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Deep Decarbonization in Practice:
Solutions and Challenges for Low-Carbon Building Retrofits

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Abstract
This paper examines efforts taking place in London, San Francisco and Stockholm to implement deep greenhouse gas emission cuts—'deep decarbonization'—through the transformation of buildings and urban energy infrastructure for increased energy efficiency and low/zero carbon energy supply. Drawing on interviews, policy document analysis, and site tours to buildings and energy infrastructure, this paper analyzes how deep decarbonization is being embedded into urban buildings, energy systems, and institutions. It argues that practitioners are finding ways to create new low/zero carbon future buildings, but are having difficulty correcting the historical development path through retrofitting. This paper examines solutions and challenges brought to light by urban decarbonization in practice targeting existing buildings from which other cities can learn. Four key lessons for low/zero carbon retrofits are highlighted: 1) shift primary targets from homeowners to owners of multiple buildings, 2) expand the suite of resources available to support zero carbon retrofits, 3) experiment and teach using public investment, and 4) institutionalize energy and carbon reporting linked to municipal department targets. Given the necessity of low-carbon, efficient, and climate-resilient building retrofits to address the climate crisis, action can be scaled up by considering buildings and energy infrastructure an infrastructure priority for public investment.

Keywords: urban; cities; climate change; decarbonization

Résumé
Cet article examine les efforts déployés à Londres, San Francisco et Stockholm pour mettre en place une réduction profonde des émissions de gaz à effet de serre—«décarbonisation en profondeur»—par la transformation des bâtiments et des infrastructures énergétiques urbaines pour l'efficacité énergétique et l'approvisionnement d'énergie à zéro ou faible intensité carbone. S'appuyant sur des entretiens, l'analyse de documents de politiques publiques et des visites de sites d'immeubles et d'infrastructures énergétiques, cet article analyse comment la décarbonisation en profondeur est incorporée dans les bâtiments urbains, les systèmes énergétiques et les institutions. Il fait valoir que les praticiens trouvent des moyens de créer de nouveaux développements à zéro ou faibles émissions de carbone, mais ceux-ci ont du mal à corriger la trajectoire historique de développement avec l'amélioration énergétique. Cet article examine les solutions et les défis mis en évidence par la pratique de la décarbonisation urbaine qui cible les bâtiments existants, à partir desquels d'autres villes peuvent apprendre. Quatre leçons principales pour la rénovation à faibles émissions ou carboneutre sont soulignées: 1) transférer les objectifs principaux des propriétaires aux propriétaires de plusieurs bâtiments, 2) élargir la gamme de ressources disponibles pour soutenir les améliorations de la réduction des émissions de carbone, 3) expérimenter et enseigner en utilisant les investissements publics et 4) institutionnaliser les rapports sur l'énergie et le carbone liés aux objectifs des services municipaux. Compte tenu de la nécessité de rénover les bâtiments dans une optique de sobriété carbone, d'efficacité et de résilience face à la crise climatique, il est suggéré

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d'intensifier l'action en considérant les bâtiments et les infrastructures énergétiques comme une priorité pour les investissements publics dans les infrastructures.

Mots clés: urbain; villes; changement climatique; décarbonisation

Introduction

It is increasingly clear that urban climate change mitigation features diverse and multi-level action driven by actors from across government, industry and non-profit sectors. In this context, a number of local authorities are committing to deep greenhouse gas (GHG) emission reduction goals, such as achieving carbon neutrality by 2040, which some are describing as "deep decarbonization" (Carbon Neutral Cities Alliance 2015). However, it is less clear what deep decarbonization will look like in practice for cities and which levers might help people transform urban systems for carbon neutrality.

This paper uses a decarbonization framework. Effective urban decarbonization is the integration of 'zero carbon' into urban systems, while also achieving interconnected sustainability goals including climate adaptation and social justice outcomes. Many approaches to urban climate change mitigation policy and practice are centred on greenhouse gas emission accounting, but this paper argues that decarbonization is another useful framework. Greenhouse gas emission projections are useful for targeting initiatives towards sectors where the biggest potential impacts lie and ex post facto evaluation of overall progress, but lack the ability to capture the social and political dynamics that are essential for effective climate change mitigation initiative design and implementation.

Focusing on three case studies of deep decarbonization in Stockholm, London and San Francisco, this paper examines how decarbonization initiatives are being embedded into urban buildings, energy systems, and institutions. In particular, this paper addresses the following question: in cities targeting deep decarbonization, what lessons can be drawn from experiences in the implementation of greenhouse gas emission reduction initiatives for buildings? The paper finds that practitioners are finding ways to create low/zero carbon future development, but are having difficulty correcting the past path through retrofitting. Nonetheless, experimentation and learning by practitioners and policy-makers is leading to important lessons about low-carbon building retrofits for other cities. This paper highlights key insights related to 1) shifting primary targets from homeowners to owners of multiple buildings, 2) expanding the suite of resources available to support zero carbon retrofits (financing, technical expertise, information etc.), 3) experimenting and teaching using public investment, and 4) institutionalizing energy and carbon reporting linked to departmental targets.

The next section introduces the decarbonization framework for this paper and reviews common policy and planning approaches to urban climate change mitigation. Next, the paper describes the methods used for this research. The following section summarizes findings from the three case studies related to key energy and greenhouse gas emission targets and progress towards their achievement as context before presenting relevant low carbon building and energy initiatives. The subsequent section analyzes the lessons that can be drawn about solutions and challenges for low carbon building retrofits through the experiences implementing these initiatives and argues that decarbonization requires integrating zero carbon logics into urban development. The final section offers a conclusion.

Systemic Decarbonization of Urban Systems

Decarbonization is the process of eliminating fossil fuels from energy and economic systems and disrupting carbon lock-in (Bernstein and Hoffmann, 2018b; Seto et al., 2016; Unruh, 2000). Carbon lock-in is the path dependence of technical, institutional and behavioural systems that makes it difficult to eliminate greenhouse gas emissions despite the catastrophic threat of the climate crisis (Seto et al. 2016). Decarbonization, then, requires fundamental changes to society to disrupt the complex entanglements of carbon across technological and institutional systems. This necessary transition will be far-reaching since modern society has evolved with fossil fuels intricately embedded into many facets of our daily lives. In essence, decarbonization is transformation—of buildings, energy systems, and institutions—and it is a political socio-technical project (Bernstein & Hoffmann 2018b; Bickerstaff, Hinton, & Bulkeley 2016; Unruh 2000). It requires "disrupting the interdependent, over-lapping and reinforcing dynamics that lead to the continuing use of fossil fuels occurring across scales" (Bernstein & Hoffmann 2018a p. 250), including at the scale of urban systems. However, these transformations will be manifold, nebulous and contested (Luque-Ayala, Marvin, & Bulkeley 2018), which can make it hard to separate transformation from reinventions of the status quo.

