skill shortages, and analytical failures can lead to underinvestment in these units in a free market. Thus, government intervention is needed for the efficient distribution of social benefits (Deng & Wu, 2014; Matisoff et al., 2016). Although the benefits of energy-efficient building for society as a whole are often larger than the average cost premium to obtain energy certifications, residential developers demand significant price premiums that are likely to affect affordability (Yeganeh, McCoy, & Hankey, 2019). For instance, researchers have reported up to 10 percent sales price premiums associated with energy-efficient, single-family units with green building certifications in U.S. cities (Walls et al., 2017). Empirical studies suggest that financing initiatives can affect the adoption of renewable energy generation systems in the residential sector by as much as 100 percent (Hughes & Podolefsky, 2015). Affordable housing legislation aimed at promoting sustainability and preserving affordability could balance energy-efficiency and renewable energy needs pending the careful assessment of incentives, financing mechanisms, and technical issues involved.

5.2.2. Zero-energy buildings

Built on low-energy building research, which dates to the 1940s, zero-energy buildings have received growing attention in recent years and are being incentivized and mandated in the residential sector to help developed countries, including the U.S., achieve carbon neutrality (Carrilho da Graça et al., 2012; Deng & Wu, 2014). Zero-energy residential buildings use renewable sources of energy to generate enough energy to offset the operation-phase energy demand, which normally includes heating, cooling, ventilation, domestic hot water, fixed lighting, plug loads, and elevators. An alternative and/or complementary to on-site renewable energy generation is a utility-scale renewable energy grid, which benefits from scale economies and equalizes local peaks.

In 2010, the European Union (EU) directive on the energy performance of buildings asserted that member states should ensure all new buildings are nearly zero-energy buildings by 2020 (EU, 2020). In 2008, California's long-term energy-efficiency strategic plan, which became a mandate in 2018, adopted energy efficiency goals, stating all new residential construction in California would be zero-energy by 2020 (CAPUC, 2008). Past research concludes that energy use in the operation phase roughly accounts for 70–90 percent of a building's life cycle energy use, showing the significance of zero-energy buildings in mitigating greenhouse gas emissions. Considering the embodied energy of electricity grids, energy savings achieved in the operation of zero-energy buildings is considerably larger than the increase in embodied energy when switching from passive to zero-energy houses (Berggren et al., 2013).

The US Department of Energy (DOE) recognizes builders for leadership in increasing energy efficiency, improving indoor air quality, and making homes zero-energy ready through the Zero

Energy Ready Home program (DOE, 2020). The DOE defines a zero-energy building as "an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy" (DOE, 2017). Accordingly, delivered energy refers to "any type of energy that could be bought or sold for use as building energy", and exported energy is "on-site renewable energy supplied through the site boundary and used outside the site boundary" (DOE, 2017). In the DOE's definition, the source energy is composed of the delivered energy, plus the energy consumed in the extraction, processing, and transport of primary fuels plus energy losses in thermal combustion and power generation plants plus energy losses in transmission and distribution to the building site (D'Agostino & Mazzarella, 2019). An implicit assumption in this definition is that zero-energy buildings are not fully autonomous buildings and need to remain connected to existing energy grids that can exchange energy with buildings. According to this definition, the embodied energy of building materials, construction, and recycling, may or may not be considered in zero-energy building calculations.

The zero-energy building balance is a condition in which the sum of all generated energy is equal to or higher than the sum of all building energy loads over a period, nominally a month or a year. Load matching refers to the temporal match between load and generation and represents the building's ability to work dynamically, in synergy with the grid. Salom et al. (2011) reviews various load matching indicators. Equations 1 and 2 represent the zero-energy building balance condition, where e and d stand for exported and delivered energy, g and l stand for generation and load, and w and i stand for weighting factor and energy carrier. E, D, G, and L stand for weighted exported energy, weighted delivered energy, weighted generation, and weighted load, respectively. Equation 3 represents the load matching index, where f is the load matching index,

t is the time interval used, e.g., hour, day, or month, and n stands for the number of data samples (12 for monthly and 8760 for hourly time interval). For guidance and information on the grid interaction index equation, see Sartori et al. (2012).

$$\sum_i e_i \times w_{e,i} - \sum_i d_i \times w_{d,i} = E - D \geq 0 \quad \text{Equation 1}$$

$$\sum_i g_i \times w_{e,i} - \sum_i l_i \times w_{d,i} = G - L \geq 0 \quad \text{Equation 2}$$

$$f_{load,i} = \frac{1}{n} \times \sum_{year} min\left[1, \frac{g_i(t)}{l_i(t)}\right] \quad \text{Equation 3}$$

To maximize a zero-energy building's operation at the balance condition over time, the demand should be reduced by the means of energy efficiency, and the supply should be increased by the means of renewable energy systems. Although zero-energy buildings are often designed to achieve energy balance on an annual basis, increasing the generation-load match in smaller time scales using optimized energy storage systems reduces zero-energy buildings' stress on the existing grid, particularly at the times of peak energy demand, and reduces energy waste and carbon-related emissions (Guarino et al., 2015). Past research has examined different equations and weights to define the zero-energy building balance, including balances of primary energy, site energy, carbon emissions, and energy cost for different energy systems (Guarino et al., 2015; Mohamed et al., 2014). Data from the International Energy Agency suggest that the percentage of source energy that reaches the final end-user, which describes the overall energy efficiency in the U.S. supply sector, was 67.69 percent in 2010. The DOE definition of zero-energy buildings implies that these buildings should progress the restoration of the remaining 32.31 percent (loss) to the infrastructure system.

The surplus energy generation could be used as a basis to support asymmetric valuations of the energy exchanged between zero-energy buildings and energy grids, pricing the exported energy higher than that of the delivered energy. To export the equivalent of 32.31 percent of the annual load from multifamily buildings would require taking into account the need for large solar systems, installation of which may not currently be feasible based on design requirements and/or space availability in areas with low solar potential. For guidance and information on issues in zero-energy building, see D'Agostino & Mazzarella (2019).

5.2.3. Cost-benefit and simulation-based risk analyses

Researchers have examined the feasibility of utilizing renewable energy systems for residential and commercial purposes, while often in isolation (Aagreh & Al-Ghzawi, 2013; AlAjmi et al., 2016). The common approach is to evaluate the integration of one or more renewable energy systems like solar systems, wind turbines, heat pumps, district heating, and district cooling into new or existing developments using simulations and calculating the energy payback period or the levelized cost of energy in each scenario (Li et al., 2013).

Amasyali & El-Gohary (2018) reviews past research on data-driven building energy consumption prediction. Some studies have used simulation software, such as EnergyPlus, HOMER, and TRNSYS, in conjunction with daily or monthly load profile data obtained from study cases; most studies have focused on a single building; fewer studies have considered multiple developments with similarities and differences. Cost-benefit analyses include multiple non-financial criteria, such as the availability of technology, warranty period, ease of maintenance, required roof or ground area, avoided carbon emissions. Sensitivity analyses include the effect of changing key input variables for project outcomes, such as the effects of the cost of delivered energy, the value of exported energy, the introduction of a carbon tax, and the price of power generation technology. Few studies include an assessment of risk and uncertainty (e.g., the occurrence of alternative future events) into financial analysis, and most available studies are limited to simple financial analyses (Salci & Jenkins, 2016).

As a powerful tool for evaluating the effects of policy decisions, cost-benefit analysis relies on estimates about variables that are not accurately predictable, e.g., future prices, weather patterns, occupant behavior (Sartori et al., 2014). To effectively contribute to rational decision making, an analysis (e.g., scenario analysis, sensitivity analysis, Monte Carlo simulation) of risks and uncertainties associated with observed data and modeling errors that could change the project outcome and identify the range of possible outcomes should be an integral part of any cost-benefit analysis (Boardman et al., 2017; De Rus, 2010; Eeckhoudt et al., 2011; Salci & Jenkins, 2016). A conundrum about cost-benefit analysis is the choice of discount rate for future costs and benefits of projects. The U.S. Government recommends deterministic cost-benefit models followed by sensitivity analyses and Monte Carlo simulations to perform a full risk analysis of costs and benefits of policy interventions. The U.S. Government guidelines for cost-benefit analysis of federal programs have required a discount rate of 7 percent, which is supported by recent research, recommending discount rates in the range of 6-8 percent (Burgess & Zerbe, 2011; Management & Budget, 1992).

The National Renewable Energy Laboratory (NREL) benchmarks average U.S. solar photovoltaic (PV) system installed costs, weighted by state installed capacities and accounting for all system and project development costs incurred from the perspective of the developer/installer, including the cost of the hardware profit and installer/developer profit.

According to NREL, residential rooftop systems, ranging from 3-10 kW in size, cost $2.71 per watt DC (Wdc) or $3.11 per watt AC (Wac) in the first quarter of the year 2018. Figure 5.2.1 presents the NREL-estimated, inflation-adjusted national average rooftop system costs in 2018 dollars. The gradual decrease in the total cost results from various drivers working simultaneously, including increases in module efficiency, labor productivity, small installer market share, and decreases in supply chain cost, permitting cost, and structural and electrical balance of system commodity pricing. According to the benchmarking analysis, the total cost of residential PV systems has decreased by 4.91 percent, from 2017-2018, and it can be expected that in 2019 and 2020, the total cost per watt DC (Wdc) has decreased to ~$2.57 and ~$2.45, respectively. Since on-site electricity storage systems significantly increase the total cost of installation, the most common approach to zero-energy building, particularly where full retail net metering is not available, is to simply rely on the electricity grid (Ferrante & Cascella, 2011). Additional data and information on residential solar photovoltaics with energy storage systems are available in NREL's installed cost benchmarks (Ardani et al., 2016). Information on major trends in the U.S. solar industry can be found in the Solar Energy Industries Association's (SEIA) solar market insight reports (SEIA, 2020).

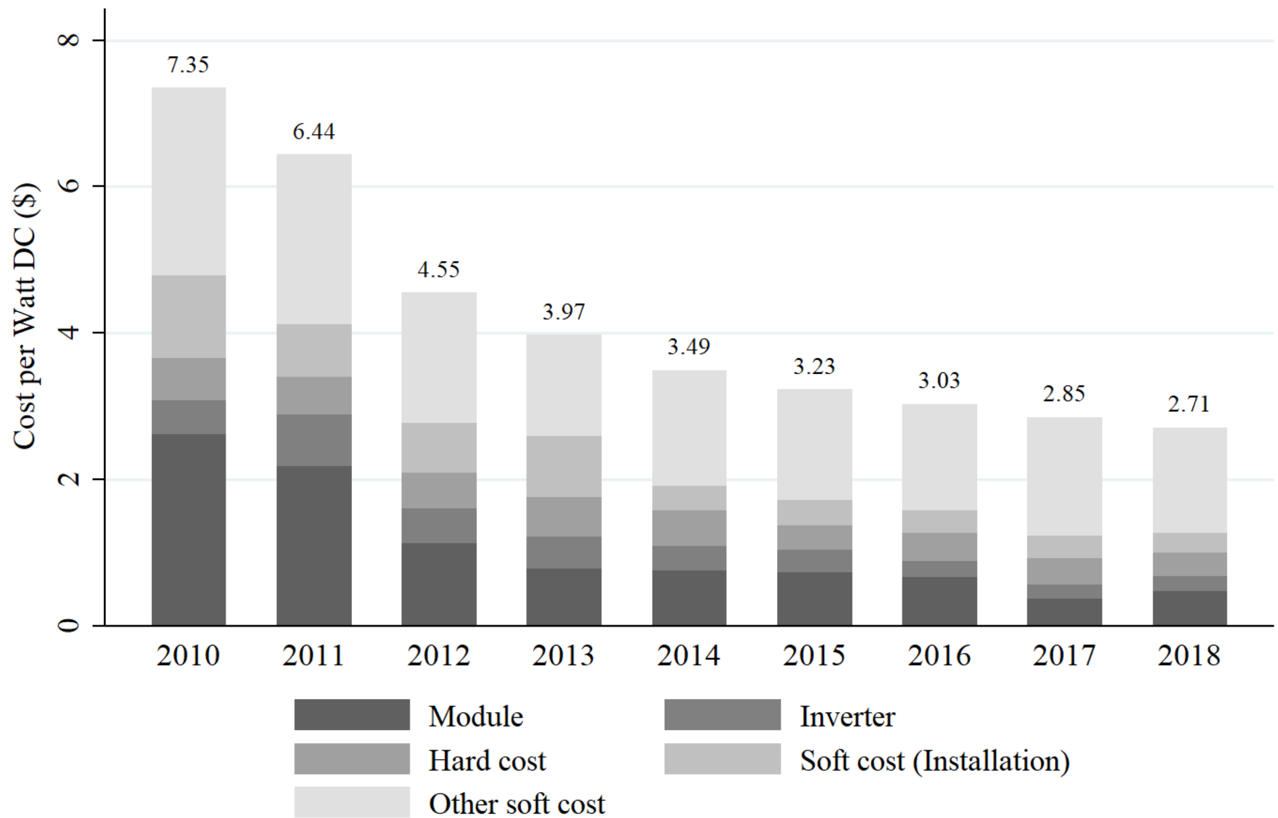


Figure 5.2.1 Inflation-adjusted cost of the residential PV system (6.2 kW) (NREL, 2018)

5.3. Methodology

5.3.1. Analysis framework

Several U.S. states, including Virginia, have enacted legislation demanding the production of 100 percent of electricity from carbon-free sources by 2050. The flowchart depicted in Figure 5.3.1 presents a generalizable framework for analyzing the feasibility of achieving regionwide or statewide zero-energy in affordable housing. Since the future lifecycle values included in the feasibility analysis of any hypothesized study cases are unknown, the framework relies on values that have the greatest probability of occurring as suggested by historical data, thus providing reasonable estimates for modeling purposes. We apply and validate this framework using empirical data in a proof-of-concept case study to test the study hypothesis and answer the research questions.

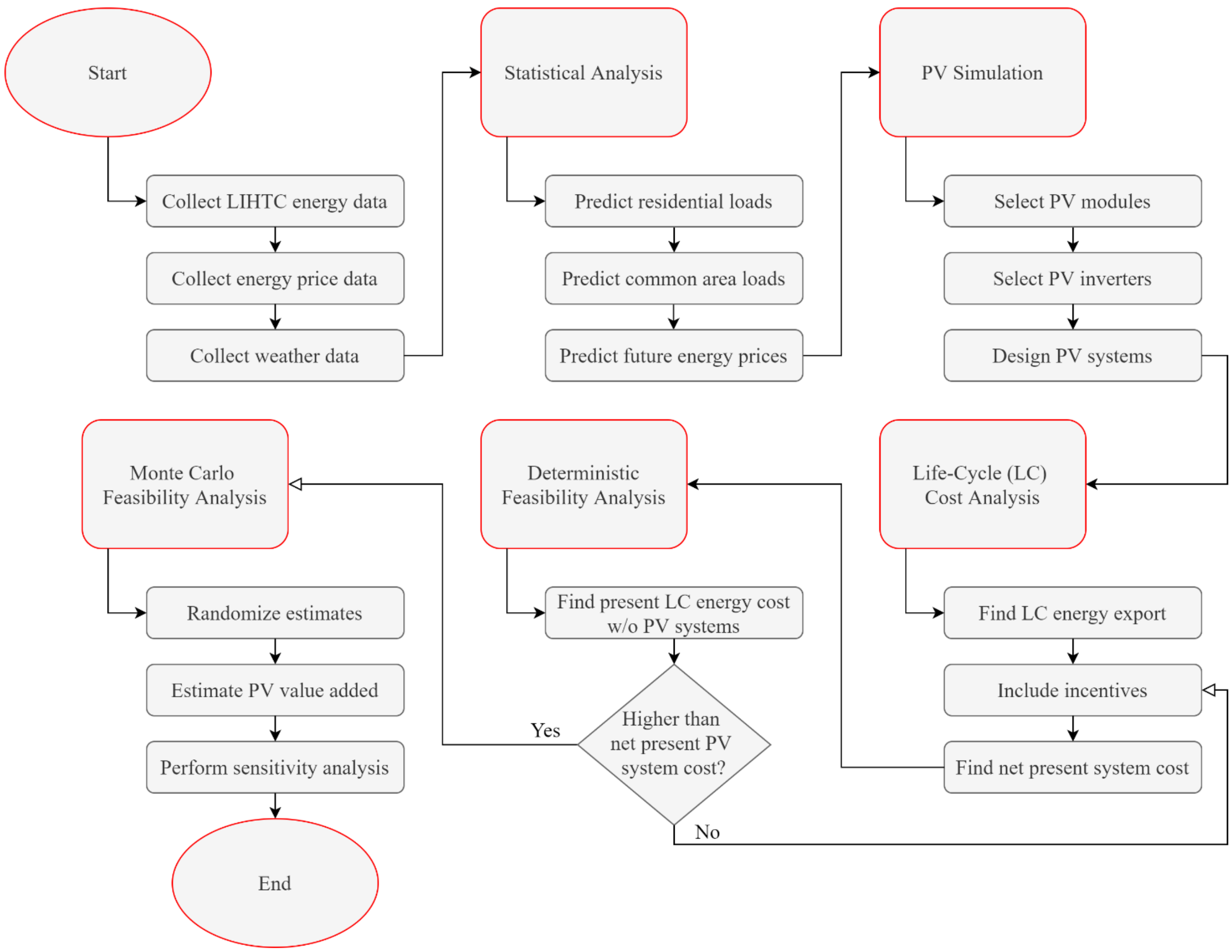


Figure 5.3.1 Zero-energy affordable housing feasibility analysis framework (https://app.diagrams.net)

5.3.2. Data collection

From the LIHTC program's inception in 1987 to 2017, 1,061 multifamily developments involving 95,854 units have been placed into service in Virginia. On average, each development has 90.43 units (± 72.58 Standard Deviation). For this study, we collected longitudinal, unit-level energy use data every month from May 2013 to April 2016 from 310 residential units across 15 LIHTC developments. The sample is large enough to represent all LIHTC units built in Virginia with a 5 percent margin of error at a 95 percent confidence interval. Electricity is the only source of energy for all units in the sample, and the monthly electricity use data are obtained with residents' consent, support from property managers, and in compliance with the Virginia Tech Institutional Review Board (IRB). The geographic clusters selected for random energy data sampling were the metropolitan statistical areas (MSAs) of Blacksburg-Christiansburg, Charlottesville, Hampton Roads, Harrisonburg, Kingsport–Bristol, Lynchburg, Richmond, and Washington-Arlington-Alexandria, which are eight of the eleven MSAs in Virginia, representing five of the six Virginia climatic divisions defined by the National Oceanic and Atmospheric Administration (NOAA) (Figure 5.3.2). In addition to unit-level monthly electricity use (kWh), the energy use dataset includes the unit-level conditioned floor area, type of construction (e.g., new or renovated), type of occupants (e.g., family or senior), and level of energy-efficiency as represented by the Home Energy Rating System (HERS) Index.

Developed and maintained by Residential Energy Services Network (RESNET), the HERS Index is the nationally recognized industry standard by which a residential unit's energy efficiency is calculated. A score of 100 is equal to the new construction standard of the year 2006 iteration of the International Residential Code (IRC). A score of 150 means the modeled unit is 50 percent less energy efficient than a standard new residential unit. To prevent inconsistencies commonly associated with the HERS Index (e.g., differences in inputs across different raters and modelers; inconsistencies among software calculation engines) a single rater developed the HERS model to obtain the benchmark for all the buildings included in this study. The IRC is upgraded on a three-year cycle, and the LIHTC developments from which energy use data are collected comply with the 2009 UBC, an amended version of the 2009 IRC/IBC. Typically, the amendment process creates a lag in adoption and enforcement. Therefore, when the sample units were being built from 2011-2013, the 2009 UBC was being enforced. We exclude common areas (e.g., lobby, hallway, manager's office, gym, elevator) from the main analysis due to high levels of variability in space programming and energy use, which reduce generalizability. Common areas in the building can be treated as one large unit that is sub-metered and billed to the developer, often based on commercial energy price rates. Common areas' energy information is available for benchmarking purposes at the Lawrence Berkeley National Lab's Building Performance Database (BPD) (https://bpd.lbl.gov), or online energy benchmarking services (www.wegowise.com). We obtained the NOAA-defined climatic divisions' data from the National Solar Radiation Database (NSRDB) weather files (https://nsrdb.nrel.gov) and we collected the state-wide, average retail electricity price data for residential and commercial use from the Energy Information Administration (EIA) website (www.eia.gov) of the U.S. DOE.

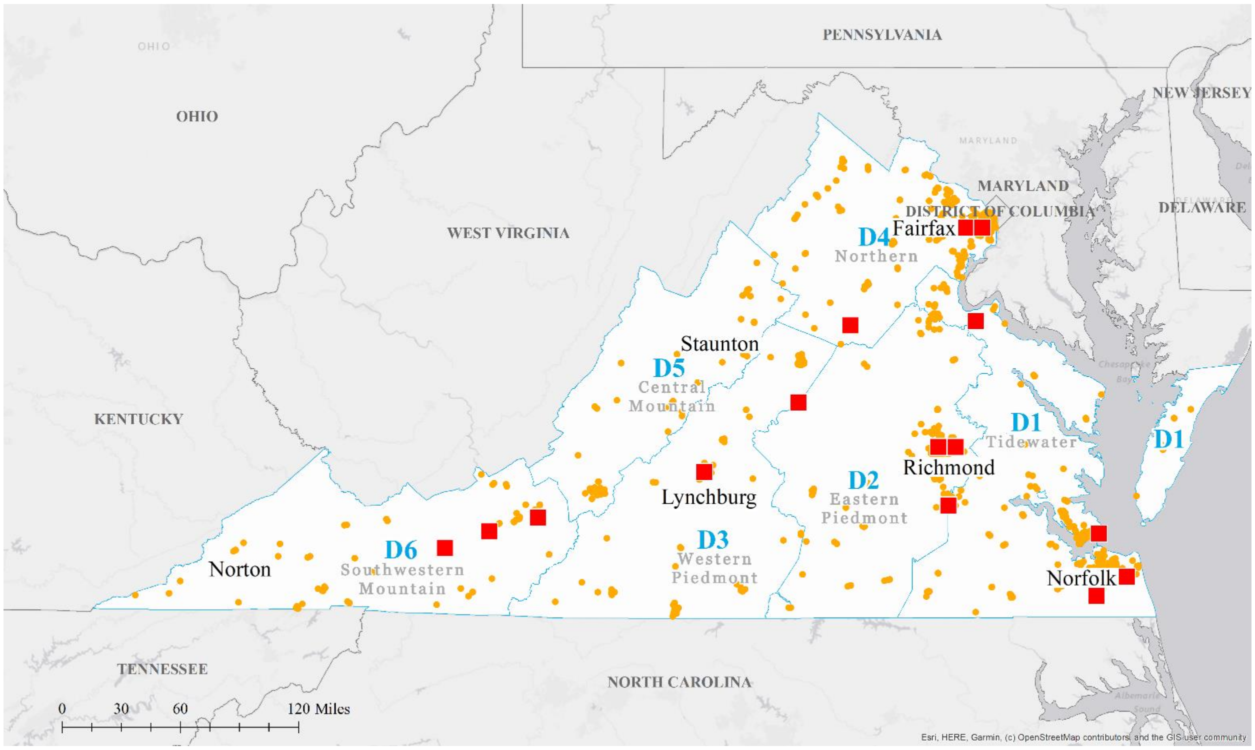


Figure 5.3.2 Sample (red squares) and existing (orange dots) LIHTC developments

5.3.3. Statistical analysis of loads

Using longitudinal data obtained from the geographical cluster sampling of LIHTC developments in Virginia, we estimate the energy load of residential units of the study case based on a multivariate regression model created in Stata 14.0 of StataCorp LLC. The regression analysis provides the mean load for a residential unit of a given size in a given climatic division, month, and year. The regression equation takes the basic form of Equation 4:

$$Sqrt(L_{ijkl}) = A_i\alpha + H_i\beta + R_i\gamma + S_i\delta + \sum_{j=1}^{6} D_{i,j}\theta_{i,j} + \sum_{k=1}^{12} M_{i,k}\lambda_{i,k} + \sum_{l=1}^{4} Y_{i,l}\mu_{i,l} + C + \varepsilon \qquad \text{Equation 4}$$

where $Sqrt(L_{ijkl})$ is the dependent variable, operationalized as the square root of energy load of the residential unit i in the climatic division j in the month k in the year l. The continuous variables A_i and H_i are the area (in square feet) and the HERS score of the unit i, respectively. The binary variables R_i and S_i denote whether the unit i belongs to a renovation – or a new construction – development and whether the unit i is occupied by senior – or family – households, respectively. The binary variables D_j , M_k, and Y_l denote the fixed effects of the climatic division, month, and year of energy load; α, β, γ, and δ are unknown coefficients; $\theta_{i,j}$, $\lambda_{i,k}$, and $\mu_{i,l}$ are vectors of unknown coefficients; C is the constant term, and ε stands for error. The square root transformation improves residual normality, reduces heteroskedasticity, and increases goodness-of-fit. We use Variance Inflation Factors (VIFs) to inspect for and avoid multicollinearity. Since the margins obtained from the model represent the conditional means of energy load, the total energy load of all units in a building is estimated by summing the predicted loads for all given unit sizes multiplied by the number of units of those sizes in the building.

Compared to conventional deterministic load forecasting based on a predefined set of load values, the adopted statistical approach can reduce uncertainty, i.e., variability whose distribution of values cannot be defined, using empirical data. The risk, i.e., variability whose distribution of values can be defined, is assessed using simulation-based risk analysis, also known as Monte Carlo analysis. Once residential loads in the reference location (Richmond, VA) are predicted, we use the energy use in kWh per degree day to estimate weather-normalized loads in other climatic divisions. We predict the annual average retail price of electricity based on a simple linear model, regressing the average price of electricity on time. For guidance and more information on available electricity price forecasting methods, see Weron (2014).

5.3.4. Study case and PV system simulation

The reference study case is a new affordable housing project in Richmond, VA, which is built to comply with the 2009 IRC building code, the same code version with which the sampled buildings comply. The average number of units per LIHTC application in Virginia from 2011-2020 is 67 (± 40 Standard Deviation). This study case is a 60-unit residential building composed of equal numbers of small (693 sf), medium (910sf), and large (1087 sf) units. We increase the PV system capacity until the generated energy during the first 30 years of operation simply exceeds the energy that would otherwise be delivered to the building from the grid on an annual basis, without any weighting factors, thus, relaxing the need to fully offset the primary energy loss in the infrastructure in favor of minimizing the required rooftop area. We use the System Advisor Model (SAM) software to design, simulate, and estimate the energy performance of the distributed photovoltaic systems for individual residential units.

The National Renewable Energy Laboratory (NREL) of the U.S. DOE developed SAM as free techno-economic software to help project managers and engineers, policy analysts, technology developers, and researchers calculate performance and financial metrics of renewable energy projects. SAM is an open-source project, allowing researchers to access its publicly available codes, explore its algorithms, and add models and enhancements to all projects. Reference manuals describing the model algorithms are available at the NREL's website (https://sam.nrel.gov). Blair et al. (2018) provides a detailed description of SAM and Gilman et al. (2018) presents the photovoltaic performance model algorithm. All the required weather information - hourly, or sub-hourly with up to one-minute time resolution - for the selected cities is obtained based on the closest weather station data available in the current version of the National Solar Radiation Database (NSRDB).

5.3.5. Feasibility analysis

The discounted cash flow (DCF) analysis tests whether the net present cost of the implementation of rooftop residential solar systems to achieve a zero-energy LIHTC building would be lower than the discounted present energy cost of an otherwise identical building with no renewable energy generation systems. The first approach to feasibility analysis is to obtain the base case deterministic Net Present Value (NPV) of investment in a solar system that its generated energy exceeds the energy load of the reference building during its lifecycle. The NPV is obtained from subtracting the net present cost of the implementation of rooftop residential PV systems from the discounted present cost of the future cash flow of energy of the same building without a renewable energy generation system at a 7 percent discount rate. We examine the two cash flow periods of 15 years and 30 years, which reflect typical LIHTC construction loan periods. Since the values included in such an analysis can vary on a random basis, we perform a simulation-based risk analysis to account for risk and uncertainty.

The Monte Carlo sampling method generates multiple probable outcomes for energy load, energy generation, and energy price based on historical data. Once the means and standard deviations of annual values of the three independent functions are predicted, the inverse cumulative distributions with random probabilities corresponding to the normal distribution of the predicted values are estimated and included in a single Monte Carlo simulation. The advantage of this method over the basic deterministic analysis is that it provides estimates of the NPV's mean, standard error, estimation error, and risk of loss (i.e., negative NPV). In Monte Carlo simulation, iterations of the simulation are treated as a sample of all possible values of the real NPV, and the true mean is estimated within a specific confidence interval and compared using the two-sample t-test to reject the null hypothesis (e.g., there are no statistically significant lifecycle savings with the solar system). This simulation includes 15,000 iterations to ensure below 2 percent error margins with a 99% confidence interval.

