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Thesis:

Climate change mitigation and adaptation co-benefits in urban transitions to Zero-Net Energy (ZNE) residential development in California

Daniel Krekelberg

United States

Supervisors: Alberto Gianoli & Stelios Grafakos

Specialization: Urban Environmental Management & Climate Change

Summary

Energy efficient homes that generate their own sources of electricity are cited by various sources as being an effective way to reduce greenhouse gas emissions in growing cities. At the same time these structures are also being researched for their ability to improve the resilience of populations and assets to increases in extreme weather conditions brought on by climate change. Urban climate change planning has recently shifted in the direction of implementing single actions that support both mitigation and adaptation. The purpose of this research is to evaluate the potential of an emerging building typology, Zero-Net Energy (ZNE), to fulfill the dual promises of mitigation and adaptation at multiple levels of governance. In California, sustainability transitions in the building and energy sectors have been gaining momentum in recent years, benefitting from progressive policies and technological advancements enabling distributed renewables and improved building design. ZNE currently represents a small but growing portion of this trend and policymakers envision a future where this becomes the default standard for new and retrofitted homes. But further interventions will be needed to move ZNE from niche to mainstream action, including the support of emerging technologies that connect renewables into the existing grid infrastructure. Although reconfiguring established models and fostering multi-stakeholder collaboration may prove to be a difficult task, this research indicates that myriad benefits may await those actors willing to take on the challenge.

Keywords

Renewables, Energy, Climate, Mitigation, Adaptation, Transitions

“Even if we could roll out the ideal zero-carbon solution tomorrow, some climate change is inevitable, and it will hit the world’s poor the hardest. The countries that have done the most to cause this problem have a responsibility to not only invest in mitigation, but also help poor countries adapt to a changing climate.” - Bill Gates, gatesnotes.com, July 29, 2015

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Abbreviations

A	Adaptation Measures for Climate Change
AB32	California Global Warming Solutions Act, Assembly Bill 32
ABM	Agent Based Models
CALGAPS	California Greenhouse Gas Analysis of Policies
CARB	California Air Resources Board
CEC	California Energy Commission
CEQA	California Environmental Quality Act
CHP	Combined Heat & Power
CO2	Carbon Dioxide Emissions
CPUC	California Public Utilities Commission
DER's	Distributed Energy Resources
EE	Energy Efficiency
EPIC	Electric Program Investment Charge
FIT	Feed In Tariffs
GHG	Greenhouse Gas Emissions
HERS	Home Energy Rating System
HG	Housing Growth
IHS	Institute for Housing and Urban Development
IOU	Investor Owned Utility
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatts of electrical energy
M	Mitigation Measures for Climate Change
M&A	Mitigation and Adaptation
MLP	Multi-Level Perspective
MMTCO2e	Million Metric Tons of Carbon Dioxide Equivalent Emissions
MTCO2e	Metric Tons of Carbon Dioxide Equivalent Emissions
MUSH	Microgrid classification for Military, Universities, Schools and Hospitals
MW	Megawatts of electrical energy
NREL	National Renewable Energy Laboratory
PG&E	Pacific Gas & Electric Utility
PIER	Public Interest Energy Research
POU	Publicly Owned Utility

PPH	Persons Per Household
PV	Photovoltaic Solar
R&D	Research and Development
RPS	Renewables Portfolio Standard
STS	Sociotechnical System
SACOG	Sacramento Area Council of Governments
SMUD	Sacramento Municipal Utility District
TH	Total Homes
TIS	Technological Innovation Systems
USGS	United States Geological Survey
ZEB	Zero-Net Energy Building
ZNE	Zero-Net Energy
∑	Overlapping co-benefits for Climate Change Mitigation and Adaptation
§	Policies and Regulations

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Chapter 1: Introduction

1.1 Background

In response to rapid urban population growth in coming decades and increased concerns about the adverse impacts of climate change on assets and livelihoods, many cities are integrating climate action strategies into their planning agendas (Tyler and Moench, 2012). As a relatively new element to planning there is no generally accepted method of how to properly approach climate change action and the chosen approaches depend greatly on perceived and estimated risks and the capacities of governments and the population (Eakin, Lemos, et al., 2014). Climate actions can be implemented at local, regional or national levels and exist as stand-alone plans or merged into established environmental or sectoral planning. Existing under the wider concept of sustainability, climate change policy is pursued in many urban plans through initiatives seeking to reduce GHG emissions and improve the ability for urban populations to withstand extreme climatic conditions. These approaches are known respectively as mitigation and adaptation.