Urban climate change mitigation policies have focusd on reducing the emission of greenhouse gases from urban systems. In general, urban climate change mitigation initiatives have targeted the production and consumption of energy, urban infrastructure, urban sprawl, the built environment, and transportation. For example, common policies include energy demand reduction initiatives, subsidies to install renewable energy, capturing gas released from landfills, low-carbon transportation infrastructure expansion, vehicle fleet replacement, compact and green city projects etc., (Romero-Lankao 2012). Though urban climate responses are widespread and growing, researchers have found that urban climate change mitigation efforts so far are inadequately addressing the key drivers of climate change (Betsill & Bulkeley 2007; Bulkeley & Betsill 2013; Romero-Lankao 2012). Rather than taking a strategic approach, many initiatives have been fragmented and piecemeal (Romero-Lankao 2012). Urban climate change mitigation efforts have focused on "individual sectors or urban functions (e.g. increasing bike lanes, efficient heating systems, building insulation), rather than systemic changes (e.g. zoning regulations or urban planning)" (Reckien et al. 2014 p.335).

Stockholm, London and San Francisco are part of a new wave of cities purportedly targeting transformative and systemic change by setting 'carbon neutral' targets. These cities draw a distinction between meeting interim carbon reduction targets, which could be achieved through "continuous improvement in existing systems" (Carbon Neutral Cities Alliance 2015 p.2), and achieving carbon neutral targets that "will require transformative and systemic changes in many core city systems" (Carbon Neutral Cities Alliance 2015 p. 2). In a report on the climate mitigation activities of founding members of the Carbon Neutral Cities Alliance (CNCA), municipal deep decarbonization is targeting energy supply (e.g. increase local production of renewable power; redesign business models for utilities), building energy efficiency (e.g. incentivize and require net zero or renewable energy positive new buildings; increase the availability of building energy performance information in the marketplace), transportation (e.g. shift to a radically different mode share; move quickly toward complete, connected, regionalized mobility systems) and solid waste (e.g. get to zero waste; promote sustainable consumption).

Decarbonization is only likely to be attained by transitioning all societal systems to zero carbon orientations (Burch, Shaw, Dale, & Robinson, 2014; Levin, Cashore, Bernstein, & Auld 2012). Rather than focusing on climate policy alone, which to date has not been adequate to achieve systemic change, transformational decarbonization requires the integration of zero carbon logics as fundamental aspects of urban development (Burch et al. 2014). Bernstein and Hoffmann (2018b, p.191) define transformational decarbonization as "a phase change whereby fossil energy (and/or other GHG generating processes) is not just lessened, but a new trajectory toward replacement or zero use of carbon-based energy is generated." This means that one cannot judge transformational decarbonization based on how aggressive a city's GHG targets are. Instead, the key question is how zero carbon is being embedded in the material fabric and political institutions of the city.

Methods

The aim of this paper is to draw out lessons and challenges from experiences in the implementation of greenhouse gas emission reduction initiatives for buildings in cities targeting deep decarbonization. This paper takes a comparative case study approach. The small number of cases allows for in-depth qualitative research, which is a method that allows for a holistic understanding of social phenomenon (Creswell 2014; Yin 2009). The three cases—Stockholm, San Francisco and London—were selected because these cities: 1) have a high level of ambition for greenhouse gas emission reduction as members of the Carbon Neutral Cities Alliance, 2) have adopted climate policy documents targeting building decarbonization for several years, which I assumed was enough time for some implementation to have unfolded, and 3) are different enough from one another (within the scope of the other two criteria) to generate comparative insights. For example, the cities have different sizes of population, are made up of different types of buildings, are controlled by different levels of government and patterns of ownership for buildings, and are located in different climates. Despite these differences, there are also many conditions affecting building decarbonization that are shared across these three cases. Buildings represent tremendous private economic value across most cities, for example, and most decarbonization needs to take place in existing buildings rather than new ones.

My methods included semi-structured interviews, documentary analysis of relevant policy document and reports, and site visits to low carbon building and energy infrastructure. I conducted interviews with 40 industry, government and not-for-profit organization representatives who were involved in building and energy decarbonization over five week field visits to each case study in 2015-2016. This included 11 interviews in Stockholm, 17 interviews in London, and 12 interviews in San Francisco. I interviewed individuals participating in urban decarbonization using purposive sampling targeting departments and organizations prominently involved in climate change mitigation initiatives, while ensuring a range of affiliations across municipal government, non-governmental and private sector, and I expanded the participants using a snowball sampling method. A common interview guide was used for all three case studies. The interviews were transcribed and thematically coded. I interviewed individuals with experience working on urban greenhouse gas emission reduction projects, including:

- Employees of municipal government climate/sustainability departments
- Other relevant municipal employees (planning, built environment, energy etc.)
- Private sector participants
- Energy utility employees
- Employees for environmental NGOs
- Larger jurisdiction organization employees working on urban climate change mitigation

I also conducted 19 building tours and site visits, including in-depth and self-directed tours of buildings ranging from single-family homes to commercial buildings, as well as tours of urban energy infrastructure and site visits to eco-districts and neighbourhoods. These site visits served to expand my understanding of what implemented urban decarbonization looks like in practice.

Case Studies: Greenhouse Gas Emission Reduction Initiatives for Buildings

This section summarizes findings from the three case studies related to key energy and greenhouse gas emission targets and progress towards their achievement as context before describing relevant low carbon building and energy initiatives. An overview comparing key targets and progress in greenhouse gas emission reduction is also summarized in Table 1. The subsequent section analyzes what lessons can be learned from the experiences implementing these initiatives.