5.4. Results

5.4.1. Load profiles

Table 5.4.1 presents the location and weather characteristics of six major cities, each located in one of the six NOAA-defined climatic divisions in Virginia. We select these major cities for financial analysis to illustrate how the benefits and costs of investments in zero-energy affordable housing projects vary across the state. Since degree days – which are based on 65 degrees F, DD_{65} – can change annually, we choose the mean values for 2013-16, corresponding to the years of sample data collection, to predict energy loads. Table 5.4.2 presents descriptive statistics of historical data for the statewide retail price of residential electricity from 1990 to 2018. We use the city-specific mean retail prices of electricity for financial analysis. From 1990-2018, the nominal retail price of residential electricity in Virginia has, on average, annually increased by 0.18 cents/kWh. When adjusting the price using the Consumer Price Index (CPI) of electricity for urban consumers in U.S. cities, the real price of electricity has, on average across the U.S., decreased by 0.30 percent per year in the same period (FRED, 2020). Whether this descending trend is going to remain in place is not quite clear, while an ascending trend in the price means PV system users would accrue more financial benefits than initially estimated. The EIA has developed three different scenarios, suggesting that the national average price of 10.53 cents/kWh in 2018 can range anywhere from 9.7-11.6 cents/kWh in 2050 depending on economic growth, oil and gas resource prices, and renewable energy generating technology adoption rate (EIA, 2020). We consider these scenarios in this study.

Table 5.4.1 Location and weather characteristics of major cities in Virginia's climatic divisions

Variable	Division-1	Division-2	Division-3	Division-4	Division-5	Division-6	Unit
Selected city	Norfolk	Richmond	Lynchburg	Fairfax	Staunton	Norton	-
Latitude	36.8508	37.5407	37.4138	38.8462	38.1496	36.9334	°N
Longitude	-76.2859	-77.4360	-79.1422	-77.3064	-79.0717	-82.6290	°W
Global horizontal	4.50	4.08	4.44	4.27	4.44	4.28	kWh/m^2/day
Direct normal	5.01	4.36	4.88	4.54	4.84	4.51	kWh/m^2/day
Diffuse horizontal	1.60	1.60	1.63	1.69	1.71	1.75	kWh/m^2/day
Average temperature	14.50	14.90	12.80	11.80	11.10	10.80	°C
Average wind speed	3.60	0.80	0.10	1.90	0.30	0.10	m/s
2013 DD_{65}	5201	5440	5509	5920	5958	5639	°F
2014 DD_{65}	5235	5502	5625	6027	6102	5766	°F
2015 DD_{65}	5063	5225	5254	5722	5617	5235	°F
2016 DD_{65}	5296	5324	5313	5753	5683	5434	°F
Mean 2013-16 DD_{65}	5198.75	5372.75	5425.25	5855.50	5840.00	5518.50	°F

Table 5.4.2 Descriptive statistics of the price of residential electricity

Variable	Description	Mean	Std. Dev.	Min	Max
Electricity price	Yearly average retail price of electricity (1990-2018)	8.976207	1.630367	7.25	11.73
Year	Year	2004	8.514693	1990	2018

Table 5.4.3 introduces descriptive statistics of the sample data, and Table 5.4.4 presents the conditional mean multivariate regression model of electricity use (the leftmost column) and three corresponding quantile regression models on the right, representing energy load at the first, second, and third load quartiles. Nearly all the variables are statistically significant at one percent and, the main model represents about 41.4 percent of the variability of energy load around the mean. We can attribute the unexplained variability to the impacts of occupant behavior, variations in electrical appliances, and microclimatic factors, which have been extensively studied in literature (Delzendeh et al., 2017; Huebner et al., 2015; Martinaitis et al., 2015). According to the conditional mean model, holding all variables at the mean, each additional square foot of residential unit area increases energy load by ~0.048 kWh per month; units in rehabilitation developments have, on average, ~227.52 kWh per month less load than otherwise identical units in new construction developments; and units occupied by senior households have, on average, ~1,288.57 kWh per month more energy load than otherwise identical units occupied by family households.

Table 5.4.3 Descriptive statistics of energy use

Variable	Description	Mean	Std. Dev.	Min	Max	P^2
Load	Monthly load of electricity in kWh	543.7161	303.7686	4	2930	
Sqrt. load	Square root of monthly load in kWh	22.48242	6.185601	2	54.12947	
Residential area	Residential unit floor area in square foot	899.788	232.0067	595	1774	0.3452***
HERS	HERS score of residential unit	68.05397	10.62989	15	98	0.0043
Rehabilitation	Rehabilitation (1) or new construction (0)	0.5807464	0.4934585	0	1	-
Senior living	Senior living (1) or family living (0)	0.4095745	0.4917767	0	1	-0.0058
Climate id	National Weather Service climate division id	2.552407	1.684382	1	6	-
Month	Month of electricity use	6.431897	3.429335	1	12	-
Year	Year of electricity use	2014.297	0.9548647	2013	2016	0.1056***

Note: P denotes the uncontrolled Pearson Correlation Coefficient of dependent variables and electricity use.

Table 5.4.4 Multivariate regression models of electricity use

Variable	Coef.	Std. Err.	P>t	25th Perc. Coef.	50th Perc. Coef.	75th Perc. Coef.
Residential area	0.0069323	0.0003169	0.000	0.0064999***	0.0060889***	0.0065996***
Rehabilitation	-0.4769924	0.1506556	0.002	1.4119500***	-0.3180811*	-1.3594700***
Senior living	1.135154	0.1968914	0.000	2.4538260***	1.3024960***	0.3886456
HERS	0.0679031	0.0053108	0.000	0.0305185***	0.0383766***	0.0797102***
Division_2	-2.887875	0.1665886	0.000	-2.8858520***	-2.9138500***	-2.6076770***
Division_3	0.7784545	0.281223	0.006	1.8117380***	0.6446663**	0.7666906*
Division_4	-5.08997	0.234813	0.000	-3.1304970***	-4.2182950***	-4.7952220***
Division_6	-2.119919	0.2131439	0.000	-0.3015351	-1.5618940***	-2.5685620***
Year_2014	0.7895158	0.1521175	0.000	0.5397313***	0.6422507***	0.9825435***
Year_2015	0.5985464	0.1565756	0.000	0.3706764**	0.5375932***	0.7723584***
Year_2016	-0.5726827	0.2345463	0.015	-1.2468680***	-0.6365490**	-0.1586213
Month_2	-0.7780375	0.2689897	0.004	-0.8079312**	-0.7477670***	-0.9516986**
Month_3	-3.267251	0.269671	0.000	-3.3230600***	-3.3488190***	-3.4724800***
Month_4	-7.298903	0.2697913	0.000	-7.2202860***	-7.4866920***	-7.9802690***
Month_5	-8.170684	0.2597029	0.000	-8.6665310***	-8.3186270***	-8.5421940***
Month_6	-7.294836	0.2751729	0.000	-8.1423060***	-7.5449440***	-7.4053190***
Month_7	-6.260478	0.2759217	0.000	-7.1655020***	-6.2866500***	-6.3571220***
Month_8	-6.804348	0.2768418	0.000	-7.5921900***	-6.9534360***	-6.9179430***
Month_9	-7.970385	0.2775862	0.000	-8.5779890***	-8.1719000***	-8.2824710***
Month_10	-7.916289	0.2778584	0.000	-8.2107210***	-8.0144990***	-8.5655400***
Month_11	-5.411357	0.2781303	0.000	-5.5206710***	-5.3851030***	-5.7131440***
Month_12	-2.514067	0.2783284	0.000	-2.7976880***	-2.3983750***	-2.5310830***
Constant	18.3616	0.6047202	0.000	16.7306100***	20.7209300***	21.4468200***
Observations	7,480			7,480	7,480	7,480
Pseudo R^2				0.2486	0.2624	0.2607
Adjusted R^2	0.4135					
Root MSE	4.6783					

Note:
Division_1, Month_1, and Year_2013, are the default variables.
The sample does not include buildings located in Division_5.
*** p<0.01, ** p<0.05,* p<0.1

Figure 5.4.1 depicts the predicted energy load (left) and residuals (right) for each observation. Together, the regression models and the scatter plots suggest uncontrolled variables have large impacts on energy load. Obtained from the conditional mean model, Table 5.4.5 presents the predicted correlation of HERS score with monthly energy load with a 95 percent confidence interval, showing the practical significance of energy-efficiency measures in reducing the operation phase energy use and carbon emissions. Holding all the variables at the mean, each one-unit change in the HERS score changes energy load by ~4.61 kWh per month.

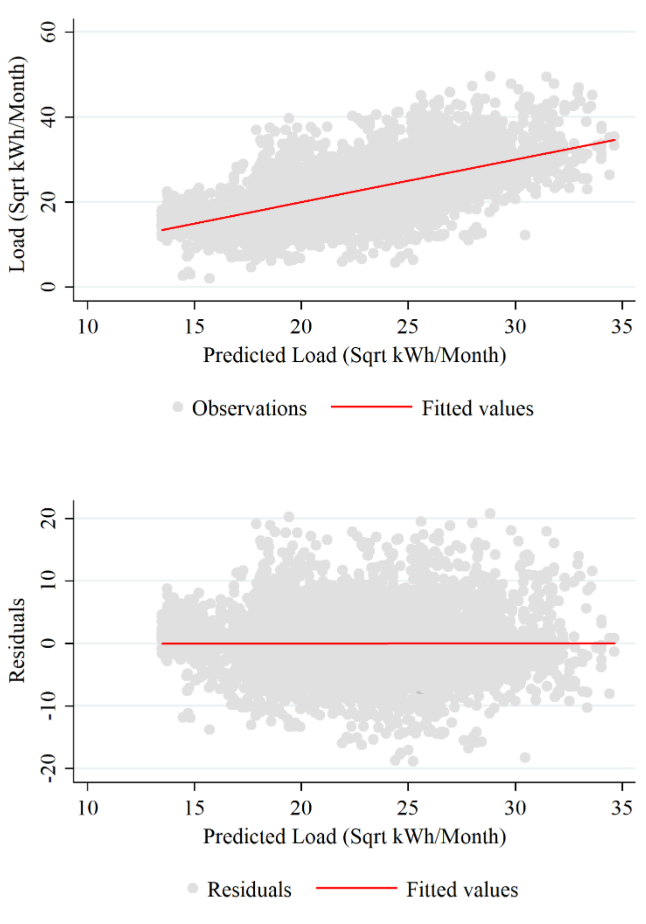


Figure 5.4.1 Post-estimated diagnostics of the multivariate regression model

Table 5.4.5 Correlation of the HERS score with the monthly load

HERS score	0	10	20	30	40	50	60	70	80	90	100
Mean load (Sqrt kWh/Month)	17.75	18.43	19.11	19.78	20.46	21.14	21.82	22.50	23.18	23.86	24.54
Std. Err. (Sqrt kWh/Month)	0.37	0.32	0.26	0.21	0.16	0.11	0.07	0.05	0.08	0.13	0.18
Mean load (kWh/Month)	314.99	339.55	365.04	391.44	418.77	447.03	476.20	506.30	537.32	569.26	602.12

Figure 5.4.2 illustrates the impacts of the HERS score, unit size, and uncontrolled variables on the annual energy load of units occupied by family households in new construction developments in the reference location, Richmond, VA. The low-, median-, and high-intensity categories refer to the predicted load values obtained from the three quantile regressions presented. Similarly, the HERS and unit size categories correspond to the first, second, and third

quartiles of the corresponding variables. Data collected from a 39-unit LIHTC building suggest that the mean load in common areas in Richmond, VA is 113.71 kWh per month per unit.

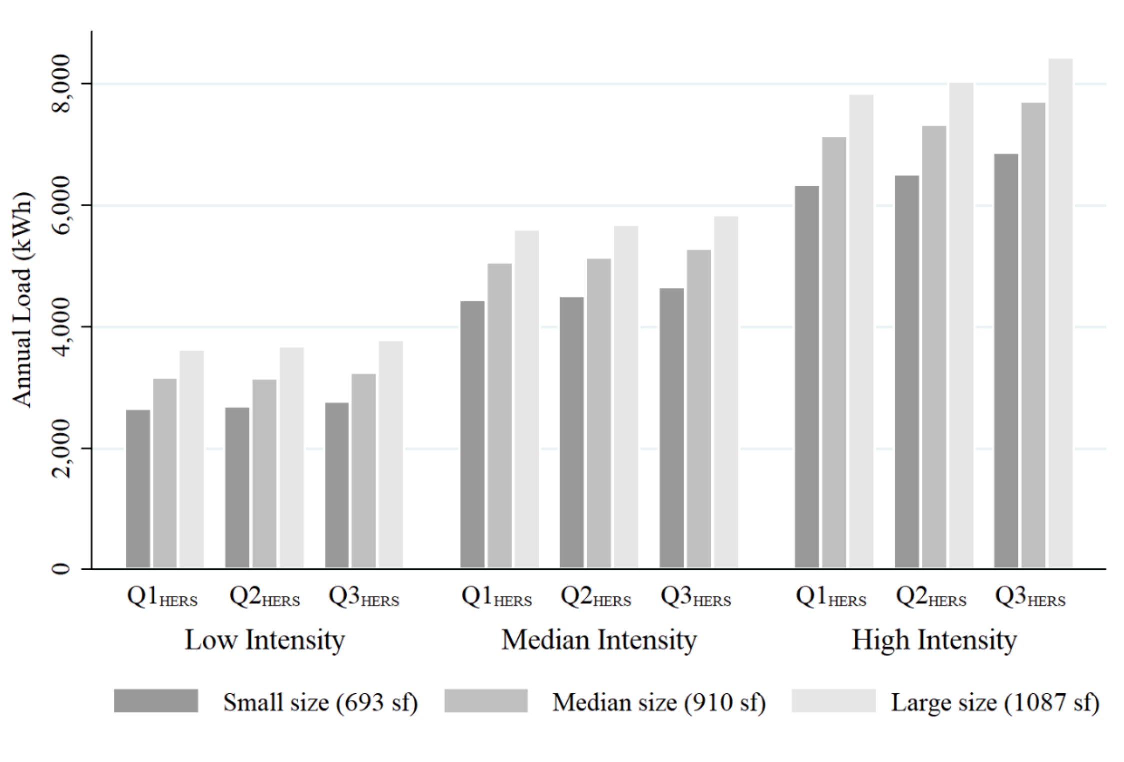


Figure 5.4.2 Load estimated based on load, unit size, and HERS score quartiles in Richmond

5.4.2. PV system simulation

Table 5.4.6 and Table 5.4.7 present the selected PV module and inverter specifications currently available in the market and the design characteristics of the PV system at the reference location. The energy generated by the system exceeds the annual energy load of a new family-occupied unit at the median unit size and the median HERS score during the first 30 years of operation. The annual balance partially restores the energy loss in the infrastructure system, but to restore all the estimated energy loss (~32.31 percent), each unit's array size must increase from 6.5kW(dc) to 7 kW(dc), which would increase each module's area from 28 m^2 to 42 m^2 . The 0.5 kW increase in capacity and the 50 percent increase in the area can increase the investment profit but may not be practical due to limited rooftop space on the 2-story building.

Figure 5.4.3 shows the monthly pattern of energy generation and load in the reference location.

Table 5.4.6 Selected photovoltaic module and inverter characteristics for all divisions

PV module	Value	Unit	Inverter	Value	Unit
Company	LG Electronics	-	Company	Fronius USA	
Model	LG250N8K-G4	-	Model	Galvo 1.5-208-240	
Material	Mono-c-Si	-	Max AC power	2500	W(ac)
Bifacial	No	-	Max DC power	2619.470215	W(dc)
Standard testing conditions	250.217	W(dc)	Day power consumption	16.735605	W(dc)
Utility-scale testing conditions	231.9	W(dc)	Night power consumption	0.75	W(ac)
Max power	250.217	W(dc)	Nominal AC voltage	240	V(ac)
Voltage at max power	25.30	V(dc)	Max DC voltage	440	V(dc)
Current at max power	9.89	A(dc)	Max DC current	7.937789	A(dc)
Length	1.30	m	Min MMPT DC voltage	100	V(dc)
Width	0.98	m	Max MMPT DC voltage	440	V(dc)

Table 5.4.7 System characteristics in Richmond, VA

Parameter	Value	Unit	Parameter	Value	Unit
Number of inverters	2		Max DC voltage	440	V(dc)
Total number of modules	22		Min MPPT voltage	100	V(dc)
Total number of strings	2		Max MPPT voltage	440	V(dc)
Total module area	28	m^2	Average annual soiling loss	5	%
DC to AC ratio	1.10		Total DC power loss	4.44	%
Desired array size	6.5	kW(dc)	AC wiring loss	1	%
Nameplate DC capacity	5.505	kW(dc)	Annual DC degradation rate	0.5	%
Total AC capacity	5.0	kW(dc)	Tilt and azimuth	20, 180	Degree
Total inverter DC capacity	5.239	kW(dc)	Ground coverage ratio	0.3	GCR

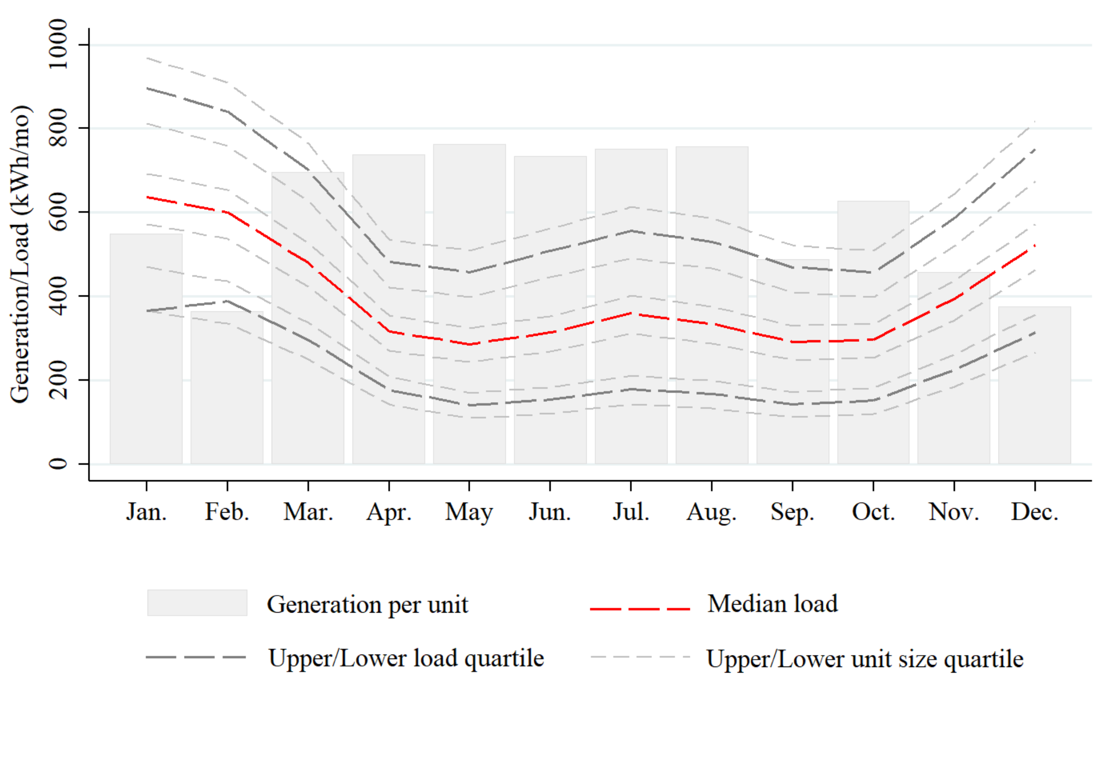


Figure 5.4.3 Energy generation per unit and load quartiles in Richmond, VA

Figure 5.4.4 depicts the result of applying the same module, inverter, and design to the same median size, median-HERS, median-load unit in the state's six climatic divisions. Divisions 1- 6 are ordered from left to right in each month and the values belong to the first year of operation. The red bars represent a negative monthly balance, e.g., generation shortage to fully offset the energy load. Table 5.4.8 presents the estimated cost of installation of the PV system in the year 2020. According to the NREL's benchmarking analysis, the national average cost of residential PV systems has decreased by 4.91%, from 2017-2018, and it can be expected that in the year 2020, the total cost per watt DC (Wdc) is approximately \$2.45. For financial analysis, we uniformly apply the total cost per watt DC of \$2.49 to all climatic divisions.

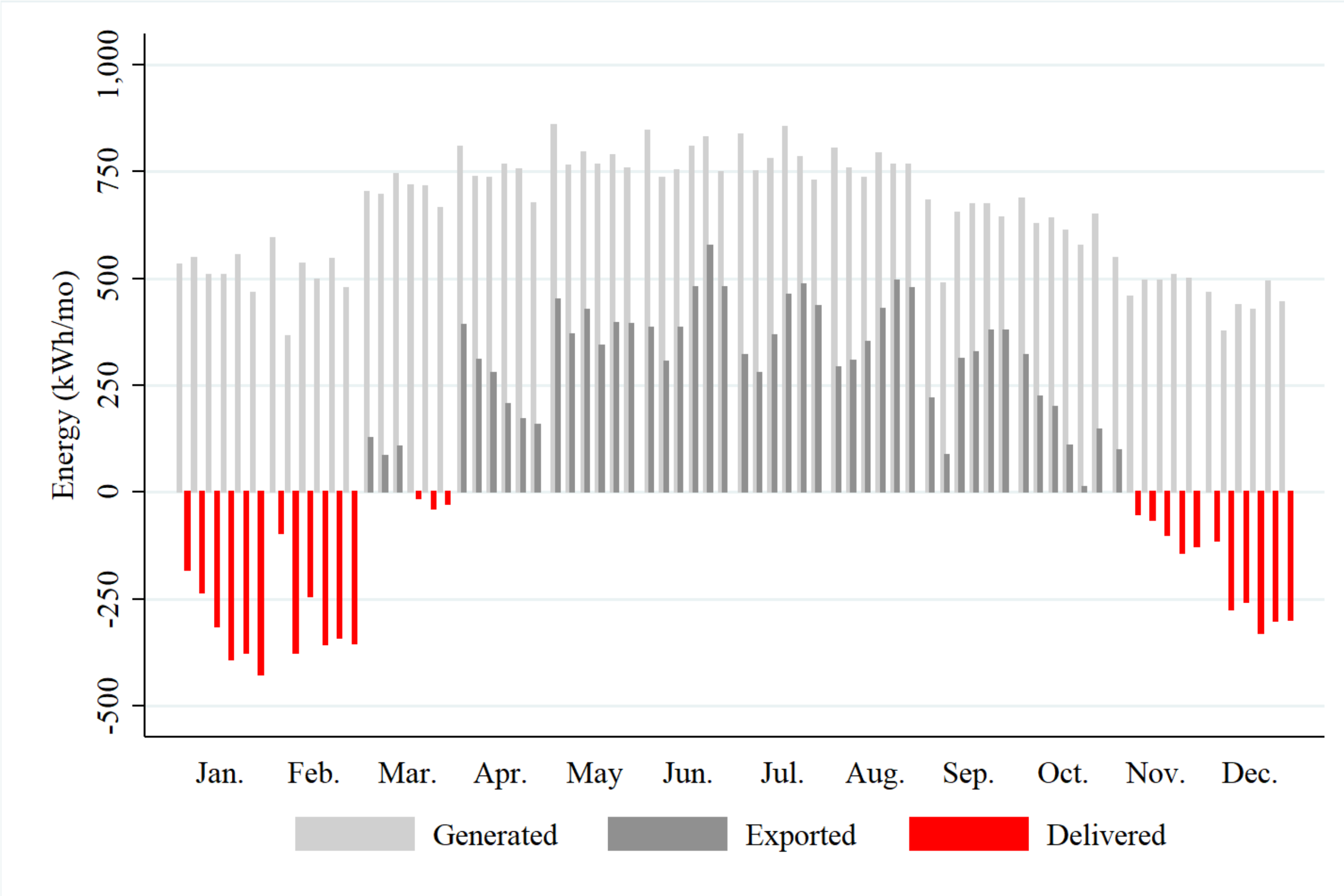


Figure 5.4.4 Generated, exported, and delivered energy of the unit in climatic divisions

Table 5.4.8 Cost of system installation for each residential unit

Item	Unit Cost ($/Wdc)	Total Cost ($)
Direct capital costs		
Module	$0.45	$2,475.00
Inverter	$0.14	$700.00
Balance of system equipment	$0.36	$1,980.00
Installation labor	$0.4	$2,200.00
Installer margin and overhead	$1	$5,500.00
Total direct cost		$12,855.00
Indirect Capital Costs		
Permitting and environmental studies		$550.00
Sales tax (0.043 in VA)		$276.38
Total indirect cost		$826.38
Total installed cost	$2.49	$13,681.38

5.4.3. *Discounted cash flow analysis*

The study case is a two-story, 60-unit LIHTC building comprising small (693 sf), medium (910 sf), and large (1087 sf) units in equal numbers. We estimate the total residential load from the sum of predicted loads for all given unit sizes multiplied by the number of units of each size – which equals 20 –in the building. Table 5.4.9 summarizes the assumptions and results of the 15-year and 30-year deterministic DCF analyses for Richmond, VA, including values from the stabilization year (2021) and the last year of cash flow periods. The year 2020 federal solar tax credit, which allows the owners to deduct 26 percent of the cost of installing a solar energy system from federal income taxes of that same year, is included in both analyses. State, local, or LIHTC-related incentives are not considered. To simplify the calculations, we first obtain the NPV of investment for the 3 individual unit sizes (called sample in the table) and then multiply it by 20.

Table 5.4.9 Deterministic DCF analysis for Richmond, VA

Items / Assumptions		15-Year Cash Flow		30-Year Cash Flow	
Items					
Load (kWh/yr)	Year 2021	DPV	Year 2035	DPV	Year 2050
Small unit load (693 sf)	5,212.16		5,212.16		5,212.16
Median unit load (910 sf)	6,071.16		6,071.16		6,071.16
Large unit load (1087 sf)	6,771.83		6,771.83		6,771.83
Total load	18,055.15		18,055.15		18,055.15
Total cost of energy without PV[1]	($2,163.36)	($21,377.95)	($2,610.28)	($30,706.96)	($3,089.12)
PV system energy generation (kWh/yr)					
Generation per unit	7,303		6,802.24		6,303
Total generation	21,908.73		20,406.72		18,908.43
Total export	5,911.21		4,409.20		853.28
Total value of exported energy[2]	$461.73	$3,791.27	$339.97	$4,642.35	$145.99
PV system cost of financing and operating					
Debt balance per unit	$10,040.80		$0.00		$0.00
Interest payment per unit	($688.80)	($3,418.53)	($49.04)	($5,080.33)	($31.58)
Principal payment per unit	($207.35)	($6,239.27)	($980.82)	($3,366.48)	($631.57)
Maintenance cost per unit	($110.00)	($1,161.28)	($155.43)	($1,770.87)	($225.10)
Insurance cost per unit	($69.00)	($728.44)	($97.50)	($1,110.82)	($141.20)
Total cost of financing and operating	($3,225.45)	($34,642.56)	($3,848.35)	($33,985.52)	($3,088.37)
Net present cost of PV system for sample (3 units)[3]		($30,851.28)		($29,343.20)	
NPV of investment for sample (3 units)[4]		($9,473.34)		$1,363.76	
NPV of investment for project (60 units)[5]		($189,466.80)		$27,275.20	
30-Year ROI				% 4.65	
Assumptions					
Inflation rate: 2.5%					
Discount rate: 7.00%					
Loan interest rate: 5.00%					
Federal incentive rate: 26.00%					
Price of electricity in 2021: $11.98/kWh					
Value of export = Retail price of electricity					
Common areas are excluded					

Notes:
(1) Total load multiplied by predicted price of energy
(2) Total export multiplied by predicted price of energy
(3) Total cost of financing and operating minus total value of exported energy
(4) Equals (3)-(1)
(5) Equals (4) multiplied by 20

The analysis suggests that with a long-term financing mechanism available, the net present cost of the zero-energy LIHTC units in Richmond, VA is lower than that of otherwise identical units that have no renewable energy generation systems. Table 5.4.10 presents the results of the 30-year Monte Carlo cash-flow analysis of the six climatic divisions based on the same assumptions presented in Table 5.4.9 with the randomized, location-specific energy price, load, and generation. Except for Norton, where the combination of low solar radiation, low ambient temperature, and low energy prices reduces the value of the investment, the NPV of investment in other cities is positive at zero or low risk of loss. Table 5.4.11 describes the sensitivity of the simulated NPVs to installation cost, assuming equal prices for the exported and delivered energy in all climatic divisions. The results suggest that achieving zero-energy LIHTC units, even with a 15 percent incentive, is feasible with low risk margins in many locations across the state. The presented sensitivity analysis can help the reader estimate impacts of further incentives from the state, locality, and the LIHTC program or potential reductions in technology costs in the next few years. At the 1.87 $/Wdc installation rate, i.e., 25 percent incentive, additional scenarios are examined to show the impacts of decreasing or increasing the future price of energy by 10 percent by the year 2050, corresponding to the US DOE scenarios. The magnitude of effects of discount rates ranging from 6-8 percent on the financial outcomes presented in this sensitivity analysis seem negligible. The NPV obtained from subtracting the net present cost of the implementation of the rooftop residential PV systems from the discounted present cost of energy of the same units without PV systems is statistically significant.