Since the mid-2000's California state and local agencies have been involved in governance actions that encourage mitigation through greenhouse gas reductions. More recently, as climate models and reports indicate the need to protect populations against inevitable climate impacts, adaptation has also been included (IPCC, 2014, Moser and Ekstrom, 2010). Researchers and planners are now evaluating ways that these mitigation and adaptation measures work together or against each other in climate change policy (Landauer, Juhola, et al., 2015). It is now being observed that there are interrelationships between multiple sectors in the mitigation-adaptation dichotomy and that the building and energy sectors have interconnected roles in mitigation and adaptation. Buildings are the spaces where human activities are carried out that create the demand for energy, and also opportunities for initiating transitions to more sustainable energy consumption patterns (Shove, 2012). For instance, demand for energy from fossil fuel based generation comes largely from activities occurring within buildings, creating a mitigation target. But as average temperatures rise, the energy used for cooling in homes to adapt will put additional demand on energy generation, creating more energy demand, and thus carbon emissions (Xu, Huang, et al., 2012). This results in a negative feedback cycle of carbon emissions and temperature increases.

Distributed energy resources (DER's) are currently being proposed as a method of improving sustainability by reducing GHG emissions and creating enhanced adaptive capacity. DER's are electrical power sources generated at the building level such as rooftop solar panels that reduce the demand for centrally supplied energy generated from fossil fuels. In applied settings, one of the most potent forms of DER deployment is found Zero-Net Energy (ZNE) buildings. ZNE combines ultra-efficient building design and DER's to a degree that buildings produce as much energy as they consume. In advanced configurations clusters of DER equipped buildings can also be linked together to form microgrids that can island from the electrical grid to keep power on for neighborhoods during severe storms (Lasseter, 2007, Hatziargyriou, Asano, et al., 2007, Considine, Cox, et al., 2012).

Although there are numerous challenges to implementing the widespread adoption of ZNE buildings, the allure of a technology that brings positive benefits toward sustainability has charted California down a path of making ZNE the standard for new residential development by 2020 (CPUC, 2011). State regulators, utilities and local governments are releasing plans and providing incentives to early adopters to pilot ZNE developments in cities. This has created a protected space for innovative firms to pilot ZNE, and these projects are already being marketed within mixed-used urban infill, suburban residential tracts and student housing in the state's real estate markets.

California's facilitation of renewable energy development is not new – the state has a history of utility-scale wind, solar, and geothermal dating back to the 1970's – but decentralization is a new direction that marks a new chapter of energy transitions.

Utility-scale renewables supplement the existing centralized power grid and are managed by a limited number of institutional actors, while DER's occur at a household and neighborhood scale with more widely distributed ownership and operation. Utility scale renewables are generally deployed over large land footprints, on the periphery of cities and transported via transmission infrastructure while DER's are integrated into the built environment. Both have important roles in enabling sustainable energy transitions. Distributed renewables arrive to the market gradually, over decades as hardware prices decline, consumers create demand and utility business models adjust to accommodate the invisible hand of market driven growth. This multiple decade growth trajectory is typical of transitions (Rotmans, René Kemp, et al., 2001) and this is an important distinction because it provides a window of opportunity for decision makers to optimize plans and policies that guide the transition down a path toward sustainability.

1.2 Problem Statement

ZNE buildings and their DER components are novel innovations that represent a deviation from established methods of housing and energy delivery. Introducing new technologies at a large scale into complex urban ecosystems is likely to create effects in ways that are not currently understood. Looking at solutions exclusively though lenses of mitigation or adaptation, short or long-term results may skew perceptions on how to implement policy in the most effective ways. There are trade-offs from energy transitions that sometimes go undetected when only the benefits of mitigation are considered. In Germany for instance, the renewables transition, or Energiewende has at times lead to the unintended consequence of more expensive energy prices for the country's low income residents (Gawel, Korte, et al., 2015). In The Netherlands, investment in offshore wind energy has led to grid interconnection issues resulting in an increased likelihood of power failures (DNV GL, 2015). Inversely, positive externalities can occur from DER deployment such as job creation and economic development (Wei, Patadia, et al., 2010) and enhanced adaptive capacities through improved resource management (Venema and Rehman, 2007). Understandings of DER's and energy efficiency on social and urban landscapes is still a work in progress, and further efforts are needed to evaluate balances between mitigation and adaption as policy support for novel energy technologies move in stride with scientific understandings of benefits and trade-offs.

1.3 Research Objective

This research will analyze positive interrelationships, or co-benefits between mitigation and adaptation for planning and policies supporting the development of ZNE residential housing at multiple levels of governance in the U.S. state of California. State, regional and household levels will be evaluated to see what potential the technology has to meeting climate change planning goals of reduce greenhouse gas emissions and building resilience to climate change.

The system where these policy decisions are made will be analyzed as well, to see how the efforts of actors involved with the development of this technology aid or inhibit the transition of ZNE to mainstream adoption.

1.4 Research Question

What climate mitigation and adaptation co-benefits are achieved through policies supporting urban transitions to Zero-Net-Energy (ZNE) communities at multiple stakeholder levels?

> What statewide climate change mitigation and adaptation co-benefits are achieved in policies supporting ZNE in California?
>
> What regional climate change mitigation and adaptation co-benefits are achieved in policies supporting ZNE in Sacramento?
>
> What are the linkages between actors engaged in developing ZNE?