Stockholm

Key Targets and Progress

The population of Stockholm is approximately 901,000. The City of Stockholm plans for the city to be fossil fuel free by 2040 and for the City's own operations to be independent of fossil fuels by 2030. Per capita emissions are intended to be reduced to 2.3 tons CO_2eq/capita by 2020 (City of Stockholm 2016). City-wide greenhouse gas emissions have been reduced approximately 56% between 1990 and 2016 (C40 Cities 2017). The City of Stockholm is aiming to halve the energy use of the existing building stock by 2050 (from 1995 levels) and has achieved about a 30% reduction so far. The City committed to reducing energy use by 10% in its own operations between 2016-2019, including the significant number of residential properties owned through the City's three property companies (City of Stockholm 2016).

The target for a fossil fuel free Stockholm by 2040 also requires changes to energy supply. District heating meets 80% of Stockholm's heating needs, which has been historically facilitated by the proliferation of communal residential buildings where owners have a share in the whole building (Dzebo & Nykvist 2017). One key task of greenhouse gas emission reduction is fuel switching to non-fossil fuels for district heating, such as biofuels and waste incineration. These new fuel sources are not necessarily benign and may represent new infrastructure path dependence that does not support sustainability (Corvellec, Campos, & Zapata, 2013; Dzebo & Nykvist 2017). In fact, reliance on incineration places a cap on progress towards decarbonization since about a third of the carbon in Swedish waste is from fossil-fuel sources (e.g. plastics) (Jones, Blomqvist, Bisaillon, Lindberg, & Hupa 2013). Nonetheless, most city-wide GHG emission reductions to date have been achieved due to this fuel switching. Energy and heat production for Stockholm comes almost entirely from cogeneration plants owned by the corporation Fortum Värme. The City of Stockholm sits on the board, but is not the majority stakeholder. There is one coal-fired combined heat and power plant in operation in Värtan, which is the single largest source of greenhouse gas emissions for the city (City of Stockholm 2010). Negotiations have suggested this plant may be closed in late 2020 or 2030 (City of Stockholm environment administration employee, interview, Nov 10 2015). Renewable energy development is also taking place, particularly solar PV installation owned by the City of Stockholm.

Low Carbon Building and Energy Initiatives

The City of Stockholm directly owns about 20% of the buildings in Stockholm and most of these holdings are residential units (City of Stockholm 2012). Furthermore, the City of Stockholm owns 70% of the land area of Stockholm. The municipal government therefore has a significant amount of control over energy and building standards. Municipal housing companies have been directed to meet efficiency standards and retrofit existing building stock to achieve energy efficiency goals. In fact, the local government developed a new internal reporting system to hold departments and agencies such as housing companies accountable for energy and greenhouse gas emission targets. Departments report regularly on progress towards goals set specifically for their operations. The City of Stockholm requires that new buildings on city-owned land demand a maximum of 55kWh/m^2, excluding plug load (e.g. HVAC, lighting, water heating etc.). After 2020, this standard is planned to be lowered to 45kWh/m^2. The Swedish Building Code already requires a high degree of efficiency, which is influenced by EU directives for all new buildings to be nearly zero energy by 2020 (Hermelink et al. 2013). Note that the Swedish building code requires follow-up monitoring to ensure that these standards are met, and developers frequently plan to build extra efficient buildings to ensure that they meet the standard in performance testing (Stockholm development industry representative, interview, Nov 23 2015). A key lesson in Stockholm has been the value of creating an internal reporting framework to hold local government departments accountable for progress toward energy and climate goals.

Table 1. Overview of population, key targets and GHG emission reduction progress for Stockholm, London and San Francisco

City	Population	Key Targets and Progress
Stockholm	901,989 (CDP, 2016)	• Targets include fossil fuel free by 2030 for city operations and 2040 for the whole city; reduce per capita emissions to 2.3 tons CO_2eq/capita by 2020; halve the energy use of the existing building stock by 2050 (from 1995 levels) (City of Stockholm, 2016) • Stockholm's GHG emissions reduced approximately 56% between 1990-2016 (C40 Cities, 2017) • Total City-wide Emissions (metric tonnes CO_2e): 2,511,000 (CDP, 2016) • Per Capita Emissions (metric tonnes CO_2e): 2.8 (CDP, 2016)
London	8.6 million (CDP, 2016)	• GHG reduction target of 60% (below 1990 levels) by 2025 (Mayor of London, 2016) • Zero carbon city by 2050 (Mayor of London, 2016) • 25% of the heat and power used in London to come from local decentralized systems by 2025 (City of London, 2015) • UK Climate Change Act: reduce greenhouse gas emissions by at least 80% of 1990 levels by 2050 • London's GHG emissions decreased 16% between 1990 and 2014 (Mayor of London, 2017) • Total City-wide Emissions (metric tonnes CO_2e): 40,190,000 (CDP, 2016) • Per Capita Emissions (metric tonnes CO_2e): 4.8 (CDP, 2016)
San Francisco	864,816 (CDP, 2016)	• 100% renewables goal: by 2030, residential electricity is planned to come from renewable sources and 80% of commercial electricity use is planned to come from renewable sources (City of San Francisco, 2013) • California building code targets: new residential buildings to be Zero Net Energy by 2020, commercial buildings in 2030 • California Global Warming Solutions Act (2006): reduce GHG emissions to 1990 levels by 2020 • San Francisco's GHG emissions city-wide decreased 14.5% between 1990 and 2010 (San Francisco, 2013) • Total City-wide Emissions (metric tonnes CO_2e): 5,381,687 (CDP, 2016) • Per Capita Emissions (metric tonnes CO_2e): 6.2 (CDP, 2016)

The City of Stockholm also leverages its ownership of prime urban land to require developers to achieve high environmental standards in special eco-districts, which are particular urban neighbourhoods where new developments are required to meet higher environmental standards than the city as a whole. Stockholm's Hammarby Sjöstad eco-district was developed on a former industrial site between 1996 and 2012 using a closed-loop urban metabolism approach for energy, water and waste. Development of the Stockholm Royal Seaport follows this experience and has set goals to be fossil fuel free by 2030 (ten years earlier than the rest of the city) and achieve a carbon footprint of 1.5 tonnes per capita (City of Stockholm 2015a).