Table 5.4.10 Monte Carlo financial analysis for all climatic divisions in Virginia

Item	Norfolk	Richmond	Lynchburg	Fairfax	Staunton	Norton
Residential electricity rate 2020 (Cent/kWh)	11.81	11.81	10.71	11.81	11.81	10.13
Commercial electricity rate 2020 (Cent/kWh)	7.80	7.80	8.56	7.80	7.80	8.63
NPV of investment						
Mean	$130,672	$27,339	$6,259	$87,249	$94,365	($55,057)
Standard deviation	$26,405	$23,644	$22,379	$25,408	$25,690	$20,651
Min	$37,986	($55,612)	($87,724)	($26,934)	$6,739	($130,664)
Max	$319,740	$469,866	$96,945	$370,786	$307,244	$101,252
Risk of loss	0.00%	12.01%	38.68%	0.04%	0.00%	99.58%
30Y ROI	22.27%	4.66%	1.07%	14.87%	16.08%	-

Table 5.4.11 Sensitivity of NPVs to installation cost assuming equal export and delivery prices

Cost ($/Wdc)		Norfolk	Richmond	Lynchburg	Fairfax	Staunton	Norton
2.12 ($/Wdc)	Mean NPV	$62,725	($40,799)	($61,371)	$19,668	$26,412	($122,984)
(2.49+15% incentive)	S.D.	$26,577	$23,209	$22,774	$25,113	$25,290	$20,444
	Risk of loss	1%	96%	100%	21%	15%	100%
	ROI	10.69%	-	-	3.35%	4.5%	-
1.99 ($/Wdc)	Mean NPV	$93,776	($9,226)	($30,740)	$50,386	$57,362	($92,188)
(2.49+20% incentive)	S.D.	$26,747	$23,508	$22,683	$25,343	$25,635	$20,707
	Risk of loss	0%	66%	91%	2%	1%	100%
	ROI	15.98%	-	-	8.59%	9.77%	-
1.87 ($/Wdc)	Mean NPV	$124,017	$21,188	($247)	$81,452	$88,097	($61,219)
(2.49+25% incentive)	S.D.	$26,442	$23,066	$22,445	$25,675	$25,470	$20,379
	Risk of loss	0%	18%	51%	0%	0%	100%
	ROI	21.13%	3.61%	-	13.88%	15.01%	-
1.87 ($/Wdc)	Mean NPV	$93,640	($5,341)	($25,607)	$52,572	$59,503	($84,566)
(2.49+25% incentive)	S.D.	$25,720	$22,951	$21,845	$24,465	$24,538	$19,913
(-10% energy price by 2050)	Risk of loss	0%	60%	88%	2%	1%	100%
	ROI	15.96%	-	-	8.96%	10.14%	-
1.87 ($/Wdc)	Mean NPV	$155,201	$47,524	$25,934	$109,623	$116,877	($37,723)
(2.49+25% incentive)	S.D.	$27,915	$24,127	$24,443	$25,972	$26,570	$21,289
(+10% energy price by 2050)	Risk of loss	0%	2%	13.68%	0%	0%	96%
	ROI	26.45%	8.10%	4.42%	18.68%	19.92%	-
1.74 ($/Wdc)	Mean NPV	$155,324	$51,938	$31,159	$112,048	$90,813	($30,365)
(2.49+30% incentive)	S.D.	$26,724	$23,208	$22,583	$25,522	$26,935	$20,694
	Risk of loss	0%	1%	8%	0%	0%	93%
	ROI	26.47%	8.85%	5.31%	19.09%	15.47%	-
1.62 ($/Wdc)	Mean NPV	$186,291	$82,995	$61,682	$142,680	$149,734	$497
(2.49+35% incentive)	S.D.	$27,014	$23,165	$22,571	$25,264	$25,488	$20,485
	Risk of loss	0%	0%	0%	0%	0%	50%
	ROI	31.74%	14.14%	10.51%	24.31%	25.51%	0.08%
1.49 ($/Wdc)	Mean NPV	$216,827	$113,598	$92,457	$173,709	$180,426	$31,109
(2.49+40% incentive)	S.D.	$26,613	$23,438	$22,347	$25,239	$25,499	$20,566
	Risk of loss	0%	0%	0%	0%	0%	6.31%
	ROI	36.95%	19.36%	15.75%	29.60%	30.74%	5.30%
1.37 ($/Wdc)	Mean NPV	$247,893	$144,586	$123,280	$204,108	$211,022	$62,421
(2.49+45% incentive)	S.D.	$26,756	$23,318	$22,590	$25,804	$25,459	$21,032
	Risk of loss	0%	0%	0%	0%	0%	0%
	ROI	42.24%	24.64%	21.01%	34.78%	35.96%	10.64%

5.5. Discussion

5.5.1. Key results and comparison with previous research

Based on the 30-year discounted cash-flow analysis, the net present cost of the implementation of rooftop residential solar systems to achieve zero-energy units in Virginia can be lower than the discounted present cost of energy of otherwise identical units that have no renewable energy generation systems, and the value of cost savings can be statistically significant. The investment value often depends on the zero-energy building definition, weather characteristics, retail price of electricity, and incentive rate. The DOE's definition of zero-energy buildings implies that these buildings should progress the restoration of the 32.31 percent loss (based on data from the 2010s) to the infrastructure system. The problem with this requirement in Virginia, where the solar potential is lower than that of states located in the South East, South West, and West regions, is not financial viability but the need for extra installation space. The analysis presented here relaxes this specification to minimize the required module area.

According to the SAM analysis, each PV module should increase by 50% in size to fully restore the source energy loss, which is an increase from 1,680 m^2 (~18,083 sf) to 2,520 m^2 (~27,125.1 sf) in the total installation area, whereas the total usable rooftop area of the building is approximately 2500 m^2 (~26,900 sf) in the best-case scenario. Offsetting the total load of common areas, if included in the analysis, would require an additional 350 m^2 (~3,767 sf) rooftop space. In areas where the combination of high solar potential and high price of energy exists, an increase in the array size can increase the investment's net present value. Therefore, it is feasible to fully offset the annual load of the entire building but achieving the DOE definition requires project designers to consider the spatial needs of solar systems at the conceptual design stage. Low-rise developments are the dominant building configuration (~68 percent) among the funded LIHTC projects in Virginia from 2011-2018, followed by mid-rise (~30 percent) and high-rise (~1 percent) buildings.

Although zero-energy affordable housing seems cost-effective in the long run, the costs associated with PV systems are not evenly distributed in the state, thus, leaving some areas like the Southeast more potent in adopting distributed generation systems than others like the Southwest. Differences in solar radiation, ambient temperature, energy prices, and diminishing prospects of the federal solar tax credit can affect consumers' willingness to invest in PV systems. Analyzing these variations and the significance of carbon emissions avoided because of renewable energy generation is a key to support the construction industry in bridging the gap to zero-energy buildings, particularly in affordable housing.

Achieving an annual balance of primary energy is a required step toward performance improvement, but zero-energy design and upgrade considerations can include an optimized combination of power storage systems, mechanical and electrical operation control systems, and additional energy-efficiency measures that help buildings achieve balance in all individual months, reduce stress on existing power infrastructure, reduce greenhouse gas emissions, and increase the building's economic value (Penna et al., 2015; Popescu et al., 2012). The HERS score analysis presented here suggests that further reductions in the embodied energy are achievable by applying energy-efficient construction methods, systems, and components. Virginia's solar potential is not as abundant as that of other US states located at lower latitudes, thus, achieving a cost-effective balance that compensates for losses in primary to final energy conversion may not be widely implemented soon using distributed generation, but the potential to reduce energy demand by improving design and construction standards exists.

5.5.2. Zero-energy LIHTC opportunities and barriers

Until recently, variability in net-metering agreements across utilities created barriers to the adoption of zero-energy housing. For example, a developer would have to analyze energy consumption rates ($/kWh) and a different rate for producing and selling excess electricity to the local utilities. Utilities would charge $0.11/kWh for consumption, and only pay $0.05/kWh for excess generation. The difference between consumption and generation rates would disincentivize solar PV adoption in housing and create confusion. Following a 2015 change to Virginia law (Virginia Code §56-594) investor-owned utilities like Dominion and Appalachian Power and cooperatives compensate customers at a one-to-one retail rate with a system size limit of 1,000 kW. State codes (Virginia Code § 58.1-3661) now allow localities to offer property tax exemption on solar energy equipment for a certain number of years. State, municipalities, utility companies, or other organizations willing to promote solar energy have offered limited-time rebates that can help significantly reduce installation costs. Other than direct federal, state, and local incentives, potential mechanisms to increase low-income citizens' access to renewable energy include loan loss reserve, on-bill financing or recovery, and revised underwriting criteria (NREL, 2020).

In 2019, the General Assembly of Virginia approved the Low-to-Moderate Income Solar Loan and Rebate Fund to provide a solar financing platform for solar installations or energy efficiency improvements specific to residents with a household income at or below 80 percent of the state or regional median income. Other recent legislative developments in the state include House bill HB 572 Distributed renewable energy sales of electricity under third-party agreements and Senate bill SB 629 Shared solar programs, which promote the establishment of distributed renewable energy and allow customers to purchase electric power through a subscription in a shared solar facility. The Low-Income Energy Affordability Data (LEAD) Tool (www.energy.gov/eere/slsc/maps/leadtool) and the Database of State Incentives for Renewables & Efficiency (DSIRE) (www.dsireusa.org) provide data and information on some existing low- and moderate-income renewable energy policies (Ma et al., 2019).

Despite significant decreases in total installation costs and increases in emerging opportunities for residential systems, barriers to zero-energy affordable housing persist. Existing multifamily buildings have limited operating reserves, lack proper orientation or rooftop space to maximize energy generation, and need roof repair and replacement, thus, making it difficult for owners and operators to allocate sufficient funding for direct financing and installation of solar systems outside the already established 15-year operation and maintenance cash-flow schedules. Energy storage systems could increase the potential value of residential systems at the building level, e.g., through allowing for back-up power in the event of a grid outage and reducing residential demand charges through load shifting, and at the grid level, e.g., allowing for voltage and frequency regulation, deferred infrastructure investment, and resource adequacy (Ardani et al., 2016). Nonetheless, PV-plus-storage systems are still expensive to purchase; the permitting process for installing and operating storage devices is complicated, and the interconnection and net metering is complex and costly. Finally, the lack of longitudinal performance data and regulatory nature of state QAPs creates uncertainty for developers and limits the willingness to test innovative technologies and approaches.

5.5.3. Recommendations

Beyond variability in consumption and generation rates, the metering infrastructure, e.g., sub or master-metered configurations, impacts the value of investments in zero-energy affordable housing. In submetered developments, each unit's utility usage is measured individually, and tenants pay through accounts they establish with utility companies (Figure 5.5.1). In master-metered developments (Figure 5.5.1), the owner pays for all the utility costs and passes the costs on to individual tenants within their rent costs. Within each LIHTC application, the developer identifies if the utilities will be master or submetered. There is little incentive to invest in energy efficiency and renewable energy systems in master-metered developments since the developers cannot distribute additional costs on tenant rents due to the competitive nature of many rental assistance or housing production programs.

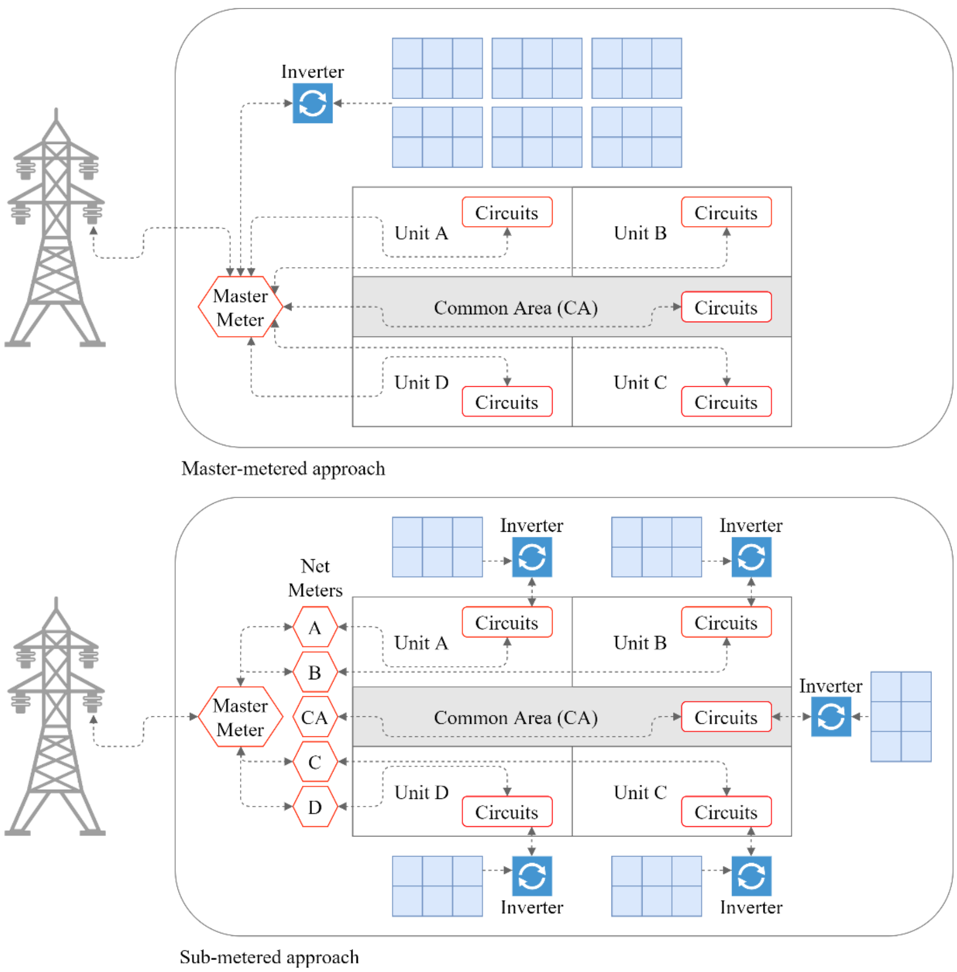


Figure 5.5.1 Common LIHTC metering approaches

Submetering may to some extent address the so-called "split-incentive" problem in energy efficiency transactions, at least, by allowing individual residents to control the use of energy. In many cases, developers can sub-meter common areas at commercial rates, which helps reduce costs of operation and maintenance but decreases the value of investments in renewable energy systems for common areas. Therefore, variations in metering infrastructure and rates and the effects should be considered in the financial analysis of individual zero-energy buildings. In practice, housing programs have started to increase incentives where developers can demonstrate that tenants can benefit from energy efficiency or renewable energy generation systems.

We suggest that state housing finance agencies evaluate new methods for metering developments. For example, in addition to a single utility provided master meter, zero-energy developments can employ circuit-level owner metering to better manage development performance (Figure 5.5.2). The approach provides real-time, high-resolution data on unit-level and circuit-level energy consumption, as well as solar system performance. Extant research suggests occupants are generally poor at managing systems with lags in information and delayed evaluation loops (Sterman, 1989). Current utility-provided metering technologies fail to provide customers with usable or timely data in managing system performance, improving occupant experiences, or meeting zero-energy goals. With this approach, developers install metering hardware in each unit's circuit panel and measure energy use in one-second intervals. The accompanying software allows easy analysis of performance at circuit, unit, and development levels and could be leveraged for predictive analytics, e.g., identifying HVAC system maintenance issues before they occur. Circuit-level meters are commercially available starting at ~$300 per system and have been employed in pilot zero-energy developments (Agee et al., 2018).

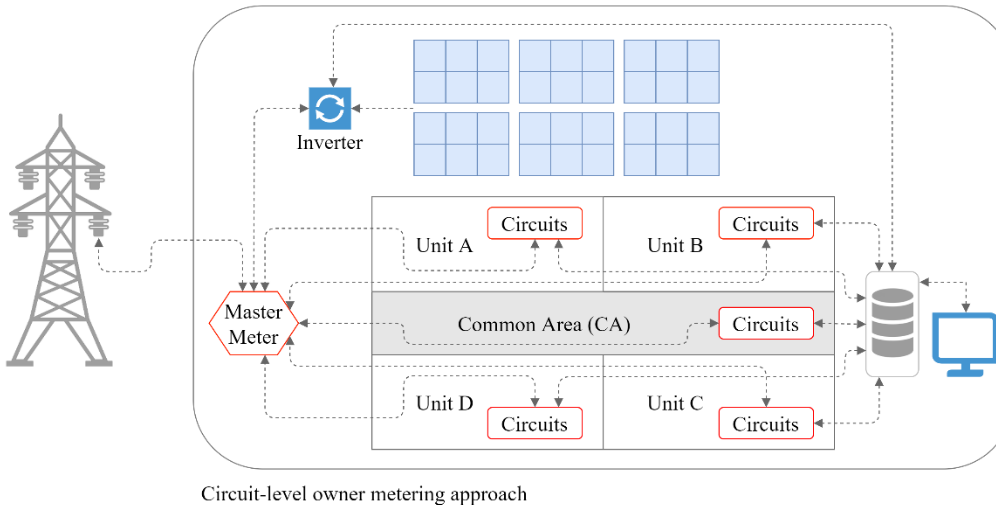


Figure 5.5.2 Circuit-level owner metering

We recommend analyzing the net present values of incentivizing distributed generation using PV systems for specific stakeholders, such as private sector interests, the economy, and the government budget. Incentivizing PV systems should include an analysis of state-wide variations in solar radiation as QAP selection criteria and allocate additional scores for developments located in climatic divisions with below-average solar potential. Since the existing federal solar tax credit is expected to gradually decrease in the coming years, it is essential for housing agencies to identify financing mechanisms that help fill the gap to maintain the feasibility of zero-energy developments in the 2020s.

As evidenced by past research and this analysis, a significant part of the variability in energy consumption is attributable to human-building interaction. Since the extra spending on utilities impacts housing affordability and the economic well-being of low-income residents, empowering final users to have an active role in reducing energy consumption, particularly for heating and cooling purposes, is becoming increasingly important (EU, 2019). Such activities can be included in the state's free energy efficiency and appliance testing and repair services that help create energy savings by reducing energy bills for qualified low-income, elderly, and disabled residents in rental and owner-occupied houses (ACEEE, 2020). To further reduce energy demand, architects and engineers can design zero-energy projects to maximize energy-efficiency and include monitoring and control technologies that reduce user-imposed inefficiencies and contribute to the cost-effective operation of new or existing buildings (Kolokotsa et al., 2011; Lu et al., 2015).

5.6. Conclusion

This study investigated the feasibility of zero-energy affordable housing by analyzing historical data on climate, energy use, and energy system costs in Virginia. Addressing the knowledge gap in the literature on renewable energy system adoption in affordable housing, the study contributes to the body of knowledge through the examination of generalizable statistical energy load prediction methods and simulation-based risk analysis, which have essential applications in planning and policy analysis but have received little attention in existing feasibility studies. The results suggest that, in most areas in Virginia, the net present lifecycle cost of the implementation of rooftop residential solar systems to achieve zero-energy affordable housing is currently lower than the discounted present cost of energy of otherwise identical buildings that have no renewable energy generation systems, and the estimated savings are statistically significant. The annual electricity generated using the PV system in the 60-unit study case is ~146,060 kWh/yr. The greenhouse gas emissions avoided by the PV system per year equal ~103 metric tons of carbon dioxide. This avoided carbon dioxide in 30 years amounts to nearly 348,600 gallons burnt of gasoline or 7,687,620 miles driven by an average passenger vehicle, suggesting the presence of great potentials for emission reductions and contributions to economic, environmental, and equitable developments in Virginia through promoting zero-energy affordable housing in the 2020s (EPA, 2015).

This study suggests that many other southern U.S. states can accrue benefits from zero-energy affordable housing developments. Based on the presented analysis, conventional LIHTC units built in the 2010s, which are more energy-efficient than those included in the study sample, can be converted to zero-energy with potentially higher investment rates of return than those estimated here. Since buildings represent nearly 40 percent of global energy use and 30 percent of global greenhouse gas emissions, investments in distributed renewable energy generation in buildings can help promote sustainable development and mitigate climate change.

CHAPTER SIX: GREEN HOUSING OR GREEN GENTRIFICATION?

Chapter Summary

Research on green building has primarily focused on energy efficiency, smart growth, resource conservation, and health protection benefits of green building standards. Adoption of a reductionist sustainability planning language can turn green-certified houses into luxury goods that surrender equity to profitability by attracting higher-income, highly educated, pro-environmental households who, in turn, displace existing long-term, lower-income residents in core urban areas. The remaining question is to what extent the construction of green-certified houses affect neighborhood change and gentrification? We use Central Virginia Multiple Listing Service (MLS) transactions' pooled cross-sectional data (2005-2019) and the U.S. Decennial Census (2000) and American Community Survey data (2019) and present the differential effect of the new construction of market-rate, green-certified houses in a natural experiment by difference-in-differences estimates. We find that the new construction of green-certified houses causes statistically significant increases in population, new construction, and house values. Effects on neighborhood class composition exist but do not reach statistical significance in the study period. As post-industrial cities are turning to sustainability as a framework to guide redevelopment, equity-minded planners and policymakers should assess decision-making paradoxes involved by addressing economic and environmental imbalances that expedite gentrification.

6.1. Introduction

The world is observing unprecedented, devastating, yet growing effects of climate change. Covid-19 has slowed the economy; energy prices are rising; unemployment remains high; consumer debt and budget deficit are climbing, and the wealth inequality has reached an all-time high. Still, 89% of the energy consumed in the United States comes from non-renewable sources and the U.S. is among the top OECD countries with the highest median rent burden (EIA, 2020; OECD, 2020).

The development and recognition of green building rating systems in the early 2000s represented the real estate market's response to the need for environmental sustainability and climate change mitigation. Green buildings are planned, designed, constructed, operated, and recycled to increase environmental, health, and productivity performance over that of conventional buildings, and green building rating systems reward relative levels of compliance or performance with certain environmental goals (USGBC, 2020). Most studies on green buildings have focused on promoting co-benefits of green buildings and numerous cities across the globe have incentivized the construction of green buildings, viewing positive effects of green-certified houses on property values and tax revenues as an economic benefit and a key to justifying the high cost of green urban redevelopment initiatives (Zuo & Zhao, 2014).

Recently, social justice researchers have raised concerns over green gentrification, which involves the class-based resettlement of inner cities, a reinvestment in the housing stock, and the displacement of existing residents. The economic and environmental aspects of redevelopment initiatives have, in many cases, surpassed or obscured the equity aspects, and efforts towards environmental protection, consciously or not, have resulted in the creation of luxury goods that subordinate equity to profit-minded urban developments that displace existing households or increase their cost of living. Literature has documented the presence of contradictory linkages between economic, environmental, and equity goals of development policy and planning in large-scale, smart-growth, mixed-use, and transit-oriented redevelopment initiatives but limited studies have made progress on the links between gentrification and the new construction of green-certified houses to help craft more efficient and equitable housing policies.

This study contributes to the growing body of scholarship on urban sustainability governance by quantifying price premiums, price spillovers, and neighborhood changes connected with the new construction of private-market-led, green-certified single-family houses. We explore whether the construction of these houses can trigger a process of neighborhood change by increasing the value of nearby properties and displacing existing long-term residents. We examine four interrelated hypotheses: 1) Green-certified houses have transaction price premiums; 2) Green-certified houses cause positive spillover effects; 3) Green-certified houses cause neighborhood change and gentrification; 4) Willingness to pay for green-certified houses has decreased over time. We use Central Virginia Multiple Listing Service (MLS) transactions' pooled cross-sectional data (2005-2019) and the U.S. Census Bureau's Decennial Census (2000) and American Community Survey data (2019) and present the differential effect of the new construction of market-rate, green-certified houses in a natural experiment by difference-in-differences estimates. The paper opens with a concise review of recent scholarship on environmental gentrification. We then describe the study hypotheses, context, data, and econometric models. In closing, we summarize and discuss the major findings and suggest policy implications and future research avenues.

6.2. Literature Review

6.2.1. Environmental gentrification

In the 1920-1930s, studies of neighborhood change had a focus on inner-city neighborhoods' decline and disinvestment and relocation of higher-income residents (Hoyt, 1939). Since Ruth Glass first applied the term 'gentrification' in describing the displacement of London's working class in the 1960s, a massive body of scholarship on neighborhood change has evolved and investigated the class remake of the central city landscape (Davidson & Lees, 2005; Glass, 1964). As a form of neighborhood change, gentrification is the middle or upper-class colonization of urban property in poor or working-class neighborhoods, which can involve significant displacement of long-time, low-income residents after higher-income households purchase residential properties in the neighborhoods to inhabit, rebuild, upgrade, or rent out the properties at a higher rent (Landis, 2016). Due to having both costs and benefits, neighborhood change has been a complex, controversial, and hotly-debated planning topic (Mujahid et al., 2019).

The environmental gentrification field of research is the advanced capitalism era's iteration of old discourses about equitable urban development and the point of convergence of urban redevelopment, ecologically-minded initiatives, and environmental justice activism (Checker, 2011). The terms ecological, environmental, or green gentrification frequently apply to the process in which pro-environment policies, programs, or practices aimed at responding to the demand for livable urban environments and/or reduced suburbanization exclude, displace, and discriminate against existing, low-socioeconomic status residents (Rice et al., 2020). Ethnographic studies in the 2000s and a growing number of recent quantitative studies describe investments in large-scale environmental initiatives (e.g., green spaces, smart growth, mixed-use densification, and transit-oriented development) in brownfields and core urban areas, where the difference between the actual and potential ground rent is high, have replaced low-rent houses occupied by low-socioeconomic status residents with high-end real estate for higher-income, often white in-migrants (Anderson et al., 2012; Dong, 2017; Gould & Lewis, 2016; Loughran, 2014).

Sustainability thinking has long encouraged integrated, interdisciplinary approaches and policies that holistically address multiple contemporary problems and achieve a balanced integration of economic, environmental, and equity goals in traditionally siloed policy sectors, such as housing (Bowen et al., 2017; Briassoulis, 2017b; Tosun & Leininger, 2017). Substantive policy goals in broad and diverse sectors like energy, environment, and climate change, cannot be realized until incorporated into other sectors, such as housing, transport, and agriculture (Cejudo & Michel, 2017; Persson & Runhaar, 2018; Schmidt & Fleig, 2018), researchers have developed a wide array of approaches, strategies, and instruments that facilitate the integration of policy goals into development planning and address inherent conflicts involved in reaching sustainable development (Di Gregorio et al., 2017; Runhaar, 2016). Conflicts arise when achieving the goals of one pillar of sustainability, i.e., economy, environment, and society, is incompatible with achieving the goals of another pillar (Figure 6.2.1). Researchers have attributed environmental gentrification to the environment-equity conflict of sustainability, which is the economic conundrum of providing sustainable conditions for the natural environment and, simultaneously, a subsistence existence for low-socioeconomic status populations (Campbell, 1996).

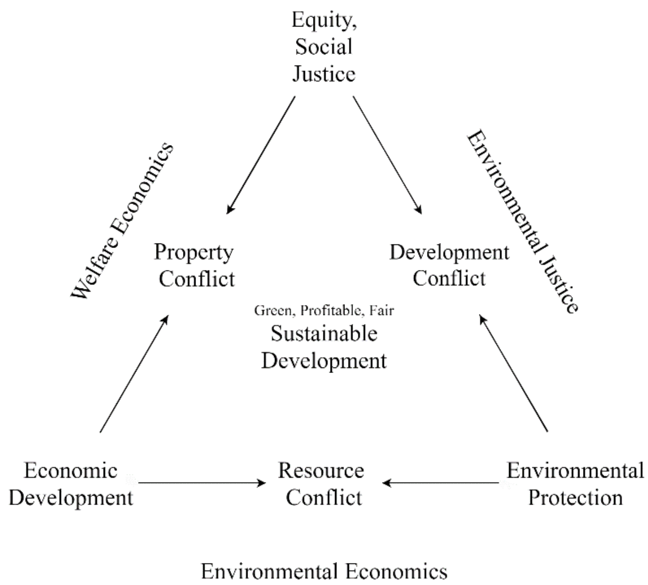


Figure 6.2.1 Conflicting planning goals triangle (Campbell, 1996)

Through the lens of distributive/distributional, procedural/participatory, or interactional/recognition justice, the environmental justice scholarship has highlighted disparities in environmental amenities (e.g., clean air and water, landscape, green transport infrastructure, public parks, beaches) that increasingly divide today's cities, informing activists to improve neighborhood conditions for low-socioeconomic-status groups by removing environmental burdens like air and water pollution, toxic and hazardous facilities, vehicle traffic, landfill sites, flood risk (Banzhaf et al., 2019; Kronenberg et al., 2020). Nonetheless, post-industrial cities' selective adoption of environmental sustainability as a redevelopment framework and corresponding efforts to improve existing neighborhoods have, in many cases, displaced existing long-term residents by attracting an inflow of affluent residents. This trend has captured the attention of a growing number of environmental justice researchers to study inequities involved when existing environmental burdens in cities are reinvested and transformed into environmental amenities (Anguelovski et al., 2019).