1.5 Significance of the Study

As policy makers seek to mainstream the adoption of renewables and energy efficiency (Tapper, 2015, McEvoy, Lindley, et al., 2006) and move beyond a dichotomy of climate mitigation and adaptation as separate actions (Biesbroek, Swart, et al., 2009) there is importance in understanding how specific technologies in ZNE can fill these roles. In the future ZNE developments are expected to increase in major cities throughout the globe. Although the high initial costs of DER equipment may lead to perceptions that ZNE growth is limited to high-income markets, studies are showing that ZNE housing can already be successfully piloted in emerging megacities of India (Bulkeley and Broto, 2012) and China (Lu, Yu, et al., 2014, Zhang, Li, et al., 2014). Since many global cities and countries are including adaptation and mitigation in their planning, investigating whether ZNE creates co-benefits can assist with determining whether it should be a prioritized solution.

Since this study evaluates a transition, it may also be useful for bringing urban perspectives to the field of Transition Studies. Transition studies is a field of social sciences developed in The Netherlands that is increasingly being applied in international settings to explain and manage the growth of technological innovations in society. While significant research has been conducted in transitions since its emergence in the late 1990's, it's representation in North America as well the fields of urban studies and local governance are limited (Markard, Raven, et al., 2012). It is suggested that the field could benefit from more studies that evaluate the interplay between actors in sociotechnical systems (Musiolik and Markard, 2011).

1.6 Scope and Limitations

This study is focused on co-benefits of policies associated with ZNE, not on engineering or design. Technology in this field is continually evolving and will likely improve in parallel with increased demand for green building, but this aspect of research is covered in other academic disciplines.

Although this study is focused on California, it should be noted that ZNE projects are emerging globally in both developed and developing countries. Each jurisdiction has a unique set of regulatory, political and social dynamics influencing the ability to develop ZNE that should be considered when applying lessons learned to other locales.

As previously mentioned, interrelationships between adaptation and mitigation do not always result in benefits. This study focuses on the positive aspects of combining adaptation and mitigation, but further studies could be conducted to understand trade-offs and negative externalities.

Chapter 2: Literature Review

2.1 Zero-Net Energy

Behind the various labels applied to low carbon development exists a body of academic research seeking to conceptualize and define the principles of carbon neutral building. This section will explore some of the research in this field.

2.1.1 Defining ZNE

Since ZNE is a relatively new concept, common understandings of its underlying attributes and definitions are still evolving. At the core of most ZNE definitions is a building design where the energy generation from low carbon sources offsets those consumed from traditional sources but the way those calculations are made is a subject of debate. Multiple ways of qualifying net energy consumption exist, as well as differing opinions on the origins and types of energy that are eligible for calculation. Beyond differences in calculation, different labels and acronyms are used within academic literature, trade journals and in media publications to describe the technology, as shown in the table below.

Net-Zero Energy Buildings (NZEB)	Net-Zero Building (NZB)
Zero-Energy Buildings (ZEB)	Net-Zero Energy (NZE)
Zero Net-Energy Buildings (ZNEB)	Zero-Net Energy (ZNE)

Table 1: Acronyms denoting zero-net energy configurations from various sources.

Multiple studies in the United States and Europe have been conducted to evaluate the new definitions of ZNE and the methodologies underlying them. According to Panagiotidou and Fuller (2013), the first definition of a ZNE home was established in the United Kingdom in 2006 as part of a six tier rating system for energy efficiency that defined a zero carbon home as one with zero net emissions of CO2 from all energy use in the home including heating, lighting, hot water and miscellaneous energy uses. A limitation of this definition is that it does not include commercial buildings. During the same time period Torcellini, Pless, et al. (2006) working on behalf of the National Renewable Energy Laboratory (NREL) in the United States developed a broader definition that has been widely cited in academic research since its publication. It is stated that the importance of properly defining the ZNE concept is because ultimately this definition is what will be used to judge the success of completed projects. According to Torcellini, Pless, et al (2006); a net zero-energy building is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies.

The International Energy Agency also formed a definition that included an explicit timeframe and an acknowledgement of how ZEBs tie into the larger grid infrastructure; “Zero Net Energy Buildings are those that over a year are energy-neutral, meaning that they deliver as much energy to the supply grid as they draw from the grid. Seen in these terms, these buildings do not incur any fossil fuel debt for heating, cooling, lighting or other energy uses although they sometimes draw energy from the grid (Lautsen, 2008).”