While the municipal government also targets privately owned buildings, this sector has been difficult to reach through municipal policies or programs. Demonstration projects have been undertaken to build capacity and show that it is possible to accomplish energy retrofits in particularly common or difficult to retrofit housing. Demonstration projects pursued in partnership with public housing agencies and universities have demonstrated energy efficiency solutions, including seven apartment buildings in the suburbs. This energy efficiency demonstration project, called Vision for Järva, reduced energy use by 50% (City of Stockholm 2015b). In this way, public investment is used to experiment with cutting edge decarbonization and provide examples from which others can learn.

London

Key Targets and Progress

The Greater London Authority (GLA) has a population of about 8.6 million. In 2014, greenhouse gas emissions were 16% lower than 1990 levels with a 26% population increase since 1990. Per capita GHG emissions in 2014 were estimated at 4.4 tonnes (Mayor of London 2017). While GHG reductions in London over this time period can be partly attributed to building retrofits and changes in the transportation sector, much of these reductions are due to changes in energy supply, particularly reduced coal combustion nationally (Mayor of London 2015). The GLA has committed to greenhouse gas emission reduction targets of 60% (below 1990 levels) by 2025 and to become a zero carbon city by 2050 (Mayor of London 2016). The Mayor of London is aiming for 25% of the heat and power used in London to come from local decentralized systems by 2025 (City of London 2015). To meet this goal, "the Mayor prioritises the development of decentralised heating and cooling networks at the development and area wide levels, including larger scale heat transmission networks" (City of London 2015; p.194). The GLA acts as a regional government above the 33 boroughs of London, which are local authority districts. Some boroughs also have energy and greenhouse gas emission goals.

Low Carbon Building and Energy Initiatives

In 2006, the UK government announced that by 2016 all new homes in the UK would be carbon neutral. Over the next decade, developers engaged in discussions about what implementation would look like in practice (e.g. how much renewable energy generation would be allowed to offset energy use by the building). This policy trajectory shaped new development in London, although in 2015 the goal was scrapped to outcry from environmentalists and many homebuilders. However, in 2016, energy planning by the GLA was still set to ensure progression towards zero carbon standards but with a more nebulous timeline. Large new developments in London are subject to planning controls through the GLA's London Plan. The London Plan allows the GLA to set both energy supply and efficiency requirements for large developments in London. Since 2007, large developments have reportedly achieved average energy efficiency savings 30-40% above national building code requirements (City of London 2015).

The London Plan also requires that new major developments connect to lower carbon district energy systems and produce renewable energy using solar PV and heat pumps (Mayor of London 2015). A capacity study was carried out in 2011 that looked at lower carbon energy supply opportunities in London with a timeframe out to 2025 or 2030 (City of London 2015). The greatest opportunity was found to be district heating supplied by natural gas fuelled combined heat and power. In 2015 alone, the GLA secured commitments to the provision of gas-fired combined heat and power plants and renewable energy infrastructure including: "Combined Heat and Power (CHP) plant able to produce over 26MW of electricity…and a similar amount of heat, more than 74,000m^2 of solar photovoltaic (PV) panels…and a substantial number of heat pump installations" (Mayor of London 2015). More recently, the Greater London Authority has become interested in renewable heat (sourced from the air, ground, industrial processes etc.), which research shows is sufficiently available to meet all of London's heating needs (Mayor of London 2013). Decentralized and renewable energy development is also pursued by the boroughs. For example, the borough of Merton requires new developments to provide 10% of their energy use from on-site renewable energy generation (Merton Council 2016).

RE:FIT and RE:NEW are two key GLA programs that seek to improve the energy efficiency of existing buildings. RE:FIT has targeted public buildings since its launch in 2009. 90% of the funding for the program has come from the EU. RE:FIT provides expert support and tools to help public agencies secure energy performance contracts with the private sector to upgrade the energy efficiency of various kinds of public buildings. Through energy performance contracts, there are no up front costs for upgrades and, instead, the costs are paid over time through the cost savings generated by the efficiency upgrades. RE:FIT has been expanded within and beyond the GLA. Similarly, RE:NEW is a GLA program seeking to leverage various sources of funding to enable energy efficiency retrofits of private residential buildings. After the program launch in 2009, RE:NEW sought to increase the uptake in London of efficiency subsidies offered through obligations imposed by the national government on energy companies. Originally structured as a grant program to boroughs to support door-to-door assessment of residential energy use, the RE:NEW program was retooled in the image of RE:FIT to work strategically with boroughs and housing associations to focus on retrofitting social housing. Other energy efficiency programs are also delivered by local boroughs and by energy companies. By the end of the 2013-2014 fiscal year, broad market activity including these programs had led to retrofits of 500,000 homes in London and 400 public sector buildings (Mayor of London 2015). A key learning from this experience was that owners of multiple buildings are an efficient target for programs supporting energy efficiency retrofits.

Several subsidies, loans and other financing sources have been available in London, including through the Green Deal, the London Green Fund and energy company obligations. The Green Deal was a UK program intended to encourage energy efficiency retrofits of homes by offering low interest loans, but is widely acknowledged to have failed as a program since uptake was minimal due to problems with program design and implementation. The UK government has also required energy suppliers to deliver certain amounts of efficiency gains in homes and companies have met these obligations by offering various kinds of grants. The specific targets of the grants have varied over time, from focuses on physical characteristics (e.g. targeting homes with solid walls where insulation is more difficult and expensive) or socio-economic characteristics (e.g. reducing energy costs for low-income households). The London Green Fund is a £120 million fund with a revolving loan design that offers funding for waste, energy efficiency, decentralized energy and social housing projects. Renewable energy development is also being funded through community initiatives. Brixton Energy is a not-for-profit co-operative in south London that has developed multiple renewable energy projects in the area.

San Francisco

Key Targets and Progress

The population of San Francisco is approximately 860,000. Climate change mitigation in San Francisco is pursued in the context of the local government's 100% renewables goal, which means, by 2030, residential electricity should come entirely from renewable sources and 80% of commercial electricity use (for industrial and business purposes) should come from renewable sources (City of San Francisco 2013). In 2010, GHG emissions were 14.5% lower citywide than 1990 levels. This decrease is mostly due to the decreasing emissions intensity of electricity because of the California's Renewables Portfolio Standard and the closure of two fossil fuel plants in San Francisco (City of San Francisco 2013).