The net change in benefit for the city of selective adoption of environmental sustainability can be zero, or even negative. There is evidence that population migration due to gentrification is a cause of crime (Kirk & Laub, 2010). When a neighborhood is subject to gentrification, the cost-burdened, relocated, or displaced residents incur economic costs (e.g., job loss, falling wages, moving costs, housing costs, and transportation costs), social costs (e.g., crime increases, loss of community support, disruptions in the network of acquaintances), and health and well-being costs (e.g., damages to physical and mental health, disruptions in kids schooling), thus, requiring support from the host neighborhood and creating large negative externalities leading to welfare loss in the city. Figure 6.2.2 illustrates welfare gain from incentivizing actions to protect existing residents. In the free-market economy, residents underestimate the true social value of community protection actions. Introducing an incentive would increase the number of available resources for action (Q1) toward a socially optimal level (Q2), where the marginal cost of action to the community (MPC/MSC) is equal to the marginal social benefit of action (MSB). The upward shift in the marginal private benefit (MPB) curve creates the triangular grey area, representing the quantity of positive externality known as welfare gain from an action (Sheppard, 2012).

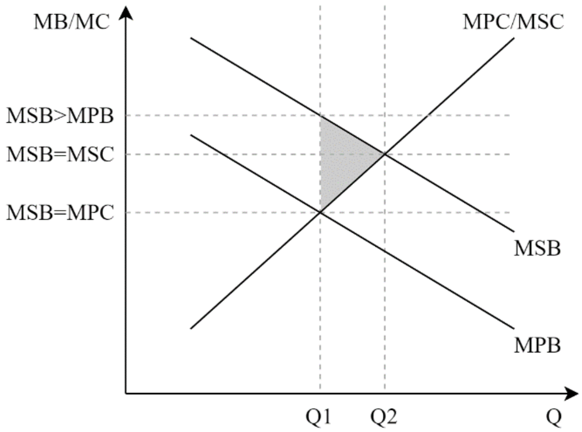


Figure 6.2.2 Incentivizing actions against displacement leads to welfare gain

With substantial reductions to spending on public projects, private funders have become key players in environmental gentrification. Researchers contend that green gentrification is not always an unintended consequence of regulatory processes and procedures, rather, city governments, private funders, real estate developers, political, economic, and cultural elites work together in green business–government coalitions that exploit underserved neighborhoods with low property values to deliberately establish "neighborhood revitalization projects" that attract higher-income, college-educated, environmentally-minded professionals (Rigolon & Németh, 2018). This collaboration in neoliberal urbanism satisfies the needs of public agencies and private developers through increased property tax revenues and substantial price premiums at the cost of social equity. The influx of high-income residents after a greening initiative can disintegrate environmental and affordable housing goals, remove connections between public and non-for-profit actors, and increase housing costs by changing the class composition of the neighborhood.

6.2.2. *Green-building-induced gentrification*

Fueled with an ever-increasing interest in pro-environment real estate, numerous green building rating systems have emerged in the 2000s, which reward relative levels of compliance with certain construction requirements. An analysis of LEED and Energy Star-certified properties over the first decade of implementation in the US suggests improvements in the rate of adoption, the share of private developers, the share of buildings certified at higher certification levels, and certification standards (Fuerst, 2009a). Some rating systems like Energy Star for Homes have a single focus area; some like LEED cover multiple components (e.g., energy efficiency, smart growth, resource conservation, and health protection); advanced rating systems like the Living Building Challenge require expensive, cutting edge, innovative practices far beyond standard building codes. The economic, environmental, political, societal, and technological composition of cities to varying extents explains the growth in the proportion of green-certified properties in cities (Fuerst et al., 2014b; Rakha et al., 2018).

Since green-certified houses incur an extra upfront cost of compliance with green building certification requirements, builders may charge over 10% price premium for conventional green building certifications (U.S. Census Bureau, 2020; Walls et al., 2017). A 10% premium is an equivalent of $32,580 increase in the median new house transaction price in the first half of the year 2020 in the US, where the federal minimum wage for blue-collar jobs is only $7.25 per hour. Thus, real estate investors' confidence in the ability to recover upfront costs through sales or rent premiums significantly increases by favorable market conditions (e.g., high property values, high energy prices, low vacancy rates, and low days on market), supportive political regulations and incentives, and the presence of higher income, well-educated professionals whose environmental desires align with green building components (Dippold et al., 2014).

Researchers have criticized private-sector-led urban intensification projects that involve the construction of green-certified houses for a lack of engagement with social justice or ecological principles. The production of green-certified houses in low-income neighborhoods where the difference between the actual and potential ground rent is high helps developers recoup cost premiums by attracting higher-income households who prefer to live in a compact, mixed-use neighborhood and drive less. Incoming households may observe savings from energy efficiency, but the level of consumption of incoming high-income residents, the rebound effect, and the high embodied energy of green-certified houses lead to significantly higher carbon emissions (Copiello, 2017). In fact, low-income households with limited access to modern energy and technology often cause very low carbon emissions but are disproportionately exposed to indoor air pollution, the world's largest single environmental health risk (Roser, 2020). Cidell (2009) argues that the development of LEED has been primarily motivated by economic considerations, and, to smaller degrees, environmental considerations, with a disregard for social processes that shape urban environments. For instance, LEED rewards occupant health promotion largely aimed at improving worker productivity and accredits environmental impact reduction without mandating a specific scientific benchmark.

While et al. (2004) conceptualizes recent forms of local economy-environment relations through the notion of "urban sustainability fix", or the selective incorporation of ecological goals in urban governance to safeguard post-industrial urban growth in response to the global ecological crisis and the rise of popular environmentalism. In this approach, the politics of urban development support environmental and social goals only so long as economic goals are not diminished. Bunce (2009) describes the high-density, mixed-use redevelopment of public lands on Toronto's waterfront where a process of policy-led gentrification that supports middle-to-high-income-oriented property development at the expense of housing affordability. Toronto's financial and educational incentives for LEED-certified structures drive the development of the “revitalization project” by large, globally-financed, private development corporations that have the capital to absorb the upfront costs of developing, publicizing, and marketing Gold-level LEED-certified properties. Goodling et al. (2015) describes Portland’s investment in urban growth boundary, transit-oriented development, and infill construction, which has contributed to Portland’s reputation for commitment to livability and sustainability by transforming vacant lots into stylish, LEED-certified condos and retail hubs, but, at the same time, has multiplied housing costs and displaced long-term, low-socioeconomic status residents.

6.2.3. Measuring gentrification

There is no best indicator, operationalization method, analysis unit, or degrees of change to measure gentrification. Neighborhoods may change both physically and socially. Therefore, quantitative studies track physical changes using physical, occupancy, and financial indicators of the building stock and track social changes using aggregate socioeconomic indicators of inhabitants and businesses. A significant increase in renovated buildings, rents, prices, taxes, and ownership rates and a significant increase in the percentage of White, young, college-educated, middle- or high-income households are both used to indicate gentrification (Dong, 2017). Some studies have also tracked the number of incoming residents and the flow of physical and capital investment into and out of neighborhoods (Landis, 2016).

Most researchers operationalize neighborhoods using administrative units of analysis due to convenience and data availability, whereas these units do not necessarily possess a single area with a distinct identity (Kirk & Laub, 2010). Mujahid et al., (2019) compares three census-based, quantitative gentrification classification methods to examine the impact of the choice of method on potential health decisions at the Census Tract level. Census tracts generally have a population size between 1,200 and 8,000 people, and Block Groups are statistical divisions of census tracts, are generally defined to contain between 600 and 3,000 people. Landis (2016) tracks significant changes in the deciles of tract-level median household income within a metropolitan area and categorizes tracts as gentrifying, declining, or stable depending on the severity of changes in the income decile often within a one-to-two-decade timeframe. Freeman (2005) uses the ACS data to track tract-level changes in household income, housing stock, urbanization, house prices, and educational attainment relative to the corresponding metro-level over a predefined period to designate gentrifying and stable tracts. Urban Displacement Project (2020) defines eight categories for gentrification and displacement to capture a more nuanced understanding of gentrification stages using several indicators on socioeconomic and housing indicators from multiple datasets. Hwang (2015) uses Google Street View imagery to capture stages of gentrification and overcome limitations in the use of census-defined boundaries as the unit of analysis. Comparative studies suggest that the choice of the method has a large impact on neighborhood categorization but the results share similarities across the studies (Barton, 2016).

Quantifying the gentrification impacts of pro-environmental redevelopment projects is a recent trend in urban studies. Immergluck & Balan (2018) examines the effect of the Atlanta Beltline – a transit-oriented redevelopment of historic railroad corridors, providing a network of public parks and multi-use trails – on value and tax appreciation of houses located within one-half mile of the project over five years. The study finds significant evidence on the creation of exclusionary housing patterns near the project, where economically advantaged households enjoy new, typically subsidized new amenities, whereas lower-income households are forced to live in less attractive neighborhoods. Dong (2017) explores gentrification effects of rail transit development in suburban Portland, Oregon, employing tract-level data on the demographic composition, housing characteristics, and location in a longitudinal quasi-experimental design. The study uses propensity score matching to designate treatment and control neighborhoods and applies several statistical t-tests to identify changes at multiple observation points and timeframes, but the author does not find statistically significant evidence of transit-induced gentrification.

A review of quantitative studies on gentrification suggests researchers' decisions have greatly impacted study outcomes in several ways. First, the choice of definition, unit, data, operationalization, location, and timeframe greatly impacts neighborhood characterization. Second, case studies are context-specific and there are biased comparisons, e.g., some neighborhoods are already very different from other ones before the introduction of a pro-environmental project. In the latter case, researchers have used matching methods to guarantee "apple-to-apple" comparisons. Third, reliance on administrative units and aggregated census data – for instance to measure housing affordability without differentiating households of different income levels – may mask underlying nuances and reduce accuracy.

Past research on environment-equity conflicts has primarily focused on adversities of large infrastructural public-private partnership projects for vulnerable residents and little research is available on locationally dispersed, green-certified houses supplied in the private market. The focus of this study is not on public green infrastructure, but on gray infrastructure gentrification driven by urban climate and sustainability politics, private developers' interest in market-rate green-certified houses, and middle- and higher-income residents' desire to live in energy-efficient houses in mixed-use, dense, walkable, bikeable neighborhoods. The following analysis could inform equity-minded housing planners, organizations, and policymakers who may face the conundrum of providing environmental amenities, and, at the same time, preventing the displacement of existing residents.

6.3. Methodology

6.3.1. Research hypotheses

Hypothesis (1): Green-certified houses have transaction price premiums. We can expect that green price premiums reflect, at least, the upfront construction cost premium and developer overhead and profit to achieve the green certification in a non-competitive market context, and, at most, the homebuyers' willingness to pay for perceived operation-phase benefits, e.g., expected savings from energy and water-efficiency, productivity gains from indoor environmental quality, and a positive green image in a competitive context. A challenge in estimating the premium is to control the impact of confounding variables, e.g., identical green-certified houses may signal different premiums if environmental attitudes of households living in one neighborhood are stronger than those of households living in another neighborhood.

Hypothesis (2): Green-certified houses cause positive spillover effects. When single-family houses are demolished, the positive price impacts on existing, nearby houses can be higher if the demolished houses are replaced with a green-certified house, rather than an identical non-certified house. The assumption is that environmentally savvy homebuyers who are willing to spend more on housing to live in a brand new, green-certified house tend to have higher incomes. Analyzing spillover effects may require an additional degree of control over confounding variables, e.g., when a house is replaced with several green-certified houses, the resulting increase in neighborhood density, traffic, and noise may hurt existing property values.

Hypothesis (3): Green-certified houses cause neighborhood change and gentrification. The main question in this study is that “Since green-certified houses raise property values and tax revenues, to what extent is the construction of these houses connected with neighborhood change and gentrification?” The supply of green-certified houses in neighborhoods where the difference between the actual and potential ground rent is high can help developers recoup cost premiums. On the demand side, homebuyers may argue that reductions in the total lifecycle cost of homeownership justify the price premium. We can expect the siting of green-certified houses to cause or be associated with neighborhood change or even gentrification if there is no policy in place to protect existing, low-income residents from displacement.

Hypothesis (4): Willingness to pay for green-certified houses has decreased over time. Employing historical market data to measure willingness to pay assumes that future market behavior can be predicted using revealed preferences in the past. However, as conventional building codes and construction methods improve, there is a perception among some researchers and practitioners that the willingness to pay for green-certified houses is declining. Also, anecdotal evidence suggests that as builders gain experience in green-certified house construction, they tend to include green features in recent developments without pursuing the certification itself to reduce the total cost of development. However, in parallel to advances in conventional construction codes, materials, methods, and professional workforce, we can also expect green rating systems to evolve to improve net income returns by addressing economic, geographical, and functional needs of developers and helping consumers maintain a positive green image by the time the debate on global warming persists.

6.3.2. Study context and datasets

The study area is a submarket in Richmond MSA, including Chesterfield, Goochland, Hanover, Henrico, New Kent, and Powhatan counties and Colonial Heights, Petersburg, and Richmond cities. We obtained the Central Virginia Multiple Listing Service (MLS) transactions' pooled cross-sectional data from 01\01\2005 to 01\01\2020, cleaned the dataset, and geocoded the addresses in ESRI's ArcMap software using the Virginia Geographic Information Network (VGIN) tool. We obtained the list of green-certified, single-family houses from EarthCraft VA and modified the original MLS dataset for accuracy. The Greater Atlanta Home Builders Association and Southface jointly established the EarthCraft green building rating system in 1999, extended it to Virginia in 2006 as EarthCraft VA (EarthCraft, 2020). Of all the Richmond MSA transactions, our sample includes all EarthCraft-certified (hereinafter certified) single-family houses plus all non-certified single-family houses in a one-mile radius distance from the certified houses for an "apple to apple" comparison. The sample contains over 50,000 transactions, which is large enough to represent nearly 550,000 housing units in Richmond MSA with a 1% margin of error and a 99% confidence interval. A priori power analysis suggests that using this sample size, our econometric models would detect small effect sizes (f^2) with the statistical power of 0.99 at the alpha level of 0.01 (Faul et al., 2009). We also obtained the Decennial Census 2000 data and the ACS 2019 5-year estimate data to quantify socioeconomic changes before (the year 2000) and after (the year 2019) the construction of certified houses. We mapped the tract-level and block group-level datasets in ArcMap and joined the year 2000 data to the year 2019 shapefiles to ensure changes in titles and delineations of census tracts and block groups during the last two decades would not impact the analysis.

6.3.3. Statistical analysis

Hypothesis (1): Formulated by Rosen (1974), the theory of the hedonic prices hypothesizes that goods are valued by their utility-bearing attributes, prices of which can be estimated from observed prices of products and the amounts of attributes associated with them. Numerous housing studies have used multivariate regression analysis to infer unobservable values of house, lot, and location attributes based on the theory of hedonic prices. In classic hedonic price functions, the observed market price of housing expenditure equals the sum of the marginal price of independent housing attributes (Can, 1990). Typically, the function is specified as Equation (1), where $\ln v_i$ is the natural logarithm of – total or per areal unit – house transaction price, which is the agreed transaction price of the property between the buyer and the seller excluding legal, agency, and other professional fees; S_i, L_i, and N_i are vectors of the structure, lot, and neighborhood characteristics; α, β, and γ are vectors of unknown coefficients, and ε_i is a vector of random error terms in ordinary least squares regression (OLS). To test the first hypothesis, we write Equation (1) as Equation (2) where G_i is a binary variable, indicating whether unit i is certified; Y_m and M_n denote the fixed effects of the year and month of transaction; C is the constant term; and η, δ, and θ are coefficients. Having a sample of all non-certified, single-family houses in a one-mile radius distance from the certified houses can reduce the need for matching and including neighborhood characteristics of density, income, and race, can reduce the risk of a selection bias, i.e., positive spatial externalities causing the green premium.

$$\ln v_i = S_i\alpha + L_i\beta + N_i\gamma + \varepsilon_i$$ Equation 1

$$\ln v_i = G_i\eta + \sum_{j=1}^{n_S} S_j\alpha_j + \sum_{k=1}^{n_L} L_k\beta_k + \sum_{l=1}^{n_N} N_l\gamma_l + \sum_{m=1}^{n_Y} Y_m\delta_m + \sum_{n=1}^{n_M} M_n\theta_n + C + \varepsilon_i$$ Equation 2

$$\ln v_i = A_i\kappa + W_i\lambda + D_i\mu + S_i\alpha + L_i\beta + N_i\gamma + \varepsilon_i$$ Equation 3

Hypothesis (2): To test this hypothesis, we add new attributes to the equation so that the resulting model captures two types of spatial externalities: fixed neighborhood effects due to shared neighborhood characteristics and spillover effects due to adjacency to immediate, certified houses. Numerous studies have employed the basic hedonic regression to estimate spillover effects, assuming an accurately specified hedonic regression model that includes all confounding covariates can reasonably capture causal effects (Gelman & Hill, 2006). Nonetheless, to rule out the probability of a selection bias (i.e., the possibility that developers strategically locate certified houses in “strong areas”, where the prices of existing properties are consistently high) we employ a difference-in-difference estimator that measures differences in the prices of nearby properties relative to properties in the control group before and after the launch of a certified house (Ooi & Le, 2013). In Equation (3), A_i is a binary variable that indicates whether unit i is sold one or more years after a certified house is built; W_i is a binary variable that indicates whether unit i is in a walkable distance (i.e., in a quarter mile radius) to a certified house; and D_i is a binary variable that captures both the spatial and time dimensions, indicating whether unit i is both located in a walking distance to a certified house and sold one or more years after a certified house is built. Table 6.3.1 summarizes the expected values of $\ln v_i$ in Equation (3). Coefficient λ reflects the baseline differences in the transaction price of houses located inside and outside of a walkable distance to a certified house. Coefficient μ is the difference in differences estimate and reflects the true spillover effect of building a certified house.

Table 6.3.1 Expected values of $\ln v_i$ in Equation (3)

Estimate	Pre-build	Post-build	Difference
In walkable distance	$\lambda + S + L + N$	$\kappa + \lambda + \mu + S + L + N$	$\kappa + \mu$
Out of the walkable distance	$S + L + N$	$\kappa + S + L + N$	κ
Difference	λ	$\lambda + \mu$	μ

Hypothesis (3): We test the third hypothesis in terms of both the association between certified house accessibility and transaction price appreciation over time and the causal relationship between the presence of certified houses and neighborhood socioeconomic change. To represent certified house accessibility, we introduce an ordinal variable composed of the year-specific quintiles of the mean geodesic distance based on the Vincenty (1975) formula between each non-certified house and all the existing certified houses (Model-3). We then add interactions of the transaction year and the ordinal measure of accessibility (Model-4) to indicate how much cumulative appreciation over time is associated with certified house accessibility (Immergluck & Balan, 2018). To examine the causal relationship with neighborhood socioeconomic change, we identify census tracts and block groups that are sites of certified houses and compare sociodemographic changes using difference-in-differences analyses, presenting the differential effect of the new construction of market-rate, certified houses at the two geographical scales in a natural experiment using propensity score matching.

Hypothesis (4): We use Equation (2) in a repeated pooled cross-sectional design for houses sold in the three intervals of 2005-2009, 2010-2014, 2015-2019 (Model-5).

All statistical analyses are performed in Stata 14.0. To prevent multicollinearity, we examine Variance Inflation Factors (VIFs) and avoid the use of highly correlated variables in regression models based on the assumption that the presence of zero-order Pearson coefficients larger than 0.80 denotes multicollinearity (Gujarati, 2009). To ensure other underlying OLS regression assumptions are not violated, we inspect standardized normal probability plot of residuals and residuals-versus-fitted-values graphs and use robust standard errors. The socioeconomic estimates are reliable at both census tract and block group levels when assessed against the coefficient of variation.

6.4. Results

6.4.1. Do green-certified houses have transaction price premiums?

Table 6.4.1 reports descriptive statistics of the sample and the operationalization of the variables. The dependent variable in all the hedonic price models is the natural logarithm of the transaction price. The average single-family residential unit in the sample in the year 2019 is sold at $331,844.20 (S.D. 167,563.60), having a floor area of 2,322.87 SF (S.D. 1,067.51). The sample includes a total of 516 certified transactions from 01\01\2005 to 01\01\2020, the market share of which reached the highest level in the year 2012 when 11.28% of all the new sales were certified and declined to the lowest level in 2019 when 4.85% of all the new sales were certified. Corresponding to the first three hypotheses, Table 6.4.2 presents three multivariate regression models, including a set of fixed effects that control for the city, year, and month of sales. Overall, the models perform well as most equation coefficients are significant at the 1% level, and the regressions explain over 86% of the variations in housing prices. Most of the control variables have the expected signs and the models suggest that housing prices decline as the distance to the central business district increases. On the other hand, houses located near the airport are sold at a discount, suggesting the presence of countervailing, negative externalities from noise and congestion. To interpret the percentage change in transaction price in these semi-log models, where the dependent variable has been log-transformed but the predictors have not, we exponentiate the coefficient of the independent variable, subtract one from the result, and multiply it by 100.

Table 6.4.1 Price model variables and descriptive statistics for a sample of 57,673 datapoints

Variable	Operationalization	Mean	Std. Dev.	Min*	Max*
Dependent variable					
Sales Price	Natural logarithm of total transaction price	12.450	0.585	10.222	14.602
Main independent variables					
EarthCraft	If house is EarthCraft (EC) certified (1 = yes)	0.009	0.094		
Post EC	If house is sold after an EC house was built (1 = yes)	0.915	0.279		
Near EC	If house is within a quarter-mile of an EC house (1 = yes)	0.233	0.423		
Post EC * Near EC	If house is sited near to and sold after an EC house (1 = yes)	0.144	0.352		
Q2 Distance to EC	If mean house distance to existing EC houses is in 2nd quintile	0.2000	0.4000		
Q3 Distance to EC	If mean house distance to existing EC houses is in 3rd quintile	0.2000	0.4000		
Q4 Distance to EC	If mean house distance to existing EC houses is in 4th quintile	0.2000	0.4000		
Q5 Distance to EC	If mean house distance to existing EC houses is in 5th quintile	0.2000	0.4000		
Control variables					
Structure					
Area	Natural log of the interior area in square feet	7.644	0.448	5.951	9.463
Baths (F)	Total number of full bathrooms	2.150	0.868	0	8
Baths (H)	Total number of half bathrooms	0.651	0.529	0	5
Year built	Year of construction	1978.984	31.541	1900	2019
Assessed	If house price is validated by assessor (1 = yes)	0.864	0.343		
Brickwork	If house facade has brickwork (1 = yes)	0.354	0.478		
Detached	If house is detached (1 = yes)	0.957	0.203		
New construction	If house is new at sales time (1 = yes)	0.187	0.390		
Pool	If house has a pool (1 = yes)	0.093	0.290		
Location					
Lot area (2)	0.1 ac <= Total lot area < 0.2 ac (1 = yes)	0.119	0.323		
Lot area (3)	0.2 ac <= Total lot area < 0.4 ac (1 = yes)	0.281	0.450		
Lot area (4)	0.4 ac <= Total lot area (1 = yes)	0.240	0.427		
Distance to Airport	Natural log of distance to the airport in miles	14.830	6.720	2.772	73.926
Distance to County	Natural log of distance to County in miles	6.372	5.813	0.185	78.327
Cul-De-Sac	If lot is in cul-de-sac (1 = yes)	0.120	0.325		
HOA	If homeowner association is present (1 = yes)	0.407	0.491		
Neighborhood**					
Density	Housing units per square mile tract area	1176.543	1506.496	16.655	12322.920
Income	Median household income in 1000 USD in 2010	74695.010	30615.690	11458.000	221767.000
Race	Percent White households	70.620	26.893	2.300	100.000
Sales city fixed effects	A set of binary variables representing sales city				
Sales year fixed effects	A set of binary variables representing sales year	2012.257	4.625	2005	2019
Sales month fixed effects	A set of binary variables representing sales month	6.676	3.142	1	12

Note:
* The missing values are binary (Min=0, Max=1).
** The data are from the US ACS 2010 5-year estimates at the census tract level.

Table 6.4.2 OLS regression analyses of house prices based on the theory of the hedonic prices

Variable	Model 1		Model 2		Model 3	
	Coef.	R. Std. Err.	Coef.	R.Std. Err.	Coef.	R.Std. Err.
EarthCraft (n = 516)	0.0494***	0.0091	-	-	-	-
Post EC build	-	-	0.2016***	0.0046	-	-
Near EC	-	-	-0.0225***	0.0036	-	-
Post EC * Near to EC	-	-	0.0418***	0.0043	-	-
Q2 EC Accessibility	-	-	-	-	-0.0804***	0.0044
Q3 EC Accessibility	-	-	-	-	-0.0793***	0.0045
Q4 EC Accessibility	-	-	-	-	-0.1033***	0.0047
Q5 EC Accessibility	-	-	-	-	-0.1152***	0.0051
Structure						
Area	0.7104***	0.0048	0.7088***	0.0048	0.7107***	0.0050
Baths (F)	0.0757***	0.0019	0.0759***	0.0019	0.0745***	0.0020
Baths (H)	0.0531***	0.0023	0.0537***	0.0023	0.0513***	0.0024
Year built	0.0006***	0.0001	0.0006***	0.0001	0.0007***	0.0001
Assessed	0.0048*	0.0027	0.0037	0.0028	0.0093***	0.0031
Brickwork	0.0391***	0.0020	0.0403***	0.0020	0.0340***	0.0022
Detached	-0.0249***	0.0057	-0.0250***	0.0057	-0.0276***	0.0061
New construction	0.1381***	0.0026	0.1394***	0.0027	0.1435***	0.0028
Pool	0.0037	0.0028	0.0029	0.0028	0.0055*	0.0028
Location						
Lot area (2)	0.0107***	0.0036	0.0114***	0.0037	0.0073***	0.0038
Lot area (3)	-0.0162***	0.0023	-0.0154***	0.0023	-0.0167***	0.0024
Lot area (4)	-0.0182***	0.0026	-0.0176***	0.0026	-0.0205***	0.0027
Distance to Airport	0.0011***	0.0003	0.0010***	0.0003	0.0033***	0.0003
Distance to County	-0.0006***	0.0003	-0.0006***	0.0002	-0.0012***	0.0003
Cul-De-Sac	0.0156***	0.0022	0.0158***	0.0022	0.0147***	0.0023
HOA	0.0770***	0.0025	0.0764***	0.0025	0.0832***	0.0026
Neighborhood						
Density	3.9500E-05***	1.0300E-06	3.9200E-05***	1.0400E-06	3.8200E-05***	1.1000E-06
Income	2.0200E-06***	5.3700E-08	2.0200E-06***	5.4400E-08	1.9800E-06***	5.6800E-08
Race	6.4925E-03***	6.7700E-05	6.5110E-03***	6.8200E-05	6.0097E-03***	7.6300E-05
Sales city fixed effects	Included				Included	
Sales year fixed effects	Included				Included	
Sales month fixed effects	Included				Included	
Constant	4.7341***	0.1340	4.7460***	0.1352	4.6251****	0.1474
Observations	57,673		57,157		52,373	
Adj R-squared	0.8638		0.8640		0.8621	
Post EC build* Near to EC Conf. Interval			0.0333	0.0503		

Note:
* Represents significant at 10%
** Represents significant at 5%
*** Represents significant at 1%

In Model 1, the positive and statistically significant coefficient for EarthCraft implies that, all the variables held constant at the average, certified single-family houses were sold, on average, with a 5.06% transaction price premium when compared to otherwise identical buildings within a one-mile radius during the study period. The lower and upper 95% confidence intervals for the premium with robust standard errors are 0.0317 (3.22%) and 0.0672 (6.95%), respectively. Based on anecdotal evidence from local builders, EarthCraft reports an upfront cost premium of 0.5–3%, suggesting that housebuilders' sales-time profit tends to be higher than normal when building certified houses.