Author (Year)	Definition
(Torcellini, Pless, et al., 2006)	A net zero-energy building is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies.
(Lautsen, 2008)	Zero Net Energy Buildings are those that over a year are energy-neutral, meaning that they deliver as much energy to the supply grid as they draw from the grid. Seen in these terms, these buildings do not incur any fossil fuel debt for heating, cooling, lighting or other energy uses although they sometimes draw energy from the grid
(California Energy Commission, 2012)	The amount of energy provided by on-site renewable energy sources is equal to the amount of energy used by the building.
(Kilkis, 2007)	A building, which has a total annual sum of zero exergy (*sic.)* transfer across the building-district boundary in a district energy system, during all electric and any other transfer that is taking place in a certain period of time.

Table 2: Various definitions of ZNE

2.1.2 Calculation Methodologies

In the report Zero Energy Buildings: A Critical Look at the Definition (Torcellini, Pless, et al., 2006) researchers evaluated seven completed ZNE projects with in the United States' commercial real estate sector to establish four types of common ZNE methodologies;

1. Site ZNE – energy that is generated from on-site sources like photovoltaic in high enough quantities that it surpasses consumption of non-renewable electrical sources.

2. Source ZNE - energy generated from a combination of on-site renewables, plus low carbon natural gas sources in high enough quantities that it surpasses consumption of non-renewable electrical sources.

3. Cost ZNE - enough energy is generated on site that the money that building owner earns from selling it back to the utility is equal to or greater than the costs needed to obtain non-renewable energy.

4. Emissions ZNE - the building uses more energy generated from renewables than from non-renewables, even if it is generated off-site.

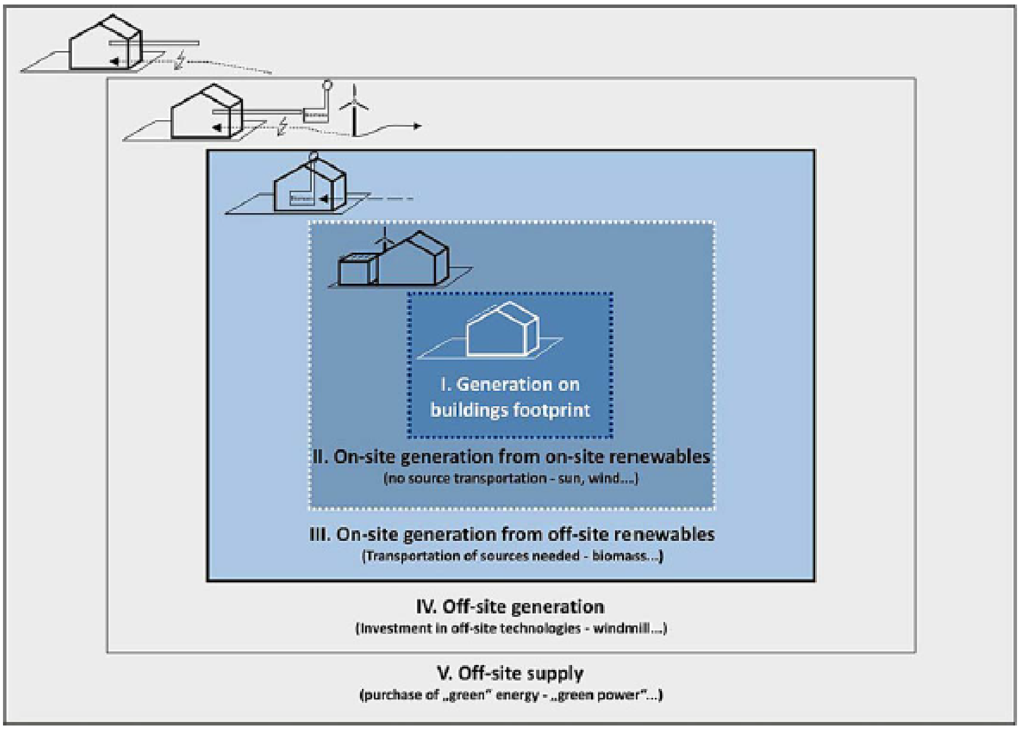


Figure 1: Site configurations for residential ZNE. Source: (Marszal, Heiselberg, et al., 2011)

A common theme between these four types is that they all rely on being connected to the main grid, for both obtaining power when it cannot be generated from renewable sources, and putting it back on the grid when there is excess. Pros and cons are identified for each configuration, and the authors conclude that that Cost ZNE is the most difficult to achieve due to fluctuations in market demand and Emissions ZNE is the easiest. The latter argument makes sense, because any household that opts to pay fee each month to procure their power from off-site renewables would be eligible to label itself ZNE, an extremely low barrier for participation.

A comprehensive review of existing ZNE definitions and applied methodologies was published in 2011 (Marszal, Heiselberg, et al., 2011). This meta-analysis of definitions looked at various aspects of ZNE definitions including metrics, timeframes, typologies, renewable supply options and integration with the existing infrastructure. Below, some of Marsal, Heiselberg, et. al observations on indicators for ZNE calculation are summarized;

Metrics – Highlighted one of the most important points. Describes the balance in calculating between energy generated on-site from renewables, imported from the grid or from fossil fuel sources like natural gas, and what is returned to the grid as excess power.