Low Carbon Building and Energy Initiatives

San Francisco adopted a Green Building Code in 2008 that required new and majorly retrofitted residential and commercial buildings to, among other things, reduce energy use beyond the requirements of the California Green Building Code. Revised three times, the San Francisco Green Building Code now requires that new construction meets California code, installs solar PV, thermal or green roof for buildings 10 floors or less, and meets city-specified requirements linked to the LEED and GreenPoint Rated green building rating systems. The latest San Francisco code only requires that the California code be met since the California code has essentially caught up to the energy efficiency requirements of San Francisco's Green Building Code. Building codes essentially just regulate the building envelope and higher levels of building envelope efficiency are difficult to justify as 'cost-effective', which is a requirement in the current regulatory environment. In 2007-2008, the California Energy Commission and the

California Public Utility Commission, which are respectively the state's energy policy and planning agency and the utilities regulator, announced the goal that by 2020 all new residential construction will be Zero Net Energy, with new commercial buildings following by 2030. The application and interpretation of this goal has played a major role in California Green Building Code updates since then. California also passed AB 32, the California Global Warming Solutions Act, in 2006, which requires California to reduce its GHG emissions to 1990 levels by 2020.

Since 2011, the San Francisco municipal government has required private owners of buildings over 10,000 sq ft to benchmark building energy performance and conduct an energy audit. Key benchmarking results must be shared with the San Francisco Department of Environment and building tenants. Building owners are not required to implement the energy efficiency upgrades that are suggested through the energy audit, but benchmarking and auditing has identified opportunities for $60.6 million USD in cost-effective energy upgrades (SF Environment 2015). The combined impact of the San Francisco and California's energy efficiency policies is leading to some energy efficiency retrofits in private buildings. For example, a report published by the City of San Francisco found that "energy use has decreased by 7.9 percent and source emissions have decreased by 17 percent among properties that consistently comply [with the energy benchmarking ordinance]" (SF Environment 2015). A key lesson has been there is a high rate of refusal for energy efficiency audits when they are optional, but that building owners are more likely to pursue an energy retrofit if they have access to energy audit information for their building.

The City of San Francisco is also "de-carbonizing the energy supply by replacing fossil fuels sources with renewable energy sources—micro-hydro, wind, geothermal, solar, wave, and biomass" (City of San Francisco 2013:p.12). The municipally-owned utility, San Francisco Public Utility Commission (SFPUC) launched a program called CleanPowerSF in 2016, which sells residential customers in San Francisco electricity incorporating a higher percentage of renewable energy at the same cost as the electricity that they were previously sold from the investor-owned utility. In 2013, 73% of city-wide electricity came from an investor-owned utility and 16% from SFPUC, with the remaining from other energy service providers (City of San Francisco 2013). This proportion is changing, however, since SFPUC's CleanPowerSF is the new default electricity offering for San Francisco electricity customers. All San Francisco customers are being transitioned to CleanPowerSF, unless they choose to opt out. The program was enabled through California's Community Choice Aggregation legislation, which allows local governments to aggregate the buying power of residents to secure renewable energy supply contracts.

California incentivizes energy efficiency with a number of programs delivered through electricity utilities, for example Energy Upgrade, which connects homeowners with energy efficiency incentives offered by their local government and utilities. San Francisco also offers capacity building programs to support energy efficiency, including Energy Watch which offers energy efficiency services and financial incentives to businesses, contractors, and apartment building owners and the Property Assessed Clean Energy (PACE) financing program, which offers loans for energy efficiency and renewable energy upgrades for homes and businesses. Renewable energy generation, particularly solar photovoltaics, is also to be supported by a number of other local government policies (City of San Francisco 2013). For example, incentive programs from the City of San Francisco support solar PV installation. Up to 2013, $15.5 million USD had been provided to reduce the installation costs of PV systems for residents, businesses and community organizations, including additional incentives for identified 'environmental justice' neighbourhoods that have experienced higher historical levels of pollution (City of San Francisco 2013:p.22).

Solutions and Challenges for Decarbonization Retrofitting for Buildings

Policy and Program Implementation for Urban Building Decarbonization

When asked about successful implementation of climate action targeting buildings in their cities, research participants overwhelmingly described actions related to new development. The policies and programs targeting new developments that were identified in the research are summarized in Table 2, which were also described in more detail in the previous case study sections. Initiatives targeting new developments were scaling up in scope and leading to regulatory requirements. For example, municipal building codes that require development in a certain area to reach higher energy efficiency than the national requirements have helped "shift the market more and more in that direction which then enables future code additions at state level to increase" (San Francisco environmental NGO employee, interview, Apr 20 2016). In addition, when regulatory requirements are increased along a predictable trajectory towards a low/no carbon goal, it can change development practices. For instance, developers in Stockholm now strive to beat existing energy efficiency standards with their proposed designs to stay ahead of anticipated increases in requirements: "it shifted in the early 2000s. If you didn't beat the standard by 20% you weren't really good" (Stockholm development industry representative, interview, Nov 23 2015). Furthermore, builders who wanted to develop buildings related to the Olympics in London had to meet a standard higher than the building regulations called Code 4 in the Code for Sustainable Homes. As one representative of the development industry explained, "that was quite challenging for the industry to deliver, but now that it's delivered, it becomes—well why wouldn't you do Code 4? Because you've got a supply chain with all of the skills and expertise to deliver that" (London development industry representative, interview, Oct 1 2015). When it comes to new development, low(er) carbon and energy use initiatives are finding pathways from voluntary action to regulation and/or widely adopted practices.