6.4.2. Do green-certified houses cause positive spillover effects?

The impact of the control variables in Model 2 is robust to the inclusion of new variables. The negative and statistically significant coefficient for Near EC, the binary variable that controls for pre-treatment price trends of units located within a quarter-mile of certified houses, implies that the baseline transaction prices of the houses are, on average, 2.28% lower than those of comparable houses located outside the quarter-mile radius. This price difference indicates that there has been a systematic choice by developers in locating certified houses in slightly less expensive areas, suggesting the 5.06% transaction price premium is not due to positive spatial externalities, thus, justifying the need for the use of the difference-in-difference specification. In Model 2, the positive and statistically significant difference-in-difference estimate indicates that, controlling for the baseline price differential of houses located inside the one quarter-mile radius and comparable houses outside this walkability threshold, certified houses cause market value spillovers on nearby, non-certified houses. Following the construction of a new certified house nearby, the average single-family house transaction price of $331,844.20 in the year 2019 would increase by $14,165.08 (i.e., 4.27%). We can expect the price increase to build up over time and at a decreasing rate, as increased competition from the supply of new housing units would reduce the pressure on local housing values. Also, we can expect the spillover effect to vary within different stages of development and depending on whether the new house is a new structure on an existing plot of vacant land – which may reduce green space and increase congestion – or the new house is the redevelopment of an existing house, which can improve neighborhood amenities, but the MLS dataset does not contain the data on preexisting conditions (Ooi & Le, 2013).

6.4.3. Do green-certified houses cause neighborhood change and gentrification?

We first investigate the association between certified house accessibility and transaction price appreciation over time. Let us consider the hypothetical "high redevelopment potential zone" as the zone that includes houses located within a one-mile radius of a certified house like any other houses in the sample but within the first quintile of certified house accessibility as determined by the mean geodesic distance to all existing certified houses in each year. The high redevelopment potential zone happens to overlap the Richmond City center. Households living in this zone would have the highest potential for spatial interaction with the households of EarthCraft-certified houses. In Model 3, the negative and statistically significant coefficients for the dependent variables Q2 to Q5 EC Accessibility, which determine year-specific quintiles of certified house accessibility, imply that, on average, transaction prices of the houses located in the "high redevelopment potential" zone, as determined by Q1, are 12.21% higher than those of identical houses located elsewhere with the lowest level of certified house accessibility. Now, we interact the level of accessibility with the sales year to indicate how much cumulative appreciation over time is associated with a non-certified house being close to all the certified houses. Table 6.4.3 reports a summary of the full two-way factorial model of accessibility quintiles and sales year, controlling for the structural, lot, and neighborhood characteristics of sales as well as the fixed effects of the sales city, year, and month. In Model 4, the positive and statistically significant coefficients for the interaction terms imply that accessibility to existing certified houses systematically affects house price appreciations over time. Figure 6.4.1 compares cumulative appreciation rates for houses located in the high redevelopment potential zone with those located in the other four zones. Independent sample t-tests show that in most years, the cumulative appreciation rate differences are statistically significant.

Table 6.4.3 Summarized factorial model of sales year and certified house accessibility quintiles

Variable	Coef.	Robust Std. Err.	Variable	Coef.	Robust Std. Err.
Q2 EC Accessibility (1 = yes)	0.0054	0.0106			
Q3 EC Accessibility (1 = yes)	0.0127	0.0100			
Q4 EC Accessibility (1 = yes)	0.0009	0.0098			
Q5 EC Accessibility (1 = yes)	0.0231**	0.0103			
Q2 EC Accessibility 2007	-0.0177	0.0159	Q4 EC Accessibility 2007	0.0132***	0.0145
Q2 EC Accessibility 2008	0.0671***	0.0186	Q4 EC Accessibility 2008	0.0168	0.0161
Q2 EC Accessibility 2009	-0.0622***	0.0189	Q4 EC Accessibility 2009	0.0161***	0.0166
Q2 EC Accessibility 2010	-0.0648***	0.0190	Q4 EC Accessibility 2010	0.0168***	0.0162
Q2 EC Accessibility 2011	-0.0947***	0.0201	Q4 EC Accessibility 2011	0.0195***	0.0167
Q2 EC Accessibility 2012	-0.1383***	0.0186	Q4 EC Accessibility 2012	0.0174***	0.0163
Q2 EC Accessibility 2013	-0.1211***	0.0162	Q4 EC Accessibility 2013	0.0151***	0.0150
Q2 EC Accessibility 2014	-0.1612***	0.0168	Q4 EC Accessibility 2014	0.0153***	0.0153
Q2 EC Accessibility 2015	-0.1586***	0.0161	Q4 EC Accessibility 2015	0.0152***	0.0147
Q2 EC Accessibility 2016	-0.1425***	0.0163	Q4 EC Accessibility 2016	0.0149***	0.0144
Q2 EC Accessibility 2017	-0.1314***	0.0162	Q4 EC Accessibility 2017	0.0143***	0.0141
Q2 EC Accessibility 2018	-0.0983***	0.0170	Q4 EC Accessibility 2018	0.0147***	0.0142
Q2 EC Accessibility 2019	-0.0624***	0.0167	Q4 EC Accessibility 2019	0.0145***	0.0141
Q3 EC Accessibility 2007	0.0156	0.0139	Q5 EC Accessibility 2007	0.0143***	0.0147
Q3 EC Accessibility 2008	-0.0133	0.0172	Q5 EC Accessibility 2008	0.0171**	0.0163
Q3 EC Accessibility 2009	-0.0497***	0.0166	Q5 EC Accessibility 2009	0.0170***	0.0167
Q3 EC Accessibility 2010	-0.0768***	0.0172	Q5 EC Accessibility 2010	0.0176***	0.0163
Q3 EC Accessibility 2011	-0.0691***	0.0193	Q5 EC Accessibility 2011	0.0192***	0.0167
Q3 EC Accessibility 2012	-0.1161***	0.0176	Q5 EC Accessibility 2012	0.0177***	0.0164
Q3 EC Accessibility 2013	-0.1445***	0.0158	Q5 EC Accessibility 2013	0.0156***	0.0151
Q3 EC Accessibility 2014	-0.1415***	0.0156	Q5 EC Accessibility 2014	0.0157***	0.0153
Q3 EC Accessibility 2015	-0.1402***	0.0149	Q5 EC Accessibility 2015	0.0151***	0.0147
Q3 EC Accessibility 2016	-0.1298***	0.0149	Q5 EC Accessibility 2016	0.0151***	0.0145
Q3 EC Accessibility 2017	-0.1298***	0.0144	Q5 EC Accessibility 2017	0.0148***	0.0142
Q3 EC Accessibility 2018	-0.1311***	0.0149	Q5 EC Accessibility 2018	0.0153***	0.0143
Q3 EC Accessibility 2019	-0.1338***	0.0146	Q5 EC Accessibility 2019	0.0150***	0.0142
Structure variables	Included				
Lot variables	Included				
Neighborhood variables	Included				
Sales city fixed effects	Included				
Sales year fixed effects	Included				
Sales month fixed effects	Included				
Constant	4.3928***	0.1467			
Observations	52,373				
Adj R-squared	0.8648				

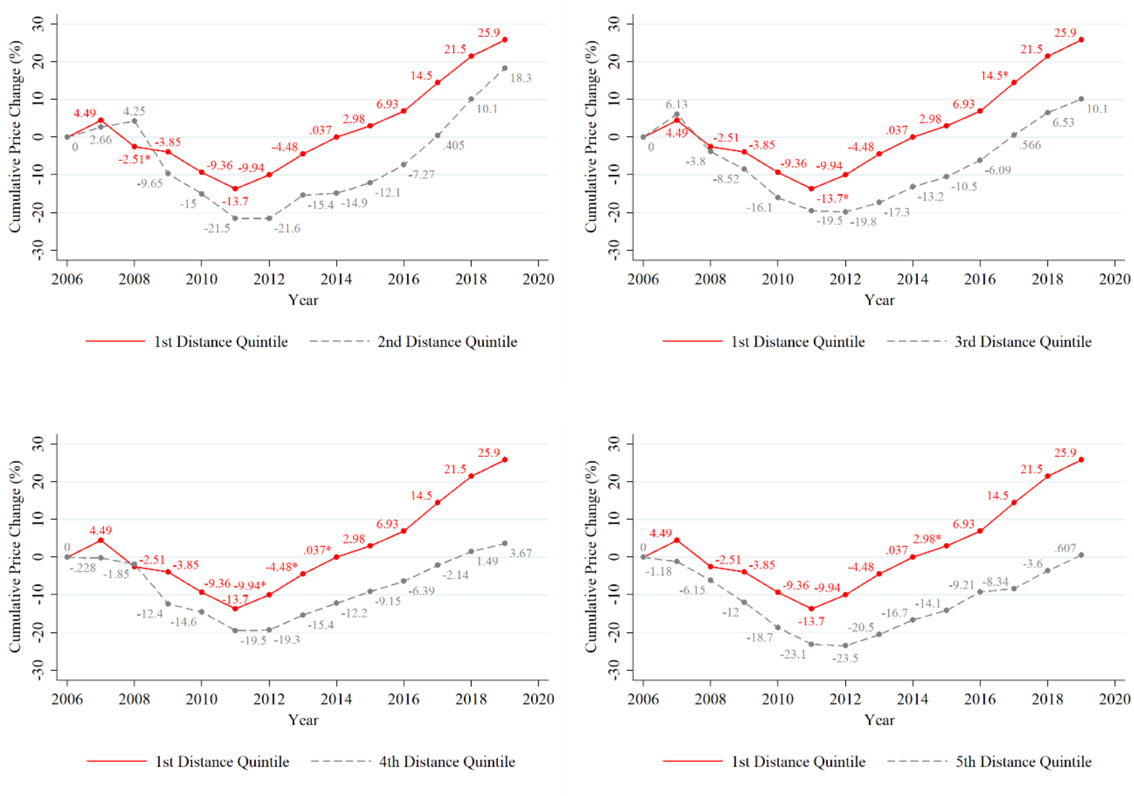


Figure 6.4.1 The effect of being close to green-certified houses on cumulative home value appreciation is in most years statistically significant. Asterisks indicate statistically insignificant differences in cumulative appreciation.

In 2006, the median transaction prices for houses in the first to the fifth accessibility quintiles were \$200,000, \$195,000, \$232,000, \$277,000, and \$322,000, respectively. Based on Model-4, the predicted average price appreciation from 2006-2019 for a house located in the high redevelopment potential zone is 25.9%. The predicted high redevelopment potential zone price appreciation premiums are 7.6%, 15.8%, 22.23%, and 25.29% when compared to houses in the second to the fifth accessibility quintiles, respectively. The median price house in the first accessibility quintile (\$200,000 in 2006) achieved, on average, \$51,800 value in appreciation, whereas the appreciation for the median-priced house in the fifth accessibility quintile (\$322,000 in 2006) was only \$1,954 in the same period. House value appreciations in the high redevelopment potential zone can raise tax revenues of the Richmond City and realize capital gains for property owners at the sales time, but owners and renters with limited disposable incomes will likely see increases in property taxes and rents as a process of neighborhood change, paving the way for gentrification. Following Landis (2016), we can designate a census block group as gentrifying if it is among one of the lowest four median household income deciles in 2000 and is improved by two or more deciles in 2019. We designate a census block group as declining if it is among one of the highest four deciles in 2000 and is declined by two or more deciles in 2019. “Stable” block groups might be at the risk of decline or gentrification in different degrees. Figure 6.4.2 presents the location of houses of high redevelopment potential, i.e., having the Q1 level of certified house accessibility, and the location of gentrifying, stable, and declining block groups, indicating associations between green-certified house accessibility, reinvestment in Richmond City core, and neighborhood change. Figure 6.4.3 presents single-family house price change trends in Richmond City versus other areas in the submarket, indicating middle-class in-migration from suburbs to the city. The large price appreciation gap created in the 2010s is currently shrinking.

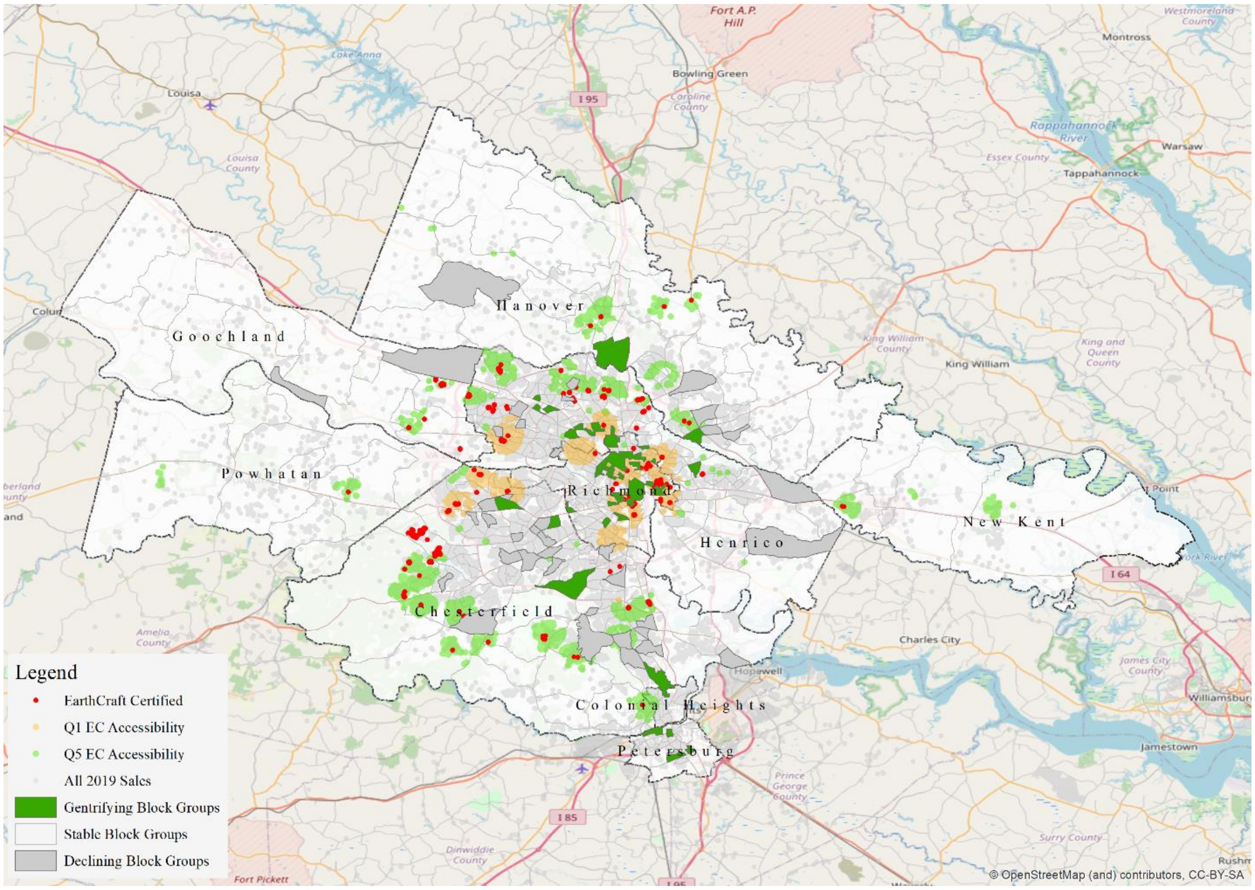


Figure 6.4.2 Gentrifying, stable, and declining block groups

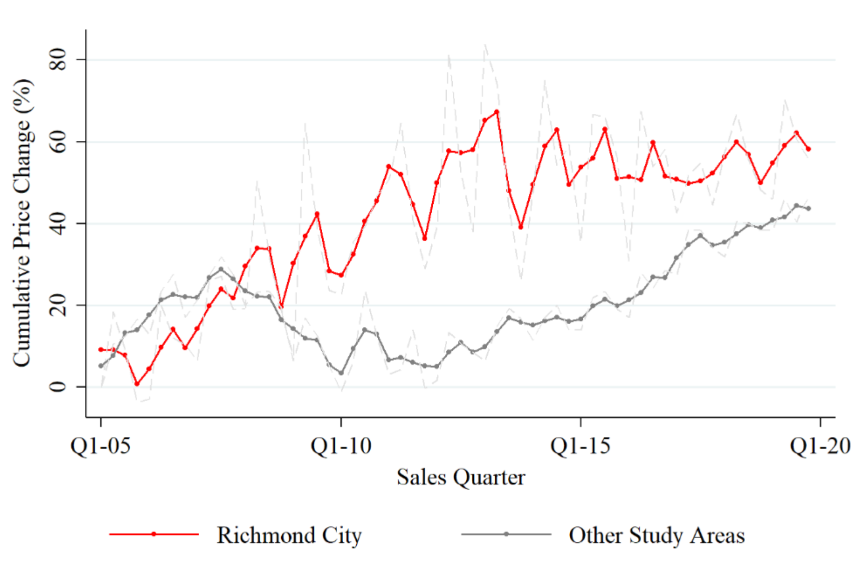


Figure 6.4.3 Single-family house price change in Richmond versus other areas in submarket

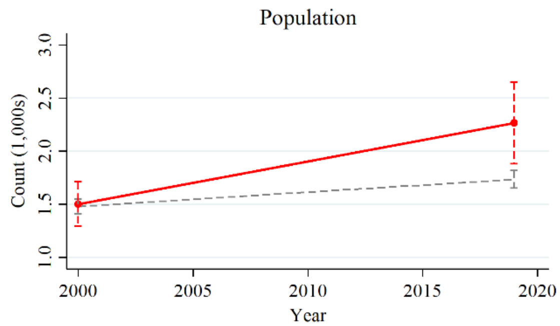
To study the causal effect of the construction of certified houses and neighborhood change, we identify census tracts and block groups that are sites of certified houses as two distinct treatment groups in two natural experiments. We perform a propensity score matching, regressing the natural log of odds of the presence of certified houses on the variables Age, Education, Income, Owner Costs, Population, Poverty, Renter Costs, Size, Vacancy, White, and the neighborhood centroid's distance to the Richmond City's central business district to identify the two control groups. We define the matching control group as those neighborhoods in which the propensity to site certified houses is within the propensity score range of the treatment neighborhoods. Table 6.4.4 reports our selected socioeconomic variables, definitions, and descriptive statistics, as well as the resulting sample sizes. Table 6.4.5 reports the results of the pre-test, post-test, and difference-in-difference analyses, showing that the socioeconomic characteristics of the treatment and control groups are not statistically different at the outset within both tract level and block group level experiments. The tract-level experiment suggests that the new construction of certified houses has not caused statistically significant effects on demographics, households, and housing characteristics during the last two decades. However, the block group level analysis shows that the new construction of certified houses has stimulated population growth, housing development, and housing value increases, and the effects are statistically significant. Figure 6.4.4 includes selected variables from the block group level analysis with large or statistically significant mean differences before (the year 2000) and after (the year 2019) the construction of certified houses in the treatment (red) and control (gray) groups. For instance, the difference between population means in both groups in 2000 is nearly zero, whereas the treatment group has gained significantly more population in two decades, resulting in $31,420 additional value gain per unit by 2019.

Table 6.4.4 Variable definitions and pre-test and post-test descriptive statistics

Variable	Operationalization	Treatment				Control			
Tract-Level									
Year		2000		2019		2000		2019	
Observations		51		51		145		145	
Demographics		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Age	(%) Population aged 25–39	22.3	5.8	21.4	7.5	22.5	6.3	21.6	8.5
Education	(%) Population with a BA degree or higher	29.8	19.3	38.4	19.1	28.2	18.3	33.2	19.2
Population	Total population (in 1,000s)	4.3	1.9	5.4	2.5	4.0	1.7	4.5	1.9
White race	(%) White population	61.7	35.2	59.0	27.4	63.4	34.3	57.2	28.0
Households									
Income	Median household income (in $1,000s)	51.7	23.8	76.5	33.8	48.2	23.0	70.0	35.7
Minority	(%) Households who are Black, Hispanic, and Latino	34.8	34.5	34.6	29.1	33.2	30.8	38.4	29.5
Minority owners	(%) Owners who are Black, Hispanic, and Latino	31.9	34.4	31.7	29.3	30.1	31.2	32.2	29.9
Minority renters	(%) Renters who are Black, Hispanic, and Latino	38.9	34.5	40.8	29.7	37.4	31.9	47.1	30.4
Owner costs	Median housing costs as a percentage of income	19.4	2.3	19.0	3.6	19.2	2.4	19.0	3.4
Poverty	(%) Households in poverty	10.7	11.7	10.8	8.9	10.3	11.2	14.0	13.5
Renter costs	Median gross rent as a percentage of income	25.2	5.6	30.3	7.2	24.9	5.4	31.1	7.2
Size	(%) Small-sized (1–2 persons) households	57.1	9.8	64.4	10.7	59.4	10.5	64.2	10.1
Tenure	(%) Owner households	70.3	20.7	66.4	21.5	66.7	24.2	62.4	25.3
Housing									
Units	Total occupied housing units (in 1,000s)	1.8	0.7	2.2	0.9	1.7	0.7	1.8	0.8
Vacancy	(%) Vacant houses	7.1	7.0	7.7	5.4	5.8	4.3	7.6	5.8
Value	Median owner-occupied house value ($1,000)	126.7	61.1	266.3	119.1	116.6	65.4	235.2	127.7
EC transactions				8.5	11.2				
Block Group-Level									
Year		2000		2019		2000		2019	
Observations		68		68		464		464	
Demographics									
Age	(%) Population aged 25–39	21.9	6.6	21.3	9.7	22.6	7.3	21.3	9.6
Education	(%) Population with a BA degree or higher	29.6	20.2	16.4	11.1	28.5	19.4	14.0	10.7
Population	Total population (in 1,000s)	1.5	0.9	2.3	1.6	1.5	0.8	1.7	0.9
White race	(%) White population	56.8	36.3	57.1	30.4	62.6	31.9	58.5	29.8
Households									
Income	Median household income (in $1,000s)	53.4	27.8	81.7	47.3	49.9	21.5	70.4	36.1
Minority	(%) Households who are Black, Hispanic, and Latino	38.3	36.8	37.1	31.5	32.1	31.9	37.0	30.6
Minority owners	(%) Owners who are Black, Hispanic, and Latino	35.7	36.6	33.5	32.3	29.5	31.7	31.8	30.6
Minority renters	(%) Renters who are Black, Hispanic, and Latino	39.9	38.4	43.0	35.6	34.9	34.3	43.1	34.8
Owner costs	Median housing costs as a percentage of income	20.2	5.3	19.7	5.9	19.5	4.2	18.7	5.6
Poverty	(%) Households in poverty	11.6	13.5	11.0	10.9	9.8	11.7	11.7	13.2
Renter costs	Median gross rent as a percentage of income	23.9	9.5	24.6	14.7	24.4	8.5	25.3	14.9
Size	(%) Small-sized (1–2 persons) households	56.6	11.0	62.9	13.6	59.2	11.6	64.1	14.0
Tenure	(%) Owner households	69.7	25.6	68.4	26.7	70.4	24.9	65.4	26.9
Housing									
Units	Total occupied housing units (in 1,000s)	0.6	0.3	0.9	0.5	0.6	0.3	0.7	0.4
Vacancy	(%) Vacant houses	7.7	7.2	8.1	7.8	5.5	5.1	7.6	7.7
Value	Median owner-occupied house value (in $1,000s)	134.0	83.8	277.5	152.7	118.8	64.6	224.2	124.0
EC transactions				6.4	9.8				

Table 6.4.5 Difference-in-differences analyses results

Analysis	Treatment		Control		Control-Treatment		Control-Treatment		Diff-in-Diff	
Tract Level										
Year	2019-2000		2019-2000		2000		2019		2000-2019	
Demographics	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Coef.	S.E.
Age	-0.93	0.98	-0.90*	0.52	0.16	1.01	0.18	1.34	-0.02	1.68
Education	8.66***	1.27	5.00***	0.61	-1.57	3.03	-5.23*	3.13	3.66	4.35
Population	1.10***	0.29	0.50***	0.11	-0.37	0.29	-0.97***	0.34	0.60	0.45
White race	-2.69	1.94	-6.17***	1.41	1.67	5.62	-1.82	4.53	3.49	7.22
Households										
Income	24.81***	2.23	21.77***	1.36	-3.48	3.78	-6.53	5.74	3.04	6.87
Minority	-0.23	1.93	5.20***	1.05	-1.58	5.18	3.85	4.79	-5.43	7.05
Minority owners	-0.23	1.90	2.16**	1.05	-1.82	5.22	0.57	4.84	-2.38	7.12
Minority renters	1.93	2.45	9.68***	1.72	-1.42	5.31	6.33	4.92	-7.75	7.24
Owner costs	-0.48	0.55	-0.14	0.26	-0.28	0.39	0.02	0.56	-0.30	0.68
Poverty	0.02	0.98	3.67***	0.51	-0.42	1.84	3.23	2.03	-3.64	2.74
Renter costs	5.02***	1.03	6.16***	0.69	-0.30	0.89	0.80	1.18	-1.10	1.47
Size	7.37***	0.97	4.77***	0.64	2.35	1.68	-0.26	1.67	2.60	2.37
Tenure	-3.93***	1.28	-4.28***	0.69	-3.62	3.80	-3.97	3.97	0.35	5.49
Housing										
Units	0.43***	0.12	0.16***	0.04	-0.13	0.11	-0.40	0.13	0.27	0.18
Vacancy	0.67	0.83	1.81***	0.33	-1.30	0.84	-0.17	0.93	-1.14	1.25
Value	139.56***	9.14	118.17***	5.75	-10.11	10.47	-31.12***	20.46	21.00	22.96
Observations	51		145							
Block Group Level										
Year	2019-2000		2019-2000		2000		2019		2000-2019	
Demographics	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Coef.	S.E.
Age	-0.56	1.02	-1.38***	0.38	0.68	0.93	-0.14	1.26	0.68	1.55
Education	-13.14***	1.63	-14.48***	0.56	-1.09	2.53	-2.42*	1.39	1.29	2.89
Population	0.76***	0.18	0.25***	0.04	-0.02	0.10	-0.54***	0.13	0.51***	0.17
White race	0.34	1.73	-4.24***	0.70	5.75	4.21	1.17	3.89	4.40	5.73
Households										
Income	28.33***	3.39	20.25***	1.08	-3.54	2.90	-11.61**	4.89	7.84	5.68
Minority	-1.16	1.78	4.85***	0.66	-0.06	3.99	-6.15	4.23	-6.06	5.81
Minority owners	-2.26	1.96	2.51***	0.73	-1.59	4.01	-6.23	4.20	-4.55	5.81
Minority renters	2.67	3.59	7.28***	1.22	0.09	4.57	-5.01	4.52	-5.17	6.43
Owner costs	-0.56	0.83	-0.76**	0.31	-0.75	0.57	-0.95	0.74	0.18	0.92
Poverty	-0.63	1.13	1.83***	0.38	-1.79	1.55	0.68	1.67	-2.51	2.28
Renter costs	0.72	1.67	0.80	0.73	0.51	1.12	0.59	1.94	-0.17	2.23
Size	6.25***	1.18	4.89***	0.57	2.60	1.49	1.24*	1.85	1.32	2.34
Tenure	-1.32	1.21	-5.13***	0.60	0.65	3.24	-3.16	3.50	3.67	4.76
Housing										
Units	0.27***	0.07	0.08***	0.01	0.01	0.04	-0.18***	0.05	0.19***	0.06
Vacancy	0.40	0.98	2.20***	0.32	-2.23	0.70	-0.44***	1.02	-1.71	1.22
Value	143.49***	9.95	104.70***	4.36	-15.18*	8.73	-53.96	16.64	38.11***	18.76
Observations	68		467							



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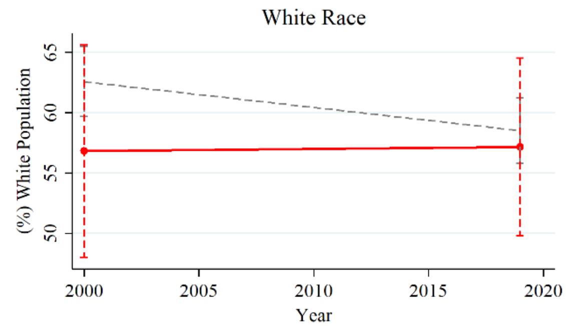

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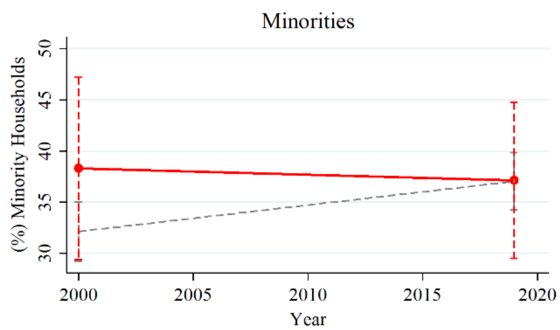

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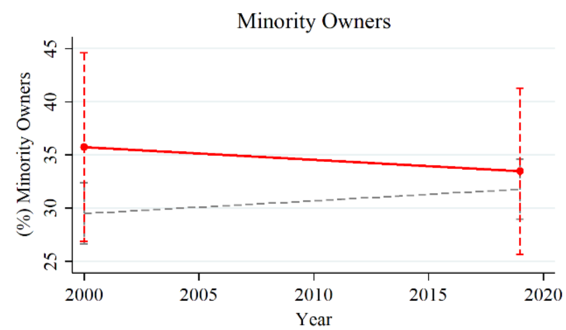

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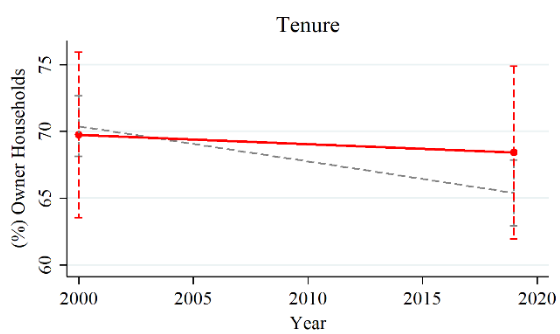
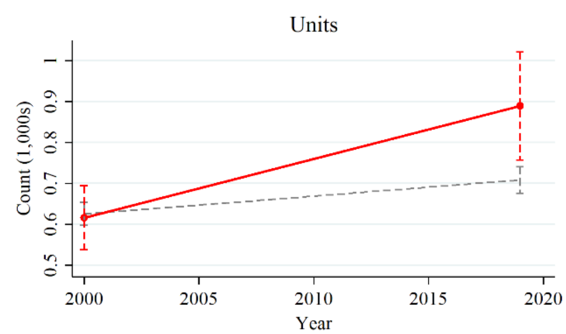
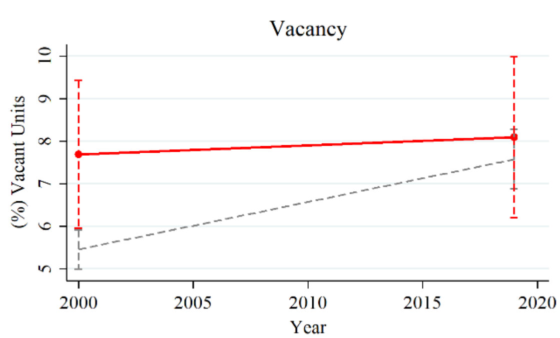


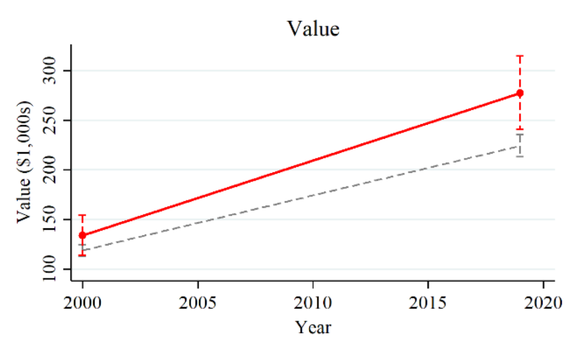
M (C-T 2000): 0.65, M (C-T 2019): -3.16, DID: 3.67



M (C-T 2000): 0.01, M (C-T 2019): -0.18***, DID: 0.19***



M (C-T 2000): -2.23, M (C-T 2019): -0.44***, DID: -1.71



M (C-T 2000): -15.18*, M (C-T 2019): -53.96, DID: 38.11***

Figure 6.4.4 Selected census block group level mean differences before (the year 2000) and after (the year 2019) the construction of green-certified houses in treatment (red) and control (gray) areas. Asterisks indicate statistically significant differences in mean differences and bars represent upper and lower confidence interval values. The difference-in-difference estimate for Value is $31,420 after accounting for inflation.