Timeframes – Most ZNE definitions use a one year timeframe to evaluate the energy imports and exports leading to zero net energy, but other researchers have proposed that the project be evaluated through its entire lifetime to also account for carbon footprints inherent in materials, construction and deconstruction (Hernandez and Kenny, 2010).

Type of Energy Use - Household energy is consumed by many types of appliances. In early research on ZNE thermal energy (ie. heating, hot water and cooling) were the primary considerations, but since then total consumption is generally considered. In rare instances the embodied energy of the project, which includes the carbon emissions required in building materials can also be quantified and spread out over the life of the dwelling.

Renewable Energy Supply Options – Renewable energy can be imported from off-site or generated at the project premises within either the project footprint, or the project site.

According to NREL researchers solar energy generated on a rooftop is ranked as the most preferable. (Torcellini, Pless, et al., 2006)

Connection with Infrastructure – Both grid connected and standalone variants of ZNE exist. The latter is referred to as an autonomous ZNE and requires some form of energy storage capacity. The requirements for storage, backup systems, and oversized solar panels drastically limit the application of autonomous ZNE in most global markets.

Regarding interconnection, off-grid autonomous ZNEs are sometimes considered the 'true' example of low carbon development and have been successfully implemented in Germany (Lautsen, 2008) although these are even more of a niche, and most ZNE configurations include some sort of tie in to the existing grid (Marszal, Heiselberg, et al., 2011). Wide scale implementation of grid-connected ZNE projects brings about its own set of issues. Torcellini, Pless, et. al. suggest that as renewables penetration increase in cities a surplus of energy can follow, suppressing the values owners can receive for their surplus energy in the future. This concern is echoed by researchers in Germany, where photovoltaic solar systems already account for a very high proportion of the country's total energy production. Voss, K., Musall, E., et. al. (2011) predict that ZNE will become more expensive to operate in the future in comparison to systems that actively balance energy inputs and outputs according to the unique consumption characteristics of the building and variable rates offered through feed in tariffs. The technologies that could be used to dynamically balance energy inputs and outputs as suggested can be found in the discussion of smart grids in section 2.4.

2.1.3 Community ZNE

Within the literature a distinction is made between ZNE development that occurs at the individual household level and ZNE that exists as a shared resource among communities. DeBaillie describes that developing ZNE as part of a community offers some distinct advantages from a financial perspective, with costs for maintenance and equipment split over a larger pool of users (2012). He also suggests that because traditional ZNE uses individual rooftops, it promotes low density sprawling development, while Community ZNE encourages higher density developments with shared renewable energy generation sources. Christian (2005) observes that Community ZNE is appealing due to higher capacity factors from renewables technologies other than Solar PV, such as biomass, concentrated solar and wind and that this configuration offers less complicated utility-to-prosumer connectivity since grid tie-ins would occur at a neighbourhood rather than a household level. Fernandez, Katipamula, et al. (2009) conducted an evaluation of five different configurations for ZNE communities that included rooftop PV, solar thermal, solar and wind farms, and concluded that individual rooftop PV indeed offered the lowest performance among the available options. This study also indicated that the cost of PV must be significantly lowered to reach a significant penetration of PV in residential and commercial real estate sectors.

Community ZNE can be defined in several ways. Carlisle, Van Geet, et al., (2009) offer four possible options based on the way that the site is configured, the level of energy efficiency and how the renewable energy is obtained. These authors suggest that developing a definition for a zero-energy community is challenging and more complex than a standard ZEB because a community uses energy not only for buildings but also for industry, vehicles, and community-based infrastructure.

Option	Name
0	Energy efficiency and demand reduction
1	Use DER in the built environment & on brownfield sites
2a	Use DER on community greenfield sites.
2b	Use DER renewables generated in local area directly on-site
3	Purchasing credits for renewables generated off-site

Table 3: Options for DER generation in community ZNE's. Source: (Carlisle, Van Geet, et al., 2009)

2.2 Mitigation, Adaptation & Interrelationships

Climate change actions have typically focused on mitigation in an effort to reduce greenhouse gas emissions, but adaptation is emerging as a new objective in public policy making at various levels of governance throughout the world (Mees, Driessen, et al., 2012). Mitigation is defined as an intervention that reduces the anthropogenic changes within the climate system and includes strategies to reduce greenhouse gas sources and emissions (Klein, Huq, et al., 2007). Adaptation refers to systemic social and environmental modifications in response to actual or expected climatic changes, which minimize harm and enable benefits to be achieved (IPCC, 2007). Some researchers contend that adaptation is imperative because no matter how effective mitigation measures are, they will not prevent climate change from happening in the next few decades (Christensen, Hewitson, et al., 2007). It is increasingly recognized that mitigation and adaptation are not mutually exclusive, but part of a dual approach to addressing climate change (Mertens, 2012). As a result of this new understanding of the importance of adaptation, climate change planners have shifted their attention toward adaptation as an important focus. Howard (2009) explains that this shift has swayed the pendulum of climate planning toward adaptation, but further research is needed to understand the interrelationships between adaptation and