Table 2. Summary of types of building and energy decarbonization policies and programs impacting Stockholm, London and San Francisco

Policy and Programs for New Development	Policies and Programs for Existing Built Environment
• Building codes (local, regional, national) or other planning powers that require increased energy efficiency and low/no carbon energy	• Grants for renewable energy installation on buildings
• Incentives to encourage developers to exceed regulated standards related to energy (e.g. access to premium development sites, eco-districts)	• Loans to homeowners to finance building retrofits (e.g. PACE, Green Deal)
• Municipalization of electricity generation to achieve renewable energy targets	• Energy use information released through benchmarking and auditing of energy use for commercial buildings
• Fuel switching in existing energy infrastructure to lower carbon energy supply	• Technical information provision about energy retrofits to building owners (e.g. Energy Watch, RE:FIT)
	• Demonstration projects of energy retrofits to build capacity
	• Requiring municipal agencies or departments to meet energy and climate targets
	• Municipalization of electricity generation to achieve renewable energy target
	• Fuel switching in existing energy infrastructure to lower carbon energy supply

However, while there was substantial progress in setting high standards for new buildings, practitioners working in the case study cities were still struggling to address the challenges posed by retrofitting existing buildings and energy systems. Table 2 also summarizes policies and programs targeting existing buildings and energy systems that were identified in the research, which were also described in more detail in the previous case study sections. Some of these initiatives are scaling up or achieve broader systemic change. For example, the RE:FIT model was planned to be expanded from a pilot project to a nationwide program (Greater London Authority environment department representative, interview, Sept 8 2015). In addition, related to building energy use benchmarking, San Francisco "advanced the state in its thinking" (San Francisco environmental non-profit representative, interview, Apr 19 2016) and state owned buildings across California must now benchmark and report on energy use. However, each of these initiatives typically targets a specific category of building (e.g. private homeowners with access to credit, large commercial buildings, large, publicly owned buildings etc.) and the suite of initiatives are not yet reaching all buildings. As a research participant in London explained, one "sector that we're not really doing any work with…is the small medium sized enterprises—very difficult group to interact with" (London borough (Croydon) employee, interview, Oct 5 2015). These untapped sectors are a significant opportunity since, for example, small and medium enterprises (SMEs) can play a crucial role in sustainability transitions and can be reached using many methods since SMEs are social actors motivated to take sustainability actions by diverse factors (Westman et al., 2019).

In addition to being limited in scope, many of these low carbon building retrofit initiatives have faced significant challenges in implementation. Practitioners often encountered difficulties altering the existing city to accommodate the material changes required for decarbonization. Installing district energy systems is one popular infrastructural approach to decarbonizing energy supply to buildings, for example, but it requires very large underground pipes to connect buildings, which can be incompatible with dense existing areas: "When you walk around London and you think how would you put an 8 metre pipe down the road. We had enough trouble just putting in cable TV and that's a tiny wire" (London development industry representative, interview, Sept 7 2015). In addition, the appearance of historical buildings is often regulated, which can limit the methods available to increase energy efficiency. Homes without wall insulation can be externally wrapped in order to make them more energy efficient, but when this is not possible or desirable because of historical and cultural value, insulation added to the interior cuts into the living space. In small homes in dense cities, this is a significant barrier.

In addition to these examples of material complications, practitioners also described implementation challenges related to urban development practices, financial tool design, and impacts on equity. A research participant from San Francisco described the behavioural and knowledge barriers impeding the adoption of new low-carbon technologies in the construction sector:

> …Even though a lot of this technology already exists, certain technologies are favoured by designers, certain technologies are favoured by owners or developers… [and] contractors might not be familiar with a certain technology…Because it's not enough to just say 'Hey, it's this great new thing that's going to save you a lot of energy'. If people don't know how to install it, don't know how to maintain it, don't perceive it to be as easy or easier to use, then they're not going to put it in (San Francisco consultant, interview, Apr 29 2016)

It is not enough that a technology can make a substantial contribution to energy efficiency or even reduce energy costs. It also must become familiar to construction professionals and integrated into installation and maintenance practices so that building owners and developers confidently select, install and maintain it. In addition, financial tools, mostly grant and debt models, have also encountered barriers. Loan programs have faced challenges in implementation, whether through contestation from national mortgage lenders for the PACE model in California or poor uptake of the Green Deal in the UK because homeowners found the program too complicated without offering an enticing interest rate. When it comes to energy efficiency grants, many are delivered through investor-owned utilities that also sell electricity to those same clients, which discourages utilities from effectively implementing energy efficiency programs that would drive deep reductions in energy use. These programs often target the cheapest, most 'cost-effective' retrofits, rather than deep decarbonization retrofits that drastically reduce energy demand. Utilities need new business models to address this disincentive. Finally, many of initiatives targeting existing buildings align energy retrofitting with home/building improvement and debt, which means that 'upgraded' buildings can be subject to rent increases. Retrofitting can therefore be controversial and have equity implications: "sometimes there can be fights about raising the rents and people are not very happy about having to move out" (Stockholm politician, interview, Nov 27 2015). In this example, rent increases due to building upgrades sometimes force lower income residents to relocate to cheaper housing.

Lessons and Insights for Low Carbon Building Retrofit Initiatives

Despite the challenges described in the previous section, practitioners in the case study cities are achieving some progress in the implementation of low carbon retrofits for existing buildings. In this section, I identify the ways in which experimentation and learning are helping to create progress in this difficult policy area.

Key insights from London relate to the kinds of resources that enable energy efficiency retrofits and lessons learned about targeting owners of multiple buildings as a high impact target audience. Through RE:FIT and RE:NEW, the Greater London Authority is supporting energy efficiency retrofits of private residential buildings and public buildings. These programs provide links to funding, but also technical expertise. In essence, the programs offer low cost energy consultants to owners of multiple buildings to support their learning and planning. The building owners targeted by the program have changed over time as staff have learned what works. In particular, the programs have started to target owners of multiple buildings in order to make it worthwhile to invest significant time acting as an energy consultant by reaching a large number of buildings. Owners of multiple buildings also often have an annual budget for maintenance, which can be optimized for energy efficiency. An added benefit relates to equity considerations; social housing is one sector where a single agency owns multiple buildings and targeting this sector not only provides multiple buildings to retrofit, but also can benefit more vulnerable urban communities that are not targeted by other building decarbonization initiatives that are often focused on low carbon new development provided that housing costs do not increase due to retrofits.

Experiences from San Francisco highlight the ways in which practitioners have expanded the suite of resources available as a way to motivate low carbon building retrofits. San Francisco's green building code requires a reduction in energy use compared to the California code for new buildings or when alterations are significant enough to require a permit. However, only 1-2% of building stock will be new build or major alterations in a healthy economy, so other policies are needed to reach the remaining 98% of buildings. As the case study section explained, incentives and financing were available for some types of buildings and owners. Practitioners decided that a missing piece of the puzzle was information, as well as a program that targeted large existing buildings. The Benchmarking Ordinance requires the reporting of energy consumption statistics by commercial buildings. Like in London, San Francisco practitioners learned from earlier stages of energy efficiency program design. Energy efficiency retrofit programs originally focused on door-to-door homeowner engagement and this approach taught them that there is a high rejection rate at the door before homeowners learn anything about their building's energy efficiency. They applied this learning to the design of the Benchmarking Ordinance. Since they understood from this past experience that the refusal rate for taking energy efficiency action is lower when building owners have their energy use information in front of them, they made energy use auditing mandatory. The information is released publically so that buildings can be compared not only to their own previous performance, but also to other buildings.