6.4.4. Has the willingness to pay for green-certified houses decreased over time?

Using Equation (2) in a repeated pooled cross-sectional design for houses sold in the three periods of 2005-2009, 2010-2014, 2015-2019, we find that willingness to pay for certified houses has increased in the mid-2010s, when the transactions achieve, on average, 6.49% premium (Table 6.4.6). However, the analysis suggests that transactions in the year 2015 and later are associated with smaller premiums with a mean value of 3.37%.

Table 6.4.6 Repeated OLS regression analyses of single-family house prices

Variable	2004 <Y< 2010		2009 <Y< 2015		2014 <Y	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
EarthCraft	0.0040	0.0272	0.0629***	0.0121	0.0331**	0.0156
Structure	Included		Included		Included	
Location	Included		Included		Included	
Neighborhood	Included		Included		Included	
Sales city fixed effects	Included		Included		Included	
Sales year fixed effects	Included		Included		Included	
Sales month fixed effects	Included		Included		Included	
Constant	3.7903***	0.2154	3.7174***	0.2744	5.5323****	0.2002
Observations	19,226		15,839		22,608	
Adj R-squared	0.8951		0.8655		0.8476	

6.5. Discussion

6.5.1. Key results and comparison with previous research

This analysis supports the first hypothesis by showing that certified single-family houses have statistically significant price premiums. After becoming certified, an average single-family house in the sample with the transaction price of $331,844.20 in the year 2019 would achieve, on average, a 5.06% (i.e., $16,791.32) transaction premium. New certified houses have a 19.87% price premium ($65,934.24) compared to existing non-certified houses in a one-mile radius. The presence of favorable market conditions, supportive political regulations and incentives, and high-income clients would ensure builders recover the upfront costs through this transaction premium.

Second, we find convincing evidence to accept the next hypothesis that green-certified houses cause positive and statistically significant spillover effects. Following the launch of a new certified house in the study period, the value of an average single-family house in a walkable distance to the new, certified house increases, on average, by 4.27%. The baseline transaction prices of the houses in walkable distance to green-certified houses are, on average, 2.28% lower than those of comparable houses located outside the quarter-mile radius, thus, supporting studies that argue investments in pro-environmental initiatives tend to occur in brownfields and urban areas where the difference between the actual and potential ground rent is high.

Third, the results reinforce the hypothesized causal connection between the construction of certified houses and neighborhood change and gentrification at the census block group level. The analysis indicates that the launch of certified houses, based on several measures, stimulates population, new construction, and property value growth at the census block group level, thus, accelerating neighborhood change and gentrification. In addition, there are large but not statistically significant changes in the selected socioeconomic indicators of neighborhood change before and after the construction of certified houses. For instance, in census block groups where certified houses are located, there is an upward trajectory in the share of the White population and, consequently, a reduction in both household share and ownership rates for Blacks, Hispanics, and Latinos, suggesting that neighborhoods in the treatment group are at risk for gentrification. At the same time, the share of the White population in the control group has decreased and, thus, been replaced by non-Whites. Although there is an overall decrease in ownership and occupancy rates, the treatment group neighborhoods have more stable ownership and occupancy. The difference-in-difference analysis suggests that the launch of certified houses has a more immediate effect on housing characteristics like the value and quantity of new developments than it has on household characteristics like the class composition of households, i.e., increases in the White, young, college-educated, middle- or high-income households, whose changes would achieve statistical significance in longer terms than studied here.

Lastly, we find that willingness to pay for certified houses inflates in the mid-2010s but then shrinks back as we move toward the 2020s. It is likely that because of improvements in residential building codes and construction methods and the inclusion of green features in non-certified developments, homebuyers perceive smaller differences in operational benefits of certified houses.

6.5.2. Research and policy recommendations

The choice of data, analysis unit, boundary, and timeframe impact inferences about neighborhood change and gentrification. The purpose of using area-level socioeconomic status data is to approximate individual-level data, but the use of such proxies for individual socioeconomic status is a limitation as it can systematically underestimate changes in individuals' status (Moss et al., 2021). The application of administrative units of analysis, e.g., Census-defined boundaries in the U.S., is often done out of convenience, but these boundaries are not always internally homogeneous for individuals' status (Kirk & Laub, 2010).

The size of the geographical unit should reflect the magnitude of the expected effects without violating data reliability, but there seems to be no consensus on the geographical scale and timeframe in the definition of neighborhood changes and gentrification. The smallest geographical unit for which socioeconomic data are available in Decennial Census is the census block and in the ACS survey is census block group. Many studies use census tract as the geographical unit based on which neighborhood change and gentrification should be defined and measured. However, in the case of small environmental initiatives like green-certified houses, such geographically small effects do not exist at the tract level.

Nonetheless, quantitative methods can help overcome theoretical limitations by enabling policymakers to estimate the number of individuals who have been displaced or are at risk of displacement because of reinvestment in environmental burdens. In this case, the share of minority households among all households who live in block groups that house certified houses has decreased, on average, by 6.06%, and the share of owner households who are in minority has decreased, on average, by 4.55%, both in difference-in-difference terms (Table 6.4.4).

This research highlights the need for greater policy attention to neighborhood diversity, affordable housing needs in core urban areas, and costs of gentrification. Pro-environmental reinvestments in city centers are likely to cause large-scale gentrification, thus, requiring planners to create a balance between the demands of environmental activists and the concerns of social justice advocates in crafting housing policies. Proposals to create this balance may include performing social effects assessments (i.e., vulnerability analysis), linking pro-environment development with affordable housing preservation, creating an even distribution of environmental amenities in the city to ensure equal benefits, employing mandatory inclusionary housing policies, exercising property tax growth limits, tax deferment programs, and property tax reductions for low-income households or affordable housing landlords (Haase et al., 2017; Immergluck & Balan, 2018). This analysis supports past research by showing that the positive spillover effects of pro-environmental redevelopment projects quickly capitalize into housing prices in the area, thus, accelerating the growth in housing costs and neighborhood change. Once the risk of gentrification is recognized, planners should acknowledge that "development without displacement" requires early-stage diversity and affordability interventions as integral components of planning. Otherwise, significant increases in land values would make future community protection and improvement actions very expensive.

6.6. Conclusion

Middle- and higher-income residents are immigrating from suburbs to the city to live in energy-efficient houses in mixed-use, dense, walkable, bikeable neighborhoods. Investments in environmental initiatives in brownfields and core urban areas, where the difference between the actual and potential ground rent is high, have replaced low-rent houses occupied by low-socioeconomic status residents with high-end real estate for higher-income, often white in-migrants. The launch of green-certified houses accelerates neighborhood change and gentrification based on several measures, such as population growth, new construction, and property value increases. When a neighborhood is subject to gentrification, the cost-burdened, relocated, or displaced residents incur economic costs, social costs, and health and well-being costs, thus, requiring support from the host neighborhood and creating large negative externalities leading to welfare loss in the city. There is evidence that population migration due to gentrification is a cause of crime. The net change in economic, environmental, and social benefits for the city of selective adoption of sustainability can be zero or even negative, suggesting that planners should create a balance between the demands of environmental activists and the concerns of social justice advocates by crafting housing policies that protect social as well as environmental sustainability.

Climate change is set to reshape future population distributions, triggering large-scale migrations away from affected areas and disproportionately escalating existing hardships faced by low-socioeconomic status populations (Curran & Hamilton, 2012; Hauer, 2017; Kulp & Strauss, 2019). Amid an unraveling climate crisis, a lack of consideration for affordable housing in urban reform, renewal, revitalization, and redevelopment plans endangers the health and wellbeing of the working class and low-income households who are essential to a functioning economy (Rigolon & Németh, 2018).

CHAPTER SEVEN: INCENTIVIZING GREEN AFFORDABLE HOUSING

Chapter Summary

Local governments are in a unique position to facilitate green affordable housing, that could reduce cost burdens, environmental degradation, and environmental injustice. Nonetheless, limited studies have made progress on the costs and benefits of green affordable housing, to guide decision-making, particularly in small communities. This study investigates density bonus options for green affordable housing by analyzing construction costs, transaction prices, and spillover effects of green certifications and affordable housing units. The authors employ pooled cross-sectional construction cost and price data from 422 Low-Income Housing Tax Credit (LIHTC) projects and 11,016 Multiple Listing Service (MLS) transactions in Virginia. Using hedonic regression analyses controlling for mediating factors, the study finds that the new construction of market-rate green certified houses is associated with small upfront costs, but large and statistically significant price premiums. In addition, the construction of market-rate green certified houses has large and statistically significant spillover effects on existing non-certified houses. Existing non-certified affordable housing units show small and often insignificant negative price impacts on the transaction prices of surrounding properties. The study concludes that the magnitude of social benefits associated with green building justifies the local provision of voluntary programs for green affordable housing, where housing is expensive relative to its basic cost of production.

7.1. Introduction

In the year 2017, the residential sector in the US consumed 20% of total energy production, and 89% of the total energy consumed by all sectors was produced using non-renewable energy sources, including petroleum, natural gas, coal (all of them considered fossil fuels) and nuclear power (not a fossil, but a nonrenewable, fuel) (USDOE, 2019). In the same year, according to the American Housing Survey data, about 47% of tenant households were cost-burdened (i.e., spent more than 30% of their income on housing costs) often due to poverty and, in large metropolitan areas, rising house prices (Glaeser & Gyourko, 2003). These trends indicate that there is a critical need to simultaneously address housing affordability and environmental sustainability in the residential sector, to reduce growing concerns about national economy, energy security, declining world reserves, and climate change.

The sustainable development paradigm has established Environmental Policy Integration (EPI) as a key strategy to increase organizational effectiveness in policy coordination and achieve equal weighting of sectorial and environmental policy (Adelle & Russel, 2013; Jordan & Lenschow, 2010). US states have integrated green building with affordable housing programs to achieve multiple environmental objectives, e.g., improving energy efficiency and water conservation, increasing indoor environmental quality, providing safe, healthy, and productive built environments, and promoting sustainable environmental stewardship (Pearce et al., 2007). Simultaneously, empirical measures have shown that green building increases housing affordability, through energy-efficiency savings that constitute a significant percentage of the annual income of extremely low-, very low-, and low-income families (Zhao et al., 2018). In the US, the supply of green affordable housing tends to be initiated by a synthesis of public and private sector actions, facilitated by mandates and incentives that address the risks and return of investment concerns of investors, owners, and financiers. Despite an overall increase in the market penetration of green buildings since the early 2000s, the diffusion of buildings with high environmental performance has been slow, as well as relegated to a slower new construction market, and the need for more affordable housing persists, particularly in areas where housing is expensive relative to its basic costs of production (Fuerst et al., 2014a). Currently, green buildings represent less than one percent of the total building stock, and tend to be in larger cities with higher socioeconomic capacity, and there is a concern about the economic viability of green affordable housing, particularly in smaller urban areas with existing stock (Chegut et al., 2019; McCabe, 2011).

To make cost and benefit analyses of different policies and programs, and to estimate the amount of incentives required to offset the upfront cost of green affordable housing in the residential sector, local governments need substantial empirical evidence on viability in the local housing market (Fuerst et al., 2014a; Hu, 2019). Previous research has primarily focused on the capitalization of nationally recognized labels (e.g., EnergyStar and LEED) into commercial property prices in larger cities, thus leaving little information on private and public benefits in the residential sector. The lack of systematic analyses and evidence on the construction costs and price impacts of green affordable housing could lead to irrational underinvestment, based on the widespread perception of green buildings as expensive to build, and affordable housing as the cause of lowered property values (Kahn & Kok, 2014).

This study investigates the potential benefits and policy implications of the integration of green building and affordable housing by analyzing the construction costs, sale prices, and spillover effects of affordable and market-rate houses, built to local green building standards. The next section describes recent empirical evidence regarding the costs and benefits of green building and affordable housing, and presents a concise microeconomic background of the application of cost and price premiums in the development of local tax and subsidy systems. Then, the authors employ pooled cross-sectional construction cost data from Low Income Housing Tax Credit (LIHTC) projects in Virginia to analyze the impact of an increase in the level of EarthCraft Virginia certifications (hereafter termed EarthCraft VA, and called Viridiant as of 2018)—a regional green building rating system—on the total construction cost of affordable housing projects between 2011 and 2019. This analysis focuses only on EarthCraft VA certified developments, since nearly 100% of approved LIHTC projects have pursued EarthCraft VA certification, and LIHTC project data, and detailed technical information on the design and construction of EarthCraft VA certified projects, are subject to the Freedom of Information Act (FOIA) and publicly available. The authors use pooled cross-sectional sale price data from Multiple Listing Service (MLS) transactions, the primary source of real estate market information in the US, to provide evidence on the magnitude and statistical significance of sale price premiums associated with market-rate EarthCraft VA certified single-family houses in Montgomery County, VA. In addition, we use MLS data to monetize spillover effects of certified market-rate houses and non-certified affordable houses in the county. We use the obtained results to analyze the feasibility of a voluntary density incentive program that offsets the upfront construction costs of green affordable housing.

Based on regression analysis, the authors concludes that (1) EarthCraft VA certified affordable housing developments are associated with small and statistically insignificant upfront costs, but large and statistically significant price premiums; (2) existing non-certified houses benefit from positive and statistically significant spillover effects, resulting from their proximity to recently constructed market-rate certified houses; (3) existing non-certified affordable housing units have negligible and often statistically insignificant negative spillover effects. Our data suggest that the diffusion of green buildings has not progressed in the county since 2014, despite the presence of significant social benefits. In the presence of regulatory barriers to mandatory green affordable housing programs, voluntary density incentive policies and programs could help facilitate the integration of green building with affordable housing, to promote environmental sustainability, environmental justice, and economic development where housing is expensive relative to its basic costs of production.

7.2. Literature Review

7.2.1. Costs and benefits of green building and affordable housing

The US Green Building Council (USGBC) defines green building as a comprehensive approach to planning, design, construction, operations, and, ultimately, end-of-life recycling or renewal of structures with several central considerations, including energy use, water use, indoor environmental quality, material selection and the building's effects on its site (USGBC, 2019a). There are several green building rating programs that encourage the development of green buildings and energy-efficient products and appliances in the US, of which LEED and EnergyStar are often cited as the two most prominent. USGBC, a private, membership-based, non-profit organization, developed LEED in 1999, and the Environmental Protection Agency and the Department of Energy jointly developed EnergyStar in 1992, extended it to buildings in 1995, and initiated the EnergyStar labeling program for buildings in 1999 (USGBC, 2019a). In a parallel effort, and at the regional level, Greater Atlanta Home Builders Association and Southface established EarthCraft jointly in 1999, which was extended to Virginia in 2006 as

EarthCraft VA, and named Viridiant since 2018, whose certification standards are similar to or higher than EarthCraft's (EarthCraft, 2019). To become certified, an EarthCraft project must meet or exceed the local International Energy Conservation Code (IECC), requirements for the energy code for energy and water efficiency, and meet certain required standards and optional points in a series of categories, determining Certified, Gold, or Platinum levels of certification (i.e., the expected levels of environmental performance). An analysis of LEED and Energy Star-certified properties suggests several trends over the first decade after the programs' inception: increases in the rate of adoption, improvements in certification standards, decreases in the share of buildings certified at the lowest level, growth of the share of private, versus public, developers (Fuerst, 2009b). Previous research has compared the costs and benefits of green buildings to those of conventional buildings (e.g., in terms of energy and water efficiency, indoor environmental quality, health and productivity), using a variety of indicators, but construction costs and price premiums are among the most concrete indicators to reflect total costs and total benefits for the purpose of policy and planning (Zuo & Zhao, 2014).

During the last decade, a growing body of empirical research has tracked the economic performance of green buildings, based on reported construction costs, rent, sale prices, and occupancy rates. So far, there is little evidence on the magnitude of upfront green construction cost premiums in the residential sector in the US, and available studies in the commercial sector provide no conclusive answers. Two recent reviews, covering a variety of geographies, building types, and rating systems, Dwaikat & Ali (2016) and Zhang et al., (2018) report that the majority of incremental costs for all levels of certification fall within the range of -0.4%–21% and -0.4%–11%, respectively. Large-sample statistical studies of new constructions, however, have reported narrower ranges. For instance, Matthiessen & Morris (2004) and Matthiessen & Morris (2007) did not find a statistically significant upfront cost premium from an analysis of the actual cost of green buildings when compared to conventional ones. Based on anecdotal evidence from homebuilders, EarthCraft reports an upfront cost premium of 0.5%–3%, which is consistent with a hypothesis by Fischer & Lyon (2014), suggesting that entry-level certification standards and costs are often kept loose and low to attract stakeholders with low willingness to pay for environmental labels (Earth Craft, 2019). In addition to the impacts of confounding variables that could explain the variability of results (e.g., stage of involvement with the program, choice of program and the magnitude of its requirements, builders' level of experience, building characteristics, the choice of research methodology), some variability is attributed to the nature of green building programs (e.g., the availability of optional easy or hard credits, and interactions of project-specific issues and program credits) (GSA, 2004).

Although empirical cost estimates are often based on industry reports, more comparable systematic studies have emerged on estimated rents and sale price premiums of green certification on office properties in the US, based on commercial real estate databases (Eichholtz et al., 2010, 2013; Fuerst & McAllister, 2011a, 2011b; Robinson & McAllister, 2015; Wiley et al., 2010). According to these studies, average sale price premiums for EnergyStar and for LEED-certified buildings could fall between 5.1%–31% and 11.7%–28.4%, respectively. In some cases, results are not statistically significant, and contrasting results have been found on the incremental premiums associated with different levels of certification. In the residential sector, there is comparatively less research available on both construction costs and price premiums. In a study of three US metropolitan areas between 2005 and 2011 Walls et al., (2017) finds 2% and 4%–9% sale price premiums associated with single-family units with EnergyStar and local green building certifications, respectively. Kahn & Kok (2014) finds EnergyStar certified single-family dwellings in California transacted at an average premium of 4.7% between 2005 and 2012, with higher premiums for GreenPointRated and LEED certifications, although these differences were insignificant. Stephenson (2012) estimated a sale price premium of 8.3% for EarthCraft certified houses in Atlanta. Using American Community Survey 2007 data, Koirala et al., (2014) estimated that energy efficiency codes IECC 2003-06 resulted in an increase of 23.25% in house rents. Based on contingent valuation analysis, Robinson et al., (2016) estimated that the aggregate stated willingness to pay for green features was 9.3%. A general conclusion from the past analyses is that green buildings can have small upfront cost premiums, but price premiums often offset the cost of certification.

The US Department of Housing and Urban Development (HUD) broadly defines affordable housing as "housing for which the occupant(s) is/are paying no more than 30% of his or her income for gross housing costs, including *utilities*" (Ezennia & Hoskara, 2019; HUD, 2019a). While helpful, this definition combines all the potential reasons for lack of affordability (e.g., housing prices, housing quality, household income, household choices, public policies), thus, making affordability difficult to understand (Quigley & Raphael, 2004). A voluntary inclusionary housing program—used interchangeably with an affordable housing program—places a rent or price control on a percentage of new developments to keep its units affordable to very low-, low-, or moderate-income households for a pre-determined period of time, and in return, offers economic or zoning benefits to builders to offset the imposed costs (Powell & Stringham, 2005). Many program-specific studies on the costs and benefits of affordable housing have explored diverse effects of housing conditions (e.g., affordability, stability, quality, location) on program participants (e.g., residential mobility, residents' satisfaction, health outcomes, labor market outcomes, educational outcomes, criminal offenses, parenting behavior, etc.) and stakeholders (e.g., origin communities, host communities, taxpayers, and government agencies) but the most common method has been quantifying the value impact of locating near affordable housing properties (Baum-Snow & Marion, 2009; Johnson et al., 2002; Mueller & Tighe, 2007). A general conclusion from existing value impact analyses is that conventional affordable housing properties can have negative but small spillover effects, which should be addressed by planning and policy instruments (Nguyen, 2005). However, there is also evidence that the construction of well-maintained affordable housing properties can appreciate property values in neighborhoods containing abandoned or physically deteriorating housing units (Santiago et al., 2001).

Since the inception of green building rating systems in the early 2000s, state and local governments have provided incentives to promote the integration of green building with affordable housing. Many researchers have seen the integration of environmental principles into traditionally single-purpose policy sectors, such as affordable housing, as a goal of governance to reduce policy conflicts and inefficiencies (Kivimaa & Mickwitz, 2006; Runhaar et al., 2014). As affordable housing advocates increasingly demand the inclusion of affordable housing in locations beyond central cities, this integration could make affordable housing developments more acceptable for host neighborhoods in the suburbs, and more cost-effective for low-income occupants on a life-cycle basis, thus helping to achieve multiple policy goals (Bradshaw et al., 2005; Foy, 2012; Mueller & Tighe, 2007). Nonetheless, costs and benefits of green affordable housing have rarely been investigated, despite the fact that low-income households are often exposed to low quality housing conditions and thus bear disproportionate costs of energy, transport, healthcare, safety, etc. (Chegut et al., 2016; Zhao et al., 2018). Except for a few recent studies in the EU, available evidence on green building cost premiums is from the gray literature on the commercial sector, thus leaving little information for public and private entities considering green building certifications in the housing sector (Chegut et al., 2019; Zhang et al., 2018).

7.2.2. Incentivizing the supply of green affordable housing

Focused on quantifying the relationships between local characteristics and the market penetration of green buildings, a number of previous studies have recognized the importance of economic, political, environmental, and social composition of urban areas to the market penetration of green building. For instance, Eichholtz et al. (2016) concluded that some industry types (e.g., the financial services industry) are more likely than others to choose to locate in green buildings, thus, cities with a high concentration of those industries are more likely to have a higher number of green buildings per capita. The work of Fuerst et al. (2014a) concluded that large, growing, and wealthy cities with a highly educated workforce are more likely to have a higher adoption of green buildings. Financial benefits of green buildings and features (e.g., solar panels, green roofs, etc.) increase where more energy savings can be achieved due to the scarcity of water reserves (i.e., higher water costs) or frequency of heating or cooling degree days (Kahn & Kok, 2014; Simons et al., 2009). Such economic, political, environmental, and social drivers could help to explain the reasons behind the slow market penetration of green buildings, despite documented tangible benefits. Therefore, municipal policy measures—whether regulatory policies or incentives—should be seen as a small fraction of all drivers of green building (Choi, 2010; Simcoe & Toffel, 2014).

Besides findings on the effective real-world performance and economic viability of green buildings, states and local governments have increasingly developed policies and programs that require or encourage public–private partnerships to internalize life-cycle externalities associated with conventional buildings (e.g., construction waste, water run-off, energy inefficiency) (DSIRE, 2019; IEA, 2019; Olubunmi et al., 2016; USGBC, 2019b). These policy instruments include a blend of energy price increases (e.g., by introducing an ecological tax), mandatory energy-efficiency standards, and incentives for new construction and rehabilitation projects (Alberini & Filippini, 2011). Mandatory green building standards often apply to publicly owned or funded projects, and voluntary economic instruments (e.g., loans, tax-based incentives, soft-cost assistance, technical assistance, information provision) and zoning instruments (e.g., height and/or density incentives, parking incentives, flexible lot sizes) influence the incorporation of green standards in both public and private sectors (Circo, 2007). Assuming other drivers of green building are, to some extent, present, the goal of an incentive is to help local builders to supply an efficient quantity of green affordable housing when the free market fails to provide a socially optimal level of such benefits for the society. Previous research considers a variety of factors that could lead to underinvestment in green building, including but not limited to, split incentives, information asymmetries, risk aversion, skill shortages, and analytical failures (Deng & Wu, 2014; Fuerst et al., 2014a; Matisoff et al., 2016).

The rationale for inclusionary housing programs (i.e., incentivizing private developers to incorporate affordable housing into market-driven developments) is the historic shortage of housing units for low-income households (Sirmans & Macpherson, 2003). Underinvestment in affordable housing has been historically exacerbated by local opposition from host neighborhoods to equitable affordable housing siting. For instance, in a survey of 74 not-for-profit and for-profit developers, Scally & Tighe (2015) found that 70% of developers experienced local opposition to affordable housing developments, leading to construction delays,

delays in leasing or selling units, denied building permits, reduction in the number of units, changes in project location, or cancellation of the entire development. The positive externalities graph (Figure 7.2.1) illustrates the effect of introducing a per square foot incentive correcting the under-provision of green affordable housing in free market. A supply incentive would increase the free market supply quantity (Q_1) toward a socially optimal level (Q_2), where the marginal private/social cost of production (MPC/MSC) is equal to the marginal social benefit of consumption (MSB). The upward shift in the marginal private benefit (MPB) curve creates the triangular grey area, which represents the quantity of positive externality known as welfare gain. Marginal private cost (MPC), also known as marginal cost of production, is the change in the producer's total cost, resulting from the production of an additional unit, and marginal private cost (MPC) could be considered equal to marginal social cost (MSC), as there is no external cost from the production of green housing relative to conventional housing.