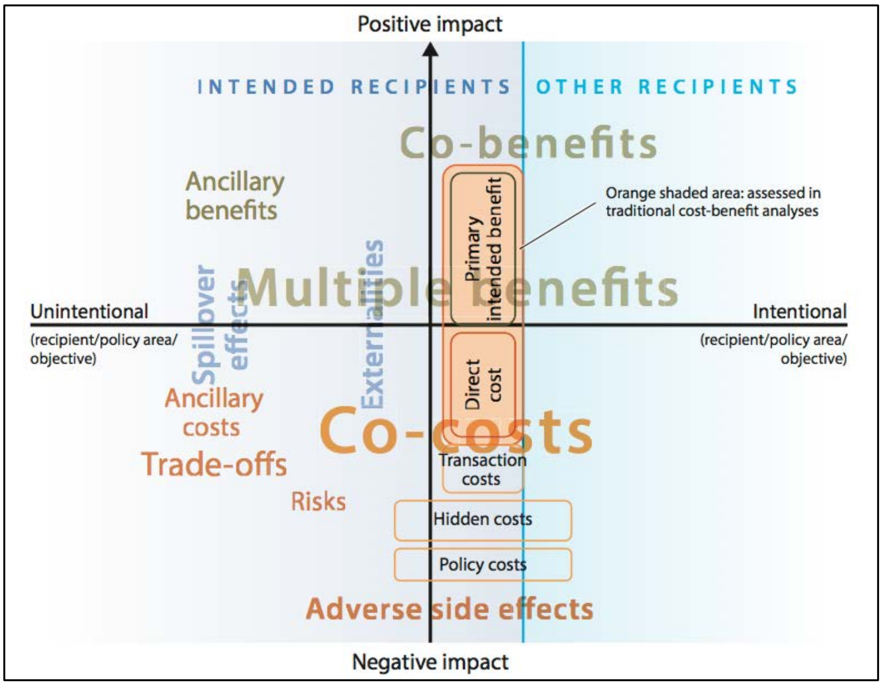


Figure 2: A conceptual framework for evaluating cost-benefits for climate mitigation and adaptation co-benefits. Source: (Ürge-Vorsatz, Herrero, et al., 2014)

mitigation to avoid creating trade-offs where mitigation policies are maladaptive or adaptation increases GHG emissions.

Interrelationships between mitigation and adaptation can be beneficial, neutral or adverse or some combination of these factors depending on the timeframe and scale used for comparison. Co-benefits are positive externalities between mitigation and adaptation actions, where the effect of one action creates benefits for the other (Biesbroek, Swart, et al., 2009). Synergies are co-benefits where mitigation and adaptation actions enacted simultaneously enhance the effect of each other (Goklany, 2007, Klein, Huq, et al., 2007). Interrelationships are sometimes described as co-impacts to denote their ability to create positive impacts and also negative impacts, and these impacts can occur as a result of intended or unintended actions (Ürge-Vorsatz, Herrero, et al., 2014).

According to some researchers the win-win solutions of co-benefits between mitigation and adaptation enable greater efficiencies than those with adverse effects, and the attractiveness of this kind of efficient policy making warrants further research into the links between these measures (Berry, Brown, et al., 2015, Laukkonen, Blanco, et al., 2009). Despite this optimism about the ability to achieve these win-win situations, some are incredulous about these benefits playing out in real life scenarios, suggesting that trade-offs may actually be more common (McEvoy, Lindley, et al., 2006). Others even go so far as suggesting that M&A should be kept as separate actions, except in limited circumstances due to persistent barriers (Tol, 2005).

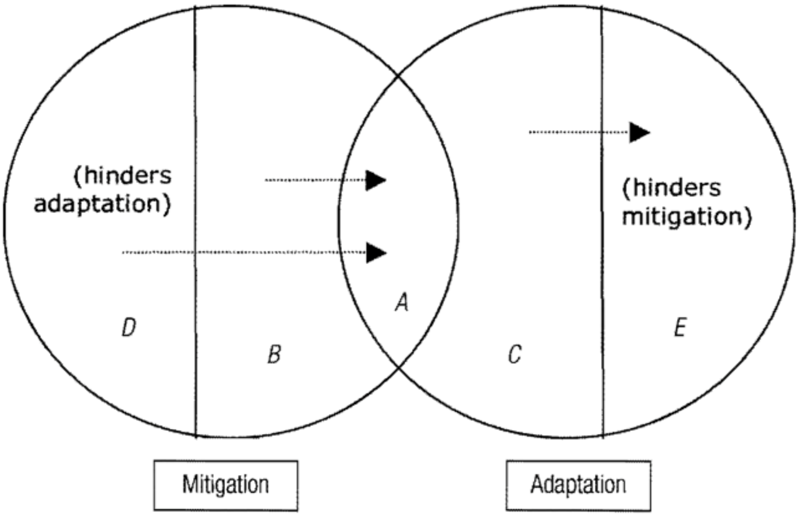


Figure 3: Mitigation and adaptation conceptualization where A = Co-benefits, B & C = support for adaptation or mitigation, but no effect on the other, D & E = support adaptation or mitigation but inhibit the other. From (Howard, 2009)