Key insights from practitioners working in Stockholm relate to teaching others using demonstration projects and institutionalizing energy and carbon reporting within the municipality. The City of Stockholm is the most significant land and building owner in city and municipal staff used this control to undertake targeted retrofits of municipal buildings and publicly owned housing with two strategies: target the most inefficient building stock ('worst offenders') and target buildings representative of common building types to show what is possible. These demonstrations use the purchasing power of the municipality to invest in low carbon retrofits, but also involved publishing accompanying materials so that others can learn from the demonstration. Finally, Stockholm has instituted an institutional reporting system where municipal departments and agencies all have their own indicators related to the decarbonization plan and have to go back to city hall multiple times a year to report. In many other cases, climate and energy reporting is done either project by project (where reporting is disconnected and ends after the project is done) or collectively for the whole municipality through GHG inventories (where responsibility to achieve GHG emission reductions is diluted across departments). Embedding decarbonization into institutional reporting within the municipality distributes accountability for climate action across all departments, not just those with the environment explicitly in their mandate.

Integrating Zero Carbon Logics into Urban Development

As decarbonization is implemented in practice in these cities, the shape that is evolving so far is the systematic alteration of future development paths towards low/no carbon with pockets of more efficient existing buildings, many of which are under municipal control. As the previous sections explained, a number of challenges are making it difficult to embed zero carbon into existing urban buildings and energy systems. While the greenhouse gas emissions may be decreasing in these cities overall, practitioners are still learning how to integrate zero carbon logics into urban development in ways that succesfully lead to extensive low carbon retrofitting. This is a concern since transformational decarbonization of cities cannot be achieved without low carbon building retrofits. In a survey of the members of the C40 Cities Climate Leadership Group, 47% of cities' greenhouse gas emissions are attributed to buildings (C40 Cities & ARUP 2014). Integrating zero carbon logic into urban systems and creating a phase change so that fossil energy is not merely lessened, but replaced, is not possible without tackling this challenge. Importantly, the barriers holding back retrofitting represent equity issues. If premium new development continues to move towards carbon neutrality and leaves existing buildings behind, low/high carbon buildings will be another urban dynamic mapped onto the inequalities of uneven urban development.

Practitioners have made progress in the implementation of low/no carbon retrofits for existing buildings by focusing at fine-grained level to layer together a suite of initiatives that target specific building types and owners. While public investment is playing a role, most initiatives focus on mobilizing private building owners to use credit and retrofit buildings as a property enhancement strategy. However, new solutions open up if one thinks of retrofit as a different kind of problem. The UK Committee on Climate Change describes the necessity of low-carbon, low-energy, and climate-resilient retrofits for the UK's 29 million existing homes as an infrastructure priority (UK Committee on Climate Change 2019). Given the climate crisis and the importance of building retrofits, it is essential that society approaches buildings and energy infrastructure as an infrastructure priority for public investment, "akin to widening roads" (Harrabin 2019). Overall, the application of a decarbonization framework has demonstrated the value of considering the performance of urban climate change mitigation policy by not only through adding up GHG outcomes, but also by considering whether and how zero carbon logics are being embedded in urban development to drive transformational decarbonization.

Conclusion

As they strive to put urban decarbonization into practice in Stockholm, London and San Francisco, practitioners are finding success in systematically transforming the future development of the city. However, they are encountering difficulty correcting the past development path. While there is substantial progress in setting high standards for new buildings, urban actors are still struggling to address the challenges posed by retrofitting the existing built environment. Recognizing that challenges are limiting the implementation of low/no carbon retrofits for existing buildings, practitioners in the case study cities are experimenting and learning to achieve progress. Based on their experiences, this paper has highlighted key insights for low carbon building retrofits related to 1) shifting primary targets from homeowners to owners of multiple buildings, 2) expanding the suite of resources available to support zero carbon retrofits (financing, technical expertise, information etc.), 3) experimenting and teaching using public investment, and 4) institutionalizing energy and carbon reporting linked to departmental targets. It is important to note that this research focused on three wealthy cities in the global North. While these lessons may be applicable in many cities striving to achieve climate change mitigation, care should be taken since there can be many paths to urban decarbonization. In particular, further work needs to be done analyzing decarbonization in cities in the global South.

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References

Bernstein, S., & Hoffmann, M. 2018a. Decarbonisation: The Politics of Transformation. In A. Jordan, D. Huitema, H. van Asselt, & J. Forster (Eds.), *Governing Climate Change: Polycentricity in Action?* (pp. 248–265). Cambridge: Cambridge University Press.

Bernstein, S., & Hoffmann, M. 2018b. The politics of decarbonization and the catalytic impact of subnational climate experiments. *Policy Sciences* 51 (2): 189-211.

Betsill, M., & Bulkeley, H. 2007. Looking Back and Thinking Ahead: A Decade of Cities and Climate Change Research. *Local Environment* 12 (5): 447–456.

Bickerstaff, K., Hinton, E., & Bulkeley, H. 2016. Decarbonisation at home: The contingent politics of experimental domestic energy technologies. *Environment & Planning A* 48 (10): 2006–2025.

Bulkeley, H., & Betsill, M. M. 2013. Revisiting the urban politics of climate change. *Environmental Politics* 22 (1): 136–154.

Burch, S., Shaw, A., Dale, A., & Robinson, J. 2014. Triggering transformative change: a development path approach to climate change response in communities. *Climate Policy* 14 (4): 467–487.

C40 Cities. 2017. Stockholm. C40 Cities website. http://www.c40.org/cities/stockholm (Accessed November 17, 2017).

C40 Cities, & ARUP. 2014. *Climate Action in Megacities 2.0.* C40 Cities.

Carbon Neutral Cities Alliance. 2015. Framework for Long-Term Deep Carbon Reduction Planning. Carbon Neutral Cities Alliance. https://carbonneutralcities.org/wp-content/uploads/2018/04/CNCA-Framework-for-Long-Term-Deep-Carbon-Reduction-Planning.pdf. (Accessed April 30, 2018).