While aiming for socially efficient green affordable housing, incentives are often linked to other urban planning goals, to further address market failures in environmental sustainability and economic development. For instance, urban planners strategically use density incentive programs to direct development to areas with locational and temporal priorities and common challenges. In addition, green building programs could provide opportunities to fund or realize long-term community benefits (e.g., open space preservation, historic preservation, pedestrian and bicycle connectivity, compliance with urban design guidelines) in new construction projects. These programs could work towards a more efficient use of existing infrastructure (e.g., higher transit ridership, reduction in road construction) and penalize goods with negative externalities (e.g., congestion, pollution) (Deng & Wu, 2014; Matisoff et al., 2016). Incentives, however, have limited power to induce general growth and increase affordability by reducing housing prices in markets with a low price-elasticity of supply or demand. In fact, any changes in supply (e.g., associated with regulations, approval delays or growth management) or demand (e.g., associated with changes in income, demographics, mortgage mechanisms) might not be feasible without major regulatory reforms (Eicher, 2008; Ganong & Shoag, 2017; Malpezzi & Vandell, 2002). Figure 7.2.2 illustrates such inefficient markets. On the left graph, S_1, D_1, Q_1, and P_0 are supply curve (marginal cost), demand curve (marginal benefit), supply quantity, and equilibrium price in the existing housing market, respectively. The introduction of a per-square-foot subsidy would create a new equilibrium, in which Q_2, P_p, and P_c are the new supply quantity, the unit price for firms, and the unit price for costumers, respectively. The right graph represents a market with a low-price elasticity of supply, in which introducing the same amount of subsidy ($P_p - P_c = P'_p - P'_c$) would have a little impact on supply quantity (Q'_2), while giving more benefits to producers than consumers. Similar mechanisms are in place for introducing new residential energy efficiency policies that depend on the price elasticity of demand for energy (Alberini & Filippini, 2011). For guidance and more information, see Varian (2014).

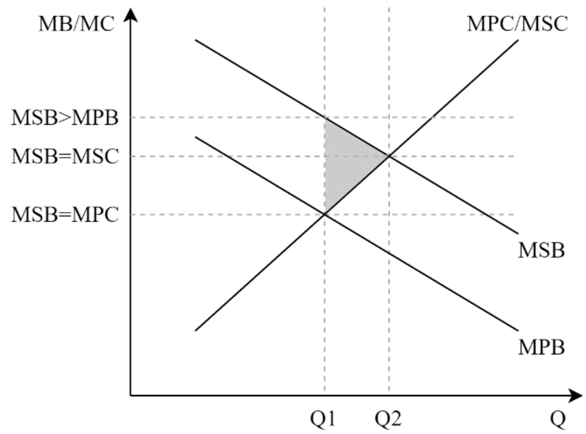


Figure 7.2.1 Marginal benefit (MB) and marginal cost (MC) for individuals and the society

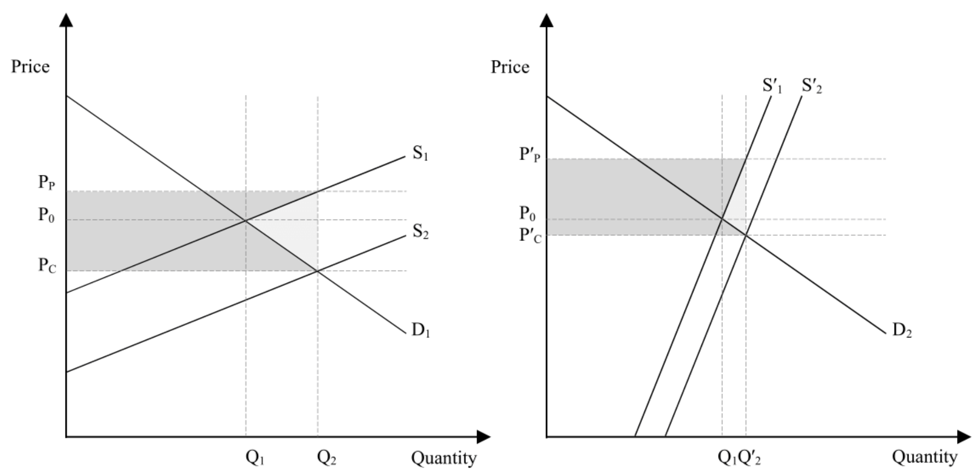


Figure 7.2.2 Price elasticity (left) and inelasticity (right) of supply

The integration of environmental principles in an affordable housing program requires innovative policymakers to monetize and evaluate the private and public costs and benefits of the program, based on local demographic and housing market data. The extant literature suggests that certified offices and houses have higher rents and/or prices that can come from energy efficiency, water efficiency, improved air quality, and occupant productivity. Nonetheless, evaluation of public benefits (i.e., positive externalities, such as eco-system protection, and waste and carbon dioxide emission reduction) associated with green building against environmental damages caused by conventional buildings has been documented with insufficient attention and consensus in the literature (Chegut et al., 2014; Zhang et al., 2018). Simulation-based life-cycle analyses have provided valuable insight into the environmental impacts of green buildings (Cabeza et al., 2014), but little, if any, research has been performed to date to analyze the spillover effects of green buildings, e.g., in terms of the impact of the presence or density of green buildings on prices of nearby non-green buildings. Such analyses would have provided more details on price dynamics and the social benefits of green buildings, and consequences for local sustainability and climate change policy. The need for monetary analyses is reinforced by the fact that construction cost data, performance data (e.g., energy use, water use) and outcome data (e.g., on health, pollution, congestion) are generally confidential, limited, or simply unavailable, and engineering simulation studies could be hard to compare or have restricted generalizability, due to heterogeneities involved in the operation stage. Monetizing all the impacts of green affordable housing could reduce uncertainties associated with forecasts, and allow policy analysts to obtain systematic and context-driven conclusions about the social benefits of such programs, based on cost benefit analysis (Fuguitt & Wilcox, 1999; Kats & Alevantis, 2003).

This analysis aims to address the lack of attention in the existing literature to the residential sector in smaller urban areas, through a cost analysis of EarthCraft VA certified LIHTC developments, a price analysis of market-rate EarthCraft VA certified single-family houses, and an analysis of spillover effects associated with market-rate certified houses and affordable non-certified houses in Montgomery County, VA. As previous research has documented large associations between the presence of density incentives and a higher production of green residential buildings in a state or county, we apply our findings on costs and prices to the design of a county-wide voluntary density incentive program, to explore how much additional floor area could compensate local builders for investment in the construction of green affordable housing units in for-sale and for-rent scenarios (Choi, 2010; Kontokosta, 2011; Sanderford et al., 2018; Sauer & Siddiqi, 2009; Simons et al., 2009).

7.3. Methodology

7.3.1. Overview of study context and datasets

This study employs two separate datasets, along with the corresponding regression analyses of construction costs and transaction prices of green affordable housing. The first dataset includes pooled cross-sectional LIHTC construction cost data from all publicly available applications on the Virginia Housing Development Authority website, as of October 2019. The cost premium sample includes 422 new construction and rehabilitation residential projects across VA, with Gold and Platinum levels of EarthCraft certification. The second dataset includes pooled cross-sectional MLS transaction data for housing units in Montgomery County, VA, between 2000 and 2019, which were used to estimate price premiums and the spillover effects of EarthCraft VA certified houses. The authors employed time-, site-, and district-specific fixed effects to capture temporal and locational changes in closed/transaction prices. We removed units built before 1800 and units with above 100 acre lots as outliers. The price premium sample includes 38 EarthCraft certified houses built between 2008 and 2019, with an average transaction price of $441,779.8 (SD 131,065), and 45 affordable rental apartment complexes. The affordable properties included Section-8 rental housing assistance apartments, apartments that accepted housing vouchers, and income-restricted complexes. The certified houses and affordable properties were in census blocks, in which 1098 and 2199 transactions took place during the study period, and located in different areas within the county, thus exhibiting no spatial autocorrelation or clustering impacts. Latitude and longitude data were obtained from Texas A&M Geo-Services website, to control for zoning characteristics and potential externalities. Data on population, education, and income at the Census-defined block group level were obtained from the US Census Bureau's 2018 ACS 5-year estimates.

We used STATA 14 to perform hedonic regression analyses, to assess the total construction cost and transaction price impacts of EarthCraft VA certification, and to estimate the spillover effects of EarthCraft VA certified homes and affordable housing properties on non-green houses in Census-defined blocks. The hedonic approach to sale price reflects both supply and demand influences and recognizes the value of a house as an additive function of the utility-bearing characteristics of the structure, the lot, and the neighborhood in which the house is located (Brueckner, 2011). Based on the theory of hedonic prices formulated by Rosen (1974), Equation 1 is one of the earliest and most frequently used applications of linear hedonic regression models in housing offered by Grether & Mieszkowski (1974), where v_i is the house value and S_i , L_i , and N_i are vectors of characteristics of the structure, lot, and neighborhood, and α, β, and γ are vectors of unknown coefficients. Virtually all previous studies on green building price premiums used similar multivariate log–linear (i.e., semi-log) hedonic models, with time and location as fixed effects (Brounen & Kok, 2011; Chegut et al., 2019; Deng et al., 2012; Walls et al., 2017). For the purpose of this study, Equation 1 could be re-written as Equation 2, where G_i is a binary variable used to obtain the price premium of having an EarthCraft VA certification, Y_m and M_n denote the fixed effect of the year and the month of transaction, C is a constant term, and η , δ, and θ are coefficients.

$$ln\, v_i = S_i\alpha + L_i\beta + N_i\gamma + \bar{\mathcal{E}}_i$$ Equation 1

$$ln\, v_i = G_i\eta_i + \sum_{j=1}^{5} S_j\alpha_j + \sum_{k=1}^{16} L_k\beta_k + \sum_{l=1}^{16} N_l\gamma_l + \sum_{m=1}^{19} Y_m\delta_m + \sum_{n=1}^{12} M_n\theta_n + C + \bar{\mathcal{E}}_i$$ Equation 2

To obtain estimates for a voluntary density incentive program for green affordable housing in Montgomery County, VA we assumed that there are 3%, 6%, and 10% increases in construction costs associated with EarthCraft VA Certified, Gold, and Platinum levels of certification, based on a synthesis of the literature, EarthCraft industry reports, and our regression analyses. To estimate the amount of additional floor area required to incentivize green building in the for-sale scenario, we set the estimated total sale profit from new construction (i.e., market price minus the total cost of financing and production, including general contractor's overhead and profit) under the density incentive zoning ordinance, equal to the estimated total profit from new construction under the existing zoning ordinance, and solved for the increased floor area under the density incentive zoning ordinance. Green building area (Q_g) can be estimated using Equation 3, where C and C_g are production and financing costs, and Q and Q_g are the total areas of non-green and green buildings, respectively, and P is the sale price of non-green buildings. Similarly, the incentivized affordable housing floor area is estimated using Equation 4, where P_m and P_a are sale prices, and Q_m and Q_a are the total areas of market-rate and affordable rate units, respectively. To solve for the necessary increase in density, Q_a is treated as a percentage of Q_m. In this equation, C_e and C_i are production and financing costs of building under existing zoning and under incentive conditions, respectively, and Q_e is the total area under existing zoning conditions. Alternatively, the total loss of a building's operating income, due to the presence of rent caps on affordable units, can be considered as a per unit area additional cost of construction. In a for-rent affordable housing scenario, the net monthly operating income is equal to the constant monthly construction loan due (A), which is found by the amortization calculator formula (Equation 5), using the total cost of construction loan (P), monthly interest rate (r), and total number of payments (n). When there is a deficit in the net monthly operating income as the result of rent caps on affordable units (often determined based on 30% of household income), the net present value of the total deficit plus the green premium, if present, is translated into a percentage of the net monthly operating income to determine the density incentive.

$$(P - C) \times Q = (P - C_g) \times Q_g \text{ or } Q_g = (P - C) \times Q/(P - C_g)$$ Equation 3

$$(P_m - C_e) \times Q_e = (P_m \times Q_m + P_a \times Q_a) - C_i \times (Q_m + Q_a)$$ Equation 4

$$A = P\frac{r(1+r)^n}{(1+r)^n - 1}$$ Equation 5

Table 7.3.1 and Table 7.3.2 include descriptive statistics of the sample set and descriptions of primary independent variables used in this analysis. In addition to these variables, price estimate models accounted for the fixed effects of years of transaction (19 variables), site characteristics (16 variables), and neighborhood characteristics (16 variables). As opposed to single-family and multi-family developments, planned residential developments (PRDs) often achieve multiple incentives (e.g., flexible unit sizes, increased FARs, and decreased minimum lot sizes, and multiple community features) and, thus, should be studied on a case-by-case basis, for the purpose of allocating density incentives (see Dowall (1985)). Third-party consultants should examine the accuracy of pro-forma statements of PRD builders, and the minimum profitable production costs and land costs can be obtained from RSMeans and linear regression of land price on land characteristics (see, e.g., Glaeser & Gyourko (2018)). Detailed sale price estimates can be obtained from MLS data using hedonic regression—or other advanced multivariate analytical tools—that accounts for the variety of unit characteristics. Once the difference between the estimated total costs and sale prices are determined, planners could negotiate with the builder on the project's expected benefits for the society, based on the magnitude of the estimated profit.

Table 7.3.1 Description of variables in construction cost models (n = 230)

Variable	Definition	Mean	Std. Dev.	Min	Max
Continuous					
Buildings	Number of buildings in a project	3.913	4.889	1	30
Cost	Total residential space construction cost in USD	11,100,000	6,876,547	2,804,831	51,300,000
Latitude	Geographical latitude of project city in decimal units	37.699	0.775	36.600	39.770
Ln_Cost	Natural logarithm of residential space construction cost	16.077	0.516	14.847	17.752
Longitude	Geographical longitude of project city in decimal units	−7.289	1.067	−86.160	−75.820
Residential Area	Total air-conditioned residential space area in square foot (SF)	77720	36982	21846	262648
Stories	Number of building stories	3.367	1.459	1	12
Year	Project year	2015.191	2.488	2011	2019
Binary					
Gold Level	If building has Gold Level EarthCraft certification (1)	0.387	0.488		
Platinum Level	If building has Platinum Level EarthCraft certification (1)	0.613	0.488		

Table 7.3.2 Description of variables in transaction price models (n = 11,016).

Variable	Definition	Mean	Std. Dev.	Min	Max
Continuous					
Acreage	Total lot area in acres	1.342	4.368	0.01	100
Area	Total finished interior space area in SF	2074.060	849.932	100	6696
Education	Percent 25+ adults with bachelor's degree or higher in BG	50.394	22.626	5.982	100
Full Baths	Total number of full bathrooms	2.172	0.722	0	6
Half Baths	Total number of half bathrooms	0.482	0.546	0	6
Income	Median household income in BG in 2017 in 1000 USD	70.866	26.453	6.86	141.25
Latitude	Geographical latitude of lot in decimal units	37.177	0.060	36.994	37.348
Ln_Price	Natural logarithm of the total house price	12.215	0.516	8.700	13.805
Longitude	Geographical longitude of lot in decimal units	−80.415	0.049	−80.611	−80.188
Month	Transaction month fixed effects	6.516	2.982	1	12
Population	Total population living in BG in 100 persons in 2017	19.271	6.339	5.29	33.51
Price	Total house price in USD	228,435.800	115,920.100	6,000	990,000
Year	Transaction year fixed effects	2010.935	5.155	2001	2019
Year Built	Year of construction	1985.561	23.454	1800	2019
Binary					
Christiansburg	If building is in Christiansburg (1)	0.394	0.489		
EarthCraft	If building is EarthCraft certified (1)	0.003	0.055		
EnergyStar	If building is EnergyStar certified (1)	0.001	0.037		
Montgomery	If building is in Montgomery (1)	0.324	0.468		
Public Transport	If public transport is within walkable distance (1)	0.088	0.283		
Recreation	If recreational facility is within walkable distance (1)	0.050	0.217		
School	If elementary school is within walkable distance (1)	0.078	0.268		
Townhouse	If building is a townhouse (1)	0.127	0.333		

7.4. Results

7.4.1. Construction cost premiums

The LIHTC properties data suggest that the level of 'greenness' of LIHTC buildings has become increasingly important, as opposed to simply obtaining the 'barely green' (i.e., EarthCraft VA Certified) certification. Table 7.4.1 presents results from the regression analysis of the total construction cost of LIHTC residential projects with Gold and Platinum levels of EarthCraft certification. To interpret the percentage change in construction cost in these semi-log models, where the dependent variable has been log-transformed but the predictors have not, we exponentiate the coefficient of the independent variable, subtract one from the result, and multiply it by one hundred to interpret coefficients in percentages. The first model (All) includes both new construction and rehabilitation projects and indicates a significant cost impact of change in the level of certification. Nonetheless, the other models distinguish new construction and rehabilitation project data, respectively, suggesting that a change of certification level does increase the average cost of new constructions (04.60%, p = 0.368) but the increase is statistically insignificant. Model 2 suggests that the change has a considerable impact on the total cost of rehabilitation, and the impact is statistically significant (12.60%, p = 0.033). The 95% confidence intervals for new construction and rehabilitation impacts based on Robust Standard Errors (R.S.E.) are -5.94%–15.91% and -0.16%–26.99%, respectively.

Table 7.4.1 Ordinary least squares (OLS) regression analyses of residential construction cost.

Variable	All		New Construction		Rehabilitation	
	Coef.	R.S.E.	Coef.	R.S.E.	Coef.	R.S.E.
Platinum Level	0.0849**	0.0406	0.0450	0.0521	0.1187**	0.0610
Rehabilitation	−0.4941***	0.0400				
Age					0.0041***	0.0012
Buildings	0.0106***	0.0032	0.0094**	0.0036		
Residential Area	1.07×10^{-5} ***	6.55×10^{-7}	8.42×10^{-6} ***	7.02×10^{-7}	1.42×10^{-5} ***	7.85×10^{-7}
Stories	0.1252***	0.0177	0.0977***	0.0217	0.1007***	0.0210
Latitude	0.1128***	0.0229	0.1908***	0.0300	0.0252	0.0391
Longitude	0.0199	0.0102	0.0505***	0.0211	0.0232	0.0121
Year	0.0571***	0.0078	0.0466***	0.0101	0.0690***	0.0110
Constant	−102.9944***	15.8505	−82.1426***	20.5282	−124.1019***	22.1574
Observations	422		230		191	
Prob > F	0.000		0.000		0.000	
R-squared	0.857		0.790		0.800	
Adj R-squared	0.854		0.783		0.792	
Root MSE	0.292		0.240		0.296	

Note: The dependent variable is the natural log of the total cost. 2. The reference level of EarthCraft certification for which the dummy variable is zero, is EarthCraft Gold. 3. *** and ** denote p < 0.01 and p < 0.05, respectively.

7.4.2. Price Premiums and Spillover Effects

Table 7.4.2 presents results from the regression analysis of single-family houses with and without EarthCraft VA certification. Based on Model 1, which includes the hedonic characteristics of houses, lots, and neighborhoods, EarthCraft VA-certified homes are, on average, associated with a 15.06% sale price premium compared to otherwise identical buildings, and the premium is statistically significant. Houses with EnergyStar appliances are, on average, associated with a 5.81% sale price premium compared to houses without those features, but the premium is statistically insignificant. Model 2 and Model 3 control for the socioeconomic (SES) variables of education, income, and population at the Census-defined block group level, the smallest geographical level for which these data are available. Although these SES variables show small coefficients, the inclusion of these statistically significant variables increases the estimated average sale price premium for EarthCraft VA-certified homes from 15.06% to 16.98% and 18.42%. The models also suggest that houses located within walking distance of public transport on MLS records are negatively affected by some undesirable locational characteristics (e.g., air pollution, congestion, noise) and, on average, are 2.69% less valuable. Nonetheless, houses located within walking distance of elementary schools are transacted with an average of 4.85% sale price premiums, compared to similar houses not located within walking distance of the district elementary school.

Table 7.4.2 OLS regression analyses of single-family house prices

Variable	Model-1		Model-2		Model-3	
	Coef.	R.S.E.	Coef.	R.S.E.	Coef.	R.S.E.
EarthCraft	0.1403***	0.0282	0.1568***	0.0260	0.1691***	0.0288
EnergyStar	0.0565	0.0425	0.0725**	0.0362	0.0475	0.0380
Area	0.0003***	0.0000	0.0003***	0.0000	0.0003***	0.0000
Full Baths	0.0534***	0.0056	0.0487***	0.0055	0.0534***	0.0056
Half Baths	0.0666***	0.0051	0.0662***	0.0050	0.0697***	0.0051
Townhouse	−0.1493***	0.0066	−0.1589***	0.0065	−0.1487***	0.0067
Year Built	0.0047***	0.0002	0.0047***	0.0002	0.0046***	0.0002
Acreage	0.0094***	0.0013	0.0094***	0.0013	0.0093***	0.0013
Latitude	0.2055	0.1513	−0.1308	0.1561	0.1431	0.1549
Longitude	−0.4008***	0.1225	−0.1932	0.1244	−0.4624***	0.1239
Public Transport	−0.0265***	0.0076	−0.0190**	0.0075	−0.0131	0.0081
Recreation	0.0183	0.0098	0.0104	0.0097	0.0178	0.0101
School	0.0474***	0.0082	0.0280***	0.0083	0.0458***	0.0083
Christiansburg	−0.0438***	0.0150	−0.0194	0.0151	−0.0474***	0.0152
Montgomery	−0.0671***	0.0100	−0.0216**	0.0103	−0.0662***	0.0102
Education			0.0032***	0.0002		
Income					0.0011***	0.0001
Population			−0.0011**	0.0005	−0.0015***	0.005
Year FE	Yes		Yes		Yes	
Month FE	Yes		Yes		Yes	
Site FE	Yes		Yes		Yes	
District FE	Yes		Yes		Yes	
Observations	11,016		10,996		10,773	
Adj R-squared	0.746		0.752		0.748	
Root MSE	0.261		0.258		0.261	

Note: The dependent variable is the natural log of transaction price. 2. *** and ** denote $p < 0.01$ and $p < 0.05$, respectively. 3. FE refers to fixed effects.

Table 7.4.3 presents results from the regression analysis of spillover effects of certified market-rate and non-certified affordable housing units on other houses within the Census-defined block. Based on Model-1, which includes hedonic characteristics of houses, lots, and neighborhoods, the presence of certified units in a block is, on average, associated with a 5.82% sale price premium for non-certified houses within the block (the 95% confidence interval is 4.43%–7.23%), and the spillover effect is statistically significant at 99%. The presence of non-certified affordable housing units is associated with an average of -0.72% sale price premiums for non-certified houses within the block (the 95% confidence interval is -1.88%–0.42%), but the spillover effect is statistically insignificant. Model 2 and Model 3 control for the socioeconomic variables of education, income, and population at the block group level, and show slight changes, but statistically significant spillover effects. Table 7.4.4 presents a similar analysis of spillover effects in four different historical periods. The first EarthCraft VA-certified houses in Montgomery County, VA, were built in 2008. Therefore, Model 1 to Model 4 suggest that: (1) blocks in which market-rate certified houses were built in 2008 were relatively more valuable than other blocks in the county; (2) the value premium of those blocks in which market-rate certified houses were built in 2008 and later, has continuously increased over time. During the study period, the presence of affordable housing units was associated with negligible spillover effects, which were often statistically insignificant.

Table 7.4.3 Spillover effects of certified houses and non-certified affordable houses

Variable	Model-1		Model-2		Model-3	
	Coef.	R.S.E.	Coef.	R.S.E.	Coef.	R.S.E.
Green building	0.0566***	0.0067	0.0447***	0.0066	0.0662***	0.0070
Affordable housing	−0.0072	0.0058	0.0037	0.0058	−0.0029	0.0059
Area	0.0003***	0.0000	0.0003***	0.0000	0.0003***	0.0000
Full Baths	0.0547***	0.0056	0.0507***	0.0055	0.0551***	0.0056
Half Baths	0.0674***	0.0051	0.0667***	0.0050	0.0713***	0.0051
Townhouse	−0.1430***	0.0067	−0.1526***	0.0067	−0.1425***	0.0068
Year Built	0.0046***	0.0002	0.0046***	0.0002	0.0046***	0.0002
Acreage	0.0094***	0.0013	0.0094***	0.0013	0.0093***	0.0013
Latitude	0.2300	0.1519	−0.1143	0.1566	0.1743	0.1552
Longitude	−0.3894***	0.1228	−0.1941	0.1243	−0.4509***	0.1238
Public Transport	−0.0301***	0.0076	−0.0221***	0.0075	−0.0159	0.0081
Recreation	0.0176	0.0098	0.0102	0.0097	0.0168	0.0101
School	0.0497***	0.0082	0.0298***	0.0083	0.0474***	0.0083
Christiansburg	−0.0429***	0.0151	−0.0186	0.0151	−0.0454**	0.0152
Montgomery	−0.0623***	0.0100	−0.0172	0.0103	−0.0594***	0.0101
Education			0.0032***	0.0002		
Income					0.0011***	0.0001
Population			−0.0011**	0.0005	−0.0017***	0.0005
Year FE	Yes		Yes		Yes	
Month FE	Yes		Yes		Yes	
Site FE	Yes		Yes		Yes	
District FE	Yes		Yes		Yes	
Observations	10,975		10,975		10,741	
Adj R-squared	0.745		0.751		0.748	
Root MSE	0.261		0.258		0.261	

Table 7.4.4 Spillover effects of certified houses and non-certified affordable houses

	2004–2007		2008–2011		2012–2015		2016–2018	
	Coef.	R.S.E.	Coef.	R.S.E.	Coef.	R.S.E.	Coef.	R.S.E.
Green building present	0.0275**	0.0137	0.0371**	0.0188	0.0573***	0.0133	0.0781***	0.0130
Affordable housing present	−0.0197*	0.0104	−0.0138	0.0152	0.0073	0.0121	−0.0061	0.0120
Area	0.0003***	0.0000	0.0003***	0.0000	0.0003***	0.0000	0.0003***	0.0000
Full Baths	0.0592***	0.0100	0.0717***	0.0138	0.0540***	0.0118	0.0527***	0.0120
Half Baths	0.0723***	0.0087	0.0783***	0.0130	0.0662***	0.0113	0.0556***	0.0103
Townhouse	−0.1196***	0.0129	−0.1263***	0.0156	−0.1714***	0.0135	−0.1732***	0.0128
Year Built	0.0038***	0.0003	0.0045***	0.0005	0.0052***	0.0004	0.0050***	0.0004
Acreage	0.0106***	0.0025	0.0183***	0.0037	0.0110***	0.0020	0.0080***	0.0019
Latitude	0.2981	0.2395	0.5963	0.4335	0.5681	0.4052	−0.8080**	0.3959
Longitude	−0.6974***	0.1801	−0.3204	0.3291	−0.0799	0.3157	−0.1861	0.3378
Christiansburg	−0.0092	0.0299	−0.0623	0.0432	−0.0771**	0.0338	−0.0232	0.0289
Montgomery	−0.0478***	0.0186	−0.0543**	0.0273	−0.1112	0.0220	−0.0589***	0.0198
Year FE	Yes		Yes		Yes		Yes	
Month FE	Yes		Yes		Yes		Yes	
Site FE	Yes		Yes		Yes		Yes	
District FE	Yes		Yes		Yes		Yes	
Observations	2,972		1,887		2,494		2,700	
Adj R-squared	0.781		0.736		0.745		0.730	
Root MSE	0.219		0.275		0.268		0.278	

7.4.3. Density Incentive Calculations

Table 7.4.5 presents the results of our density incentive estimates for single-family and multi-family housing of various sizes in for-sale and for-rent scenarios, respectively, where costs and prices are shown in per square foot of residential area. In the for-sale scenario, builders recover cost premiums at sale times, whereas, in the for-rent scenario, cost premiums are recovered in the long run. In the for-rent scenario, the amount of incentive, i.e., the percentage of additional floor area, to compensate builders, is proportional to, and slightly higher than, the green building certification cost premium expressed in percentage. Table 7.4.6 presents an example of a 100,000 sqft low-rise multifamily building, in which about 25% of the total market-based rent is lost, due to the presence of affordable housing units, dedicated to local workforce with different levels of income relative to the area median income. In this case, an increase in the residential area to 124,813 sqft could recover the loss in rent, and further increases to 128,669 sqft, 132,651 sqft, and 138,180 sqft are enough to recover the total construction cost of different levels of EarthCraft VA certification during the operation of the building. The calculations are based on a 15-year construction loan with a 5% interest rate.