Barriers to achieving co-benefits in climate change include discrepancies in the spatial and temporal scales of M&A. For instance, adaptation is carried out at the local level, designed to conform to the unique social and geographic attributes of neighborhoods (Saavreda and Budd, 2009) while mitigation occurs on a broader level to address the GHG emissions on sectoral, regional and ultimately global scales (Tol, 2005). This means that different levels of governance have varying levels of responsibility and effectiveness. Wilbanks, Leiby, et al. (2007) observed the role of M&A through top-down and bottom up approaches, concluding that adaptation is a more attractive focus at the local level, since the benefits of mitigation are less visible and occur outside the local area. Both mitigation and adaptation entail short-term investments, with the efforts of adaptation visible in the shorter term, and mitigation returns occurring over a much longer timescale (Goklany, 2007). Biesbroek, Stewart, et. al. (2009) suggest that the local and short term nature of adaptation makes land use planning an ideal tool for implementing measures at the urban level. Although majority of academic sources endorse the perception of adaptation as local and mitigation as regional, Nalau, Preston, et al. (2015) conducted a study on climate actions in European cities and found that implementation for both mitigation and adaption occur often at local scales, although the benefits are experienced at different scales. Ancillary benefits from climate change mitigation include

Inserting adaptation into local planning does not require waiting until climate threats are imminent but can be inserted during windows of opportunity like periodic updates to city general plans (Moser and Ekstrom, 2010) with integration into broader policy objectives (Tompkins and Adger, 2005). At the local level, Mees, Driessen, et al., (2012) indicate that both private and public sector have important roles in implementing adaptation. The private sector's involvement is especially critical in the United States where preferences for neoliberal governance mean limited government intervention and heavy reliance on private capital. The inclusion of private sector actors in policy formation is argued to promote greater efficiencies in environmental policy (Lemos, Agrawal, et al., 2011) creating legitimacy and providing critical input needed for the policy to resolve market failures that discourage investment. Local governments can encourage investment by reducing uncertainties in the benefits of adaptation measures and creating flexible policies that can be adapted as new information becomes available (Adger, Dessai, et al., 2009)

In local government, agencies screen vulnerabilities in their assets and resources to determine if adaptation and mitigation measures are warranted, including in the housing and energy sectors (IEA, 2009). IPCC's Fourth Assessment points out that adaptation measures within these sectors may have competing interests, and uses Sacramento's river system as an example. In this example anticipated changes in rainfall in coming decades will create challenges for water management, where flood protection in the winter must be balanced with maintaining adequate storage for low rainfall in the summer. It is stated that this shift in hydrological regimes may have an adverse impact on hydropower generation thus affecting energy delivery in the region. (Klein, Huq, et al., 2007)

Linkages between mitigation and adaptation often follow a pathway of primary and secondary actions, where one measure is an entry point that leads to another (Klein, Huq, et al., 2007). For instance, since mitigation has been the focal point for many climate plans to date, mitigation would be the entry point for measures adopted in planning, but these measures may have effects on adaptation. This can occur in reverse as well, where adaptation as the primary goal is an entry point for mitigation.