CDP. 2016. Citywide Emissions, Map. https://data.cdp.net/Emissions/2016-Citywide-Emissions-Map/iqbu-zjaj (Accessed November 29, 2019).

City of London. 2015. London's response to climate change. The London Plan, City of London.

City of San Francisco. 2013. Climate Action Strategy 2013 Update. San Francisco: City of San Francisco. https://

sfenvironment.org/sites/default/files/engagement_files/sfe_cc_ClimateActionStrategyUpdate2013.pdf. (Accessed April 30, 2018).

City of Stockholm. 2010. Stockholm action plan for climate and energy 2010–2020. City of Stockholm. City of Stockholm. http://carbonn.org/uploads/tx_carbonndata/StockholmActionPlanForClimateAndEnergy2010-2020%5B1%5D.pdf. (Accessed April 30, 2018).

City of Stockholm. 2012. The Stockholm Environment Programme 2012–2015. City of Stockholm. http://international.stockholm.se/globalassets/ovriga-bilder-och-filer/the-stockholm-environment-programme-2012-2015.pdf. (Accessed April 30, 2018).

City of Stockholm. 2015a. Stockholm Royal Seaport. City of Stockholm

City of Stockholm. 2015b. S*ustainable Järva - Re-building the Suburbs.* City of Stockholm.

City of Stockholm. 2016. The Stockholm Environment Programme 2016-2019. http://www.stockholm.se/PageFiles/130332/the-stockholm-environment-programme-2016-2019.pdf. (Accessed April 30, 2018).

Corvellec, H., Campos, M. J. Z., & Zapata, P. 2013. Infrastructures, lock-in, and sustainable urban development: The case of waste incineration in the Göteborg Metropolitan Area. *Journal of Cleaner Production* 50: 32–39.

Creswell, J. W. (\2014. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. SAGE.

Dzebo, A., & Nykvist, B. 2017. A new regime and then what? Cracks and tensions in the socio-technical regime of the Swedish heat energy system. *Energy Research and Social Science*, 29: 113–122.

Harrabin, R. 2019. Ban gas grid for new homes "in six years." BBC. https://www.bbc.com/news/science-environment-47306766. (Accessed May 1, 2019).

Hermelink, A., Schimschar, S., Boermans, T., Pagliano, L., Zangheri, P., Armani, R., Voss, K., Musall, E. 2013. *Towards nearly zero-energy buildings*. Ecofys. https://ec.europa.eu/energy/sites/ener/files/documents/nzeb_executive_summary.pdf. (Accessed April 30, 2018).

Jones, F. C., Blomqvist, E. W., Bisaillon, M., Lindberg, D. K., & Hupa, M. 2013. Determination of fossil carbon content in Swedish waste fuel by four different methods. *Waste Management & Research* 31 (10): 1052–1061.

Levin, K., Cashore, B., Bernstein, S., & Auld, G. 2012. Overcoming the tragedy of super wicked problems: constraining our future selves to ameliorate global climate change. *Policy Sciences* 45 (2): 123–152.

Luque-Ayala, A., Marvin, S., & Bulkeley, H. 2018. *Rethinking Urban Transitions: Politics in the Low Carbon City*. New York, NY: Routledge.

Mayor of London. 2013. *London's zero carbon energy resource: Secondary heat.* Greater London Authority.

Mayor of London. 2015. The Mayor's climate change mitigation and energy annual report: 2013-2014. Greater London Authority. https://www.london.gov.uk/sites/default/files/gla_migrate_files_destination/CCMES annual report_2013-14_0.pdf. (Accessed April 30, 2018).

Mayor of London. 2016. Energy planning: Monitoring the implementation of London Plan energy policies in 2015. Greater London Authority.

Mayor of London. 2017. Interim London Energy and Greenhouse Gas Inventory (LEGGI) 2014. Mayor of London, https://data.london.gov.uk/dataset/interim-london-energy-and-greenhouse-gas-inventory--leggi--2014 (Accessed April 30, 2018).

Merton Council. 2016. 10% Renewable Energy Policy (The Merton Rule). Merton Council. Retrieved from https://www2.merton.gov.uk/environment/planning/planningpolicy/mertonrule.htm. (Accessed April 30, 2018).

Reckien, D., Flacke, J., Dawson, R. J., Heidrich, O., Olazabal, M., Foley, A., Hamann, J.J., Orru, H., Salvia, M., De Gregorio Hurtado, S., Geneletti, D., & Pietrapertosa, F. 2014. Climate change response in Europe: what's the reality? Analysis of adaptation and mitigation plans from 200 urban areas in 11 countries. *Climatic Change* 122 (1): 331–340.

Romero-Lankao, P. 2012. Governing Carbon and Climate in the Cities: An Overview of Policy and Planning Challenges and Options. *European Planning Studies* 20 (1): 7–26.

Seto, K. C., Davis, S. J., Mitchell, R. B., Stokes, E. C., Unruh, G., & Ürge-Vorsatz, D. 2016. Carbon Lock-In: Types, Causes, and Policy Implications. *Annual Review of Environment and Resources*, *41*(1), 425–452.

SF Environment. 2015. San Francisco existing commercial buildings performance report 2010-2014. City of San Francisco, https://sfenvironment.org/sites/default/files/fliers/files/sfe_gb_ecb_performancereport.pdf (Accessed April 30, 2018).

UK Committee on Climate Change. 2019. *UK housing: Fit for the future?* UK Committee on Climate Change, https://www.theccc.org.uk/wp-content/uploads/2019/02/UK-housing-Fit-for-the-future-CCC-2019.pdf.

(Accessed May 1, 2019).
Unruh, G. C. 2000. Understanding carbon lock-in. *Energy Policy* 28 (12): 817–830.
Westman, L., Luederitz, C., Kundurpi, A., Mercado, A. J., Weber, O., & Burch, S. L. 2019. Conceptualizing businesses as social actors: A framework for understanding sustainability actions in small- and medium-sized enterprises. *Business Strategy and the Environment*, *28*(2), 388–402.
Yin, R. K. 2009. *Case Study Research: Design and Methods*. Thousand Oaks, California: Sage.