Table 7.4.5 Estimates of incentives for green single-family and multi-family housing

	Area (sqft)	Price/Rent	Price/Rent	Construction Cost			Incentive		
	Non-Green	Non-Green	Non-Green	Certified	Gold	Platinum	Certified	Gold	Platinum
Single-Family	1200	$199	$135	$139	$143	$149	6.85%	14.71%	27.18%
(For sale)	1400	$180	$128	$132	$136	$141	8.06%	17.54%	33.09%
	1600	$176	$123	$127	$131	$136	7.62%	16.50%	30.89%
	1800	$165	$118	$122	$126	$130	8.27%	18.04%	34.18%
	2000	$157	$113	$117	$120	$125	8.45%	18.45%	35.06%
	2200	$151	$110	$113	$116	$121	8.74%	19.16%	36.61%
Multi-Family	50,000	$204	$106	$109	$112	$117	3.44%	7.25%	13.03%
Low-rise	60,000	$204	$96	$99	$102	$106	2.82%	5.90%	10.49%
(For sale)	70,000	$204	$89	$92	$95	$99	2.47%	5.15%	9.12%
	80,000	$204	$85	$88	$91	$94	2.26%	4.71%	8.30%
	90,000	$204	$82	$85	$88	$91	2.14%	4.43%	7.80%
	100,000	$204	$81	$83	$86	$89	2.06%	4.27%	7.51%
Multi-Family	50,000	$0.96	$106	$109	$112	$117	3.09%	6.28%	10.71%
Low-rise	60,000	$0.84	$96	$99	$102	$106	3.09%	6.28%	10.71%
(For rent)	70,000	$0.76	$89	$92	$95	$99	3.09%	6.28%	10.71%
	80,000	$0.71	$85	$88	$91	$94	3.09%	6.28%	10.71%
	90,000	$0.67	$82	$85	$88	$91	3.09%	6.28%	10.71%
	100,000	$0.65	$81	$83	$86	$89	3.09%	6.28%	10.71%

Table 7.4.6 Estimates of incentives for green affordable housing in a for-rent low-rise scenario

Unit	Area Median Income	Count	Area (sqft)	Market Rent/Unit	Affordable Rent/Unit	Market Income	Income loss
0-Bedroom	30%	10	500	$750	$276	$7,500	$4,744
500 sqft	50%	10	500	$750	$458	$7,500	$2,916
1 person max	80%	10	500	$750	$733	$7,500	$169
	100%	5	500	$750	-	$3,750	$0
	120%	5	500	$750	-	$3,750	$0
	Market	4	500	$750	-	$3,000	$0
1-Bedroom	30%	10	750	$960	$368	$9,600	$5,925
750 sqft	50%	10	750	$960	$611	$9,600	$3,488
1.5 person max	80%	10	750	$960	-	$9,600	$0
	100%	5	750	$960	-	$4,800	$0
	120%	5	750	$960	-	$4,800	$0
	Market	4	750	$960	-	$3,840	$0
2-Bedroom	30%	10	1000	$1,230	$471	$12,300	$7,588
1000 sqft	50%	10	1000	$1,230	$655	$12,300	$5,750
Three persons max	80%	10	1000	$1,230	$1,048	$12,300	$1,825
	100%	5	1000	$1,230	-	$6,150	$0
	120%	5	1000	$1,230	-	$6,150	$0
	Market	5	1000	$1,230	-	$6,150	$0
Total			100,000			$130,590	$32,403

Loss of Income/Market Income Ratio (24.81%)

Area after incentive (add the Ratio)	124,813
Area after EarthCraft Certified (add 3.09%)	128,669
Area after EarthCraft Gold (add 6.28%)	132,651
Area after EarthCraft Platinum (add 10.71%)	138,180

7.5. Discussion

7.5.1. Key results and comparison with previous work

Based on an analysis of 422 LIHTC projects that applied for income tax credits between 2011 and 2019 across VA, our findings suggest that an increase in the level of EarthCraft certification, from Gold to Platinum, increases the cost of rehabilitation and new construction by 12.60% and 4.60%, on average, while controlling specifically for statistically significant attributes of the residential area, number of stories, age of existing buildings, coordinates, and the year of construction. The result of the cost premium on new construction is supported by Chegut et al., (2019), as small increases in the level of green building certification of new constructions have statistically insignificant cost impacts. However, similar increases in the level of certification in rehabilitation are associated with large and significant cost premiums. A potential reason for this cost premium is the impact of green building criteria on building enclosures, which typically constitute a large part of rehabilitation projects. Compared to new construction projects, rehabilitation projects might be more cost-effective in terms of rate-of-return, but rehabilitation project options and specifications might require additional scope and/or restrict the menu of credit-earning solutions that would be available in new constructions. Another complicating factor is that, within green building programs, there are separate certifications for the rehabilitation of existing buildings, whereas almost all research to date has focused on new construction cost premiums. Whether new construction or rehabilitation, buildings certified as green within each category are likely to take longer to complete than conventional buildings, thus requiring less experienced builders to wait longer to obtain revenues. Allocating more incentives to rehabilitation projects could be reasonable where there is a tendency to lower undesirable economic, environmental, and social impacts of developments (e.g., reduced cost and time of construction, reduced waste generation and resource consumption, increased reuse of existing materials), thus increasing social benefits (Alba-Rodríguez et al., 2017; Power, 2008).

Houses certified under the EarthCraft VA program in Montgomery County, VA are associated with significant sale price premiums, with an estimated average of 15.06%, of which about 2.79% could be attributed to locational characteristics (based on Table 7.4.2) that were not captured. Therefore, the 12.27% premium translates to a dollar value of about $32,105, considering the average home sale price for the county, of $261,660 in 2018. This finding is in general agreement with a previous study that found an increase of 8.30% associated with 300 EarthCraft certified houses from a sample of 1094 homes sold in Atlanta, GA between 2007 and

2010, which could be lesser, due to a recession in the housing market (Stephenson, 2012). In addition, Walls et al. (2017) found 8%–9% premiums associated with housing units with local certification schemes in Austin, TX after matching and hedonic analyses. The relatively higher price premium in this study could be partially attributed to a higher potential for savings from energy efficiency in the context of Montgomery, VA, compared to Atlanta, GA or Austin, TX. Anecdotally, EarthCraft VA reports an upfront cost premium of 0.5%–3% based on local builders, suggesting that the capitalization of green building features into transaction prices, on average, substantially exceeds upfront cost premiums. In this study, the impact of EnergyStar certification on housing unit prices is smaller (around 5.81%) and not always statistically significant.

The density bonus estimates suggest that, to recover 3%, 6%, and 10% incremental cost premiums associated with for-sale single-family houses in Blacksburg, VA, homebuilders need about 5–10%, 10%–20%, and 25%–40% increases in floor area, respectively. More precise estimates can be achieved based on the structural and locational characteristics of individual buildings. Nonetheless, housing prices are also confounded by dynamic market-driven factors, making it difficult to forecast housing prices using conventional methods. It is likely that regulatory and technological reforms affect certification costs and willingness to invest in certified buildings. Factors such as builders' capacity and experience in green building, the energy literacy of households, availability of professional training programs and financial solutions, and recognition of green buildings in the market, are important to the economic viability of green buildings. It is also likely that local opposition to affordable housing causes construction delays, delays in leasing or selling units, etc. Therefore, such thresholds could provide local planners with some level of flexibility in decision-making. In for-sale, low-rise and mid-rise multi-family buildings, the percentage and variability of density incentives decrease. In general, our results indicate that where housing is expensive relative to its basic costs of production (e.g., due to zoning) small increases in building area could help builders recoup their initial investment in green affordable housing, while keeping the price per unit area unchanged for home buyers and renters. Planners could strategically allocate density incentives towards meeting other goals set by local comprehensive plans or zoning codes, e.g., promoting socio-economically balanced communities, but need to ensure that other constraints, e.g., water permits and height limits, are not limiting development (Ryan & Enderle, 2012). The real test of whether the offered density incentive ordinance offsets the costs of green certification and price/rent limits is if local builders would prefer them over the existing ordinance (Powell & Stringham, 2005). Further incentives might include the use of economic instruments (e.g., tax reduction, financial assistance) or the relaxation of zoning requirements (e.g., lot coverage, parking, public space, allowing for off-site construction of affordable units) (Hickey, 2013).

Non-certified market-rate houses in proximity to EarthCraft VA certified houses have been associated with increasing sale price premiums of 3.78%, 5.90%, and 8.12%, according to the three recent models specified. Assuming about 2.79% of the associated premium belongs to unknown locational characteristics (from the 2004–2007 model), the remaining 5.33% premium in the period 2016–2018 would equate to a dollar value of $13,946 when considering the average home sale price for the county of $261,660 in 2018. The spillover effect has increased in the last few years. The combination of price premium (private benefit) and spillover effect (public benefit), which together represents the social benefits of green building in the county, is much higher than the average cost premium of obtaining green building certification and justifies the local government’s investment in an integrated green affordable housing program. The program could reduce public spending, resulting from disproportionate costs of energy, transport, healthcare, safety, etc., on low-income groups. As the clustering of green buildings could also disproportionately impact housing affordability by increasing local property values, the introduction of affordable housing units could also address potential segregation impacts. We find evidence that houses in proximity to schools have higher prices, a finding that is supported by the hedonic price literature on pedestrian-and transit-oriented development (Bartholomew & Ewing, 2011). Nonetheless, we find negative price effects associated with proximity to public transportation, which could be explained by the fact that the public transportation system in the county is primarily designed to service student riders, and more expensive houses tend to be in less congested areas.

Extant research on the spillover effects of affordable housing and LIHTC properties has found that the magnitude of effects depends on a variety of factors, including but not limited to, type and implementation of housing programs, design and management of properties, characteristics of host neighborhoods, and concentration of affordable housing (Baum-Snow & Marion, 2009; Nguyen, 2005). The literature recognizes several reasons for local opposition to any new—and even expensive —housing units, including concerns about the character and quality of structures, negative externalities, diminishing valued open space, etc., which might contribute to a decline in property values (Galster et al., 1999; Pendall, 1999). In Montgomery County, VA, non-certified housing units that co-exist with affordable housing developments in a Census block demonstrate an average sale price premium of -0.72%, which is statistically insignificant. The presence of positive spillover effects associated with certified units suggests that the integration of green building with affordable housing—along with the dispersal of affordable housing throughout the city, reducing the concentration of poverty in buildings through mixed-income developments, and quality management of affordable properties—could enhance the attractiveness of affordable properties in host neighborhoods and reduce local opposition to government-assisted housing.

7.5.2. Recommendations for Future Research

Our results show that large and significant cost impacts are associated with small increases in the level of certification in rehabilitation projects. Therefore, future research should further investigate the impact of green building certifications on rehabilitation projects, as there is currently no comparable systematic study available in the literature. Existing buildings before new energy code improvements of the late 2000s are our largest current stock. As green building policies are increasingly adopted by local governments, multi-jurisdictional studies with larger sample sizes are needed to draw firm conclusions on the external impacts of both market-rate and affordable green housing units, e.g., on local economic, environmental, and social sustainability rates (Gilderbloom et al., 2009). In this research, we examined such effects, based on either the presence or absence of such units, due to sample size limitations, but it would be more fruitful if the relationship is explored in terms of the proportion of land devoted to, and distance from, certified units and affordable units over time.

Our sample set represents all MLS transactions in the county during the last twenty years. However, the analysis in this case-study is restricted, due to the slow diffusion of green building practices in the local marketplace not allowing for further statistical analyses, e.g., propensity score weighting and matching to reduce selection bias. Despite constant increases in the frequency of transactions in the local market since 2008, and the capitalization of green certifications into house prices, the number of certified houses has not increased since 2014.

Such declines, which might be attributed to the emergence of stricter energy-efficiency codes, improvements in construction standards, cost of housing, or negative sentiments towards green buildings in the real estate industry, is worth further investigation in future research (Brounen & Kok, 2011).

A common limitation in the study of green building cost premium is the lack of organized construction data. LIHTC projects are subject to the Freedom of Information Act (FOIA), which provides the public with access to federal agency records, providing useful resources for future research on the construction costs of multi-family residential buildings. Nonetheless, most LIHTC agencies in the region did not start to organize and make construction project data electronically available until recent years. In fact, the Virginia Housing Development Authority (VHDA) had the only organized, publicly accessible archive of LIHTC construction data in the region, which itself was limited to recent projects. The availability of more LIHTC data in the future would provide researchers with opportunities to investigate the social impacts of green affordable housing, a more detailed assessment of which could help address existing barriers, and enhance the market recognition of green and affordable housing (Runde & Thoyre, 2010).

7.6. Conclusion

This empirical study explored density bonus options for green affordable housing, by analyzing construction costs, sale prices, and spillover effects for green certifications and affordable housing units. Table 7.6.1 summarizes the results from the past research and the present study. Our findings indicate that: (1) the supply of green rehabilitation projects requires more incentives than the supply of new construction projects with identical certification levels, and policymakers should account for these differences when designing incentive programs (2) the integration of green and affordable units is economically justified and socially beneficial, since both private owners and the public can enjoy its positive economic, environmental, and equity impacts (3) green and affordable housing initiatives could have a positive price impact on peer buildings and reduce the risk of investment in affordable housing, by enhancing neighborhood conditions and competition on sustainability metrics (4) Small voluntary density incentives could help facilitate the integration of green building with affordable housing, to promote multiple sustainable development goals, where housing is expensive relative to its basic costs of production. Achieving green building compliance through third-party verification programs—rather than government-designed programs—could facilitate sustainable development by reducing the cost of program administration. Since buildings represent about 40% of global energy use, and 30% of global greenhouse gas emissions, the major source of contributions to climate change, there are considerable opportunities for positive large-scale impacts on global sustainability and climate change mitigation by gradual investment in environmental sustainability of local housing markets and, at the same time, opportunities to address housing affordability and environmental justice (Edenhofer, 2015).

Table 7.6.1 Summary of results from the past research and the present study

Extant Literature Results	Study Results
1. Past research has focused on capitalization of nationally recognized labels in commercial property prices in large cities. 2. There is little evidence on the magnitude of upfront green construction cost premiums in the residential sector in the US. 3. Green buildings can have small upfront cost premiums, but price premiums often offset the cost of certification. 4. Well-maintained affordable housing properties can appreciate property values in neighborhoods containing deteriorating housing units. 5. Integration of environmental principles in affordable housing requires cost and benefit analyses based on local demographic and housing market data.	1. Green certifications increase the cost of new housing projects, but the increase is not statistically significant. 2. Green certifications has a large impact on the cost of rehabilitation projects, and the impact is statistically significant. 3. The value premium of blocks in which market-rate certified houses are built has continuously increased over time. 4. The presence of non-green affordable housing units is associated with negligible spillover effects, which are often statistically insignificant. 5. Small density incentives help builders recoup their initial investment in green building in areas where housing is expensive

CHAPTER EIGHT: CONCLUSION

First, there is a need for integration of climate protection policy adoption literature since there is not a comprehensive synthesis currently available. This analysis suggests that climate policy adoption is primarily driven by internal factors, including the level of public support and the presence of dedicated sustainability staff. Leadership from higher levels of government (i.e., state and federal) is highly desirable but has been not strongly associated with policy adoption at the local level. The results suggest that there is a strong relationship between community support and climate policy adoption, which is in general accordance with many reviewed studies. However, there are nuances in how public support might impact policy adoption, as it might have stronger influences on community-focused rather than internal government-focused programs. Government-focused programs are likely to be strongly driven by local government environmental awareness or the presence of environmental entrepreneurs. Developing climate action plans requires fiscal health and staff capabilities. Governments that heavily rely on intergovernmental funding have been far less active than governments that are relatively fiscally independent. The emergence of climate change policy entrepreneurs might also be negatively influenced by intergovernmental dependence, which leaves less incentive for action if policy decisions are dominated by higher levels of government. Among fiscally independent governments, policy adoption seems to be relatively inelastic to local government capacity. Rather, it seems to be primarily driven by the presence of a political will. This will often manifest as dedicated sustainability units, environmental entrepreneurship, and staff support for climate initiatives.

The problems, solutions, and politics of climate change policies are shifting over time and tend to have long-term impacts. Some driving forces (e.g., partisan effect) lose their initial magnitude when the adoption of climate policies becomes more widespread. The emergence of climate policy entrepreneurs could be influenced by disruptive social changes (e.g., population change) or extreme climatic events as such changes often raise public awareness. Thus, by taking a longitudinal approach, future studies could reveal more details of policy adoption in this area. In addition, it is suggested that nationally representative survey data control for geographic location (e.g., state, region), contextual effects (e.g., type of climate-related hazard), and effects of neighboring areas. The costs associated with climate change are not evenly distributed in space, leaving some areas (e.g., the Southeast) more vulnerable than others (e.g., the Northeast). Also, future empirical studies should investigate adaptation policies, as there are fewer studies available on adaptation than mitigation. Given existing deficiencies of the empirical literature, ad-hoc design and measurement methods, and differences in conclusions (e.g., on the form of government), there is clearly a need for integration of the scholarship in this area.

The importance of local support and awareness to climate policy adoption necessitates the development of public outreach, education, and engagement activities based on scientific projections and objective risk assessments, particularly in communities that are more vulnerable to environmental risks. Climate change has generally been framed and perceived as a global phenomenon without a local dimension, which makes it harder for local governments to build strong community support. Since conservative communities are relatively less receptive to such policies, a proposed solution is creating effective alignment of climate change issues with a wider set of environmental (e.g., higher density developments, reuse of brownfields), economical (e.g., clean technologies, green jobs) and public health goals (e.g., clean air, clean water) that are associated with cost savings and community benefits through participatory processes that facilitate consensus among stakeholders. There is a growing awareness among local governments of the co-benefits associated with sustainability (e.g., cost savings, growth management, and political recognition). Hence, small communities, with proportionally less capacity — and total emissions — could potentially benefit from partnerships with utilities, community groups, and regional initiatives to save costs, obtain expertise, and increase individual advantage by participation in a group.

Second, despite its significance as an opportunity to drive quality living conditions for U.S. residents and innovation in housing, green affordable housing has not received much attention in the literature. This analysis finds that state housing agencies do not equally contribute to environmental sustainability and climate protection. Housing agencies can be divided into role-model, strongly committed, committed, moderately committed, and weakly committed (i.e., least innovative) organizations. The fact that even less innovative or weakly committed agencies have frequently adopted energy efficiency and smart growth criteria suggests that most decision-makers have recognized immediate co-benefits (e.g., cost savings, pollution reduction, fuel cost reduction) associated with these criteria. Most states that rank high on the policy innovation list are in the Northeast innovation cluster, where annual heating energy loads are among the highest in the country and fuel poverty is an issue. On the other hand, states in the West and South often appear at the bottom of the list. Together, these findings suggest that while cost-benefit analysis has a strong role in prioritizing green building criteria by housing agencies, there is an innovation cluster effect, explaining significant between-region variations in the state adoption of energy-saving criteria despite the presence of similar climatic characteristics between regions. In other words, all else being equal, housing agencies are more likely to emulate green building policies of innovative agencies of nearby agencies, rather than those of innovative agencies in remote locations.

The independent variables employed in the regression models collectively explain up to approximately 60 percent of the variance in the QAP score, which raises the question about what other factors should be included in the model to explain the remaining variance. This analysis and previous research on social and psychological barriers to green building suggest policymaking for sustainable development in public organizations has not always followed pure rationality. Rather, individual-, organization-, and industry-level factors, e.g., attitudes, autonomy, entrepreneurship, motivations, leadership, maturity, resources, structures, have been involved in driving sub-optimal outcomes. The literature on organizations and the environment broadly identifies and articulates how such factors may affect organizations' interaction with complex social and environmental issues. Institutional barriers, such as adherence to rigid building codes and standards, standard operating procedures, and unquestioned biases, that impede rationality, innovativeness, and responses to societal interests regarding complex problems are very common in the construction industry and should be accounted for in future research on policy innovation. This analysis shows many housing agencies tend to adopt a set of innovative green building criteria but radically change the initial decisions within only a few years. Such organization-level decisions affect the linear trajectory of policy adoption and, thus, reduce the predictability of future outcomes.

This study shows that factors that are external to housing agencies – such as the state economy, environment, policy, regional effect, and pressure from the society – provide partial explanations regarding the adoption of green building practices. At the same time, the change in the environmental performance of LIHTC units has been slow and unsteady in coming. Thus, future studies may follow two lines of research. First, to explore how role-model housing agencies like Massachusetts and Connecticut overcome organizational inertia, approach environmental problems, and set strategies for action. Second, to study what other barriers affect the integration of environmental targets into LIHTC developments. Past research on the role of organizational culture and subculture suggests that the adoption of new practices is easier when framed as a positive and attractive option, and this analysis supports this by showing green building options having immediate financial savings are more likely to be adopted and commercialized. This line of research should account for the increased availability of green products, technological advances, federal and state subsidies, integrated design-build practices, and professional workforce, and determine what is needed to close the gap towards zero energy housing. Data-driven analyses showing a long-term reduction in LIHTC development and maintenance expenses can motivate all stakeholders to be receptive to reducing existing barriers to high environmental performance.

Third, there is very limited research on zero-energy affordable housing. If proved to be cost-effective, zero-energy developments can benefit residents and society by increasing housing affordability, environmental sustainability, and efficient distribution of federal financial incentives. The affordable housing sector in Virginia - and probably many other U.S. states in the South - is capable to become zero energy. Based on the 30-year discounted cash-flow analysis, the net present cost of the implementation of rooftop residential solar systems to achieve zero-energy units in Virginia can be lower than the discounted present cost of energy of otherwise identical units that have no renewable energy generation systems, and the value of cost savings can be statistically significant. The investment value often depends on the zero-energy building definition, weather characteristics, retail price of electricity, and incentive rate. The DOE's definition of zero-energy buildings implies that these buildings should progress the restoration of the 32.31 percent loss (based on data from the 2010s) to the infrastructure system. The problem with this requirement in Virginia, where the solar potential is lower than that of states located in the South East, South West, and West regions, is not financial viability but the need for extra installation space. The analysis presented here relaxes this specification to minimize the required module area. Although zero-energy affordable housing seems cost-effective in the long run, the costs associated with PV systems are not evenly distributed in the state, thus, leaving some areas like the Southeast more potent in adopting distributed generation systems than others like the Southwest. Differences in solar radiation, ambient temperature, energy prices, and diminishing prospects of the federal solar tax credit can affect consumers' willingness to invest in PV systems. Analyzing these variations and the significance of carbon emissions avoided because of renewable energy generation is a key to support the construction industry in bridging the gap to zero-energy buildings, particularly in affordable housing.

We suggest that state housing finance agencies evaluate new incentives and methods for financing PV systems (e.g., low-interest solar loans), designing (e.g., smart grids), and metering developments. Current network infrastructure is not built to accommodate large numbers of distributed feed-in points, and rapid fluctuations in distributed generation, such as due to cloudy weather, can present significant challenges to the grid. Therefore, smart grid technology, which allows generators and loads to interact in an automated fashion in real time, is necessary for very large amounts of renewable electricity. In addition to a single utility-provided master meter, zero-energy developments can employ circuit-level owner metering to better manage development performance. The approach provides real-time, high-resolution data on unit-level and circuit-level energy consumption, as well as solar system performance. Extant research suggests occupants are generally poor at managing systems with lags in information and delayed evaluation loops. Current utility-provided metering technologies fail to provide customers with usable or timely data in managing system performance, improving occupant experiences, or meeting zero-energy goals. With this approach, developers install metering hardware in each unit's circuit panel and measure energy use in one-second intervals. The accompanying software allows easy analysis of performance at circuit, unit, and development levels and could be leveraged for predictive analytics, e.g., identifying HVAC system maintenance issues before they occur. Circuit-level meters are commercially available starting at ~$300 per system and have been employed in pilot zero-energy developments. In crafting any policy that subsidizes renewable energy generation systems and involves very large public and private spending commitments, it is imperative to consider social equity issues.

Fourth, literature has documented the presence of contradictory linkages between economic, environmental, and equity goals of development policy and planning in large-scale initiatives but limited studies have made progress on the links between gentrification and the new construction of green-certified houses to help craft more efficient and equitable housing policies. Middle- and higher-income residents are immigrating from suburbs to the city to live in energy-efficient houses in mixed-use, dense, walkable, bikeable neighborhoods. Investments in environmental initiatives in brownfields and core urban areas, where the difference between the actual and potential ground rent is high, have replaced low-rent houses occupied by low-socioeconomic status residents with high-end real estate for higher-income, often white in-migrants. The launch of green-certified houses accelerates neighborhood change and gentrification based on several measures, such as population growth, new construction, and property value increases. When a neighborhood is subject to gentrification, the cost-burdened, relocated, or displaced residents incur economic costs, social costs, and health and well-being costs, thus, requiring support from the host neighborhood and creating large negative externalities leading to welfare loss in the city.

We find convincing evidence to accept that green-certified houses cause positive and statistically significant spillover effects. Following the launch of a new certified house in the study period, the value of an average single-family house in a walkable distance to the new, certified house increases, on average, by 4.27%. The baseline transaction prices of the houses in walkable distance to green-certified houses are, on average, 2.28% lower than those of comparable houses located outside the quarter-mile radius, thus, supporting studies that argue investments in pro-environmental initiatives tend to occur in brownfields and urban areas where the difference between the actual and potential ground rent is high.

The results reinforce the hypothesized causal connection between the construction of certified houses and neighborhood change and gentrification at the census group level. The analysis indicates that the launch of certified houses, based on several measures, stimulates population, new construction, and property value growth at the census block group level, thus, accelerating neighborhood change and gentrification. In addition, there are large but not statistically significant changes in the selected socioeconomic indicators of neighborhood change before and after the construction of certified houses. For instance, in census block groups where certified houses are located, there is an upward trajectory in the share of the White population and, consequently, a reduction in both household share and ownership rates for Blacks, Hispanics, and Latinos, suggesting that neighborhoods in the treatment group are at risk for gentrification. At the same time, the share of the White population in the control group has decreased and, thus, been replaced by non-Whites. Although there is an overall decrease in ownership and occupancy rates, the treatment group neighborhoods have more stable ownership and occupancy. The difference-in-difference analysis suggests that the launch of certified houses has a more immediate effect on housing characteristics like the value and quantity of new developments than it has on household characteristics like the class composition of households, i.e., increases in the White, young, college-educated, middle- or high-income households, whose changes would achieve statistical significance in longer terms than studied here.

This research highlights the need for greater policy attention to affordable housing needs in core urban areas, neighborhood diversity, and costs of gentrification. Pro-environmental reinvestments in city centers are likely to cause large-scale gentrification, thus, requiring planners to create a balance between the demands of environmental activists and the concerns of social justice advocates in crafting housing policies. Proposals to create this balance may include performing social effects assessments (i.e., vulnerability analysis), linking pro-environment development with affordable housing preservation, creating an even distribution of environmental amenities in the city to ensure equal benefits, employing mandatory inclusionary housing policies, exercising property tax growth limits, tax deferment programs, and property tax reductions for low-income households or affordable housing landlords. This analysis supports past research by showing that the positive spillover effects of pro-environmental redevelopment projects quickly capitalize into housing prices in the area, thus, accelerating the growth in housing costs and neighborhood change. Once the risk of gentrification is recognized, planners should acknowledge that “development without displacement” requires early-stage diversity and affordability interventions as integral components of planning. Otherwise, significant increases in land values would make future community protection and improvement actions very expensive.

Finally, previous research considers a variety of factors that could lead to an underinvestment in sustainability initiatives, including but not limited to, split incentives, information asymmetries, risk aversion, skill shortages, and analytical failures, understanding of which is critical to sustainable housing. The density bonus estimates suggest that, to recover 3%, 6%, and 10% incremental cost premiums associated with for-sale single-family houses in Blacksburg, VA, homebuilders need about 5–10%, 10%–20%, and 25%–40% increases in floor area, respectively. More precise estimates can be achieved based on the structural and locational characteristics of individual buildings. Nonetheless, housing prices are also confounded by dynamic market-driven factors, making it difficult to forecast housing prices using conventional methods. It is likely that regulatory and technological reforms affect certification costs and willingness to invest in certified buildings. Factors such as builders' capacity and experience in green building, the energy literacy of households, availability of professional training programs and financial solutions, and recognition of green buildings in the market, are important to the economic viability of green buildings. It is also likely that local opposition to affordable housing causes construction delays, delays in leasing or selling units, etc. Therefore, such thresholds could provide local planners with some level of flexibility in decision-making. In for-sale, low-rise and mid-rise multi-family buildings, the percentage and variability of density incentives decrease. In general, our results indicate that where housing is expensive relative to its basic costs of production (e.g., due to zoning) small increases in building area could help builders recoup their initial investment in green affordable housing, while keeping the price per unit area unchanged for home buyers and renters. Planners could strategically allocate density incentives towards meeting other goals set by local comprehensive plans or zoning codes, e.g., promoting socio-economically balanced communities, but need to ensure that other constraints, e.g., water permits and height limits, are not limiting development. The real test of whether the offered density incentive ordinance offsets the costs of green certification and price/rent limits is if local builders would prefer them over the existing ordinance. Further incentives might include the use of economic instruments (e.g., tax reduction, financial assistance) or the relaxation of zoning requirements (e.g., lot coverage, parking, public space, allowing for off-site construction of affordable units).

Climate change is set to reshape future population distributions, triggering large-scale migrations away from affected areas and disproportionately escalating existing hardships faced by low-socioeconomic status populations. Amid an unraveling climate crisis, a lack of consideration for affordable housing in urban reform, renewal, revitalization, and redevelopment plans endangers the health and wellbeing of the working class and low-income households who are essential to a functioning economy.

End of the dissertation

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