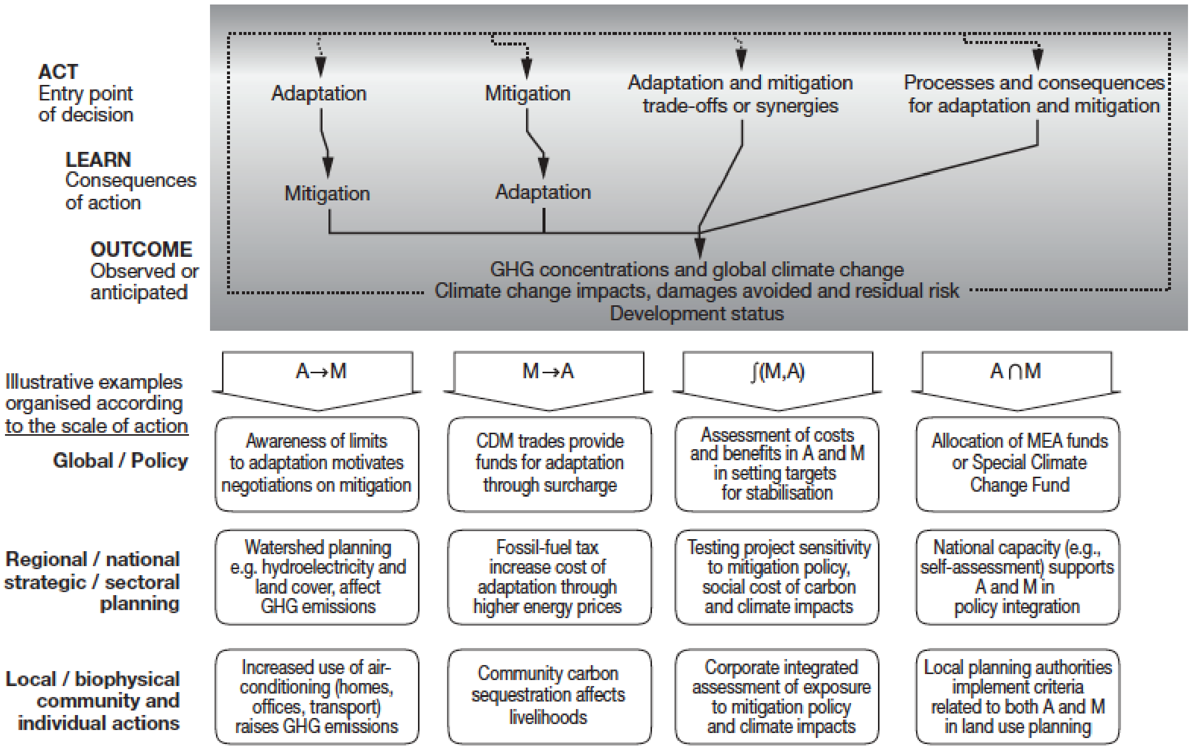


Figure 4: Entry points and interactions for mitigation and adaptation for climate change policy. Source: (Klein, Huq, et al., 2007)

Klein, Huq, et. al. (2007) give examples of relationships in the housing and energy sectors specifically. For adaptation to mitigation relationships, A→M, the increased use of air conditioning in buildings in response to urban heatwaves would result in increased energy use, thus increasing the amount of greenhouse gases generated by a city when fossil fuels are the primary source of generation. In the other direction, M→A development of renewable energy sources like solar and wind reduce GHGs in the long term while simultaneously promoting local development, economies and livelihoods. The author also lists "urban planning, and building design with benefits for both adaptation & mitigation" (p. 762). The use of renewables can also reduce vulnerability to grid outages by sourcing energy from distributed sources (Mertens, 2012). In the planning process synergies and trade-offs can be explicitly sought, identified as ∫ A,M in the above table or occur inadvertently through the simultaneous consideration of measures A∩M. In the building sector, benefits between mitigation as an entry point and adaptation have been identified by researchers based on feedback from industry professionals as shown in the table below (Udvardy and Winkelman, 2014).

MEASURE	BENEFITS	
	Mitigation	Adaptation
Energy Efficiency	↓ GHGs	Enhance electricity grid resilience. Maintain business continuity.
Building Code Updates	↑ Energy Efficiency	↑ Resilience to wind, flooding earthquakes
On-Site Renewables and CHP	↓ GHGs	Enhance electricity grid resilience. Maintain business continuity.
Microgrids	Supports efficiency & renewables	Enhance electricity grid resilience. Maintain business continuity.

Protect and Elevate Mechanical Systems	↓ GHGs from retrofitting	Enhance electricity grid resilience. Maintain business continuity.
Elevate & Protect structures	↓ GHGs from retrofitting	Protect people, building, infrastructure. Maintain business continuity.
Water efficiency	↓ GHGs from water distribution & treatment	Prepare for declining water supplies. Maintain ecosystem services.
Green Infrastructure (green roofs, green walls, landscaping)	Cooling -- ↓ Air Conditioning energy use ↓ Water treatment needs	↓ Urban heat island ↓ Stormwater runoff ↑Flood resilience Maintain ecosystem services

Table 4: Potential co-benefits in the building sector from industry experts. Source: (Udvardy and Winkelman, 2014)

Within the concept of adaptation, the terminology 'resilience' is used seemingly interchangeably with adaptation, but they are actually different concepts. Adaptation denotes measures that come in response to actual or anticipated climate changes, but resilience refers to the ability for people and urban ecosystems to withstand shocks and thrive despite such challenges (Pendall, Foster, et al., 2010). These shocks can be induced by climate change, but also by other factors like foreign trade and economic markets (Molyneaux, Wagner, et al., 2012). The resilience of the city is influenced by it's adaptation measures and adaptive capacities, hence the interconnection between the two concepts (Shaw and Theobald, 2011). According to Ford and King, (2015) the term 'readiness' is also used in the context of adaptation referring to the preparation and willingness of social and political institutions to engage in the decision making to move adaptation measures from theory to implementation. This concept has applicability in developed countries where the requisite capacities may be available to carry out adaptation, but political and institutional barriers may hinder an actual response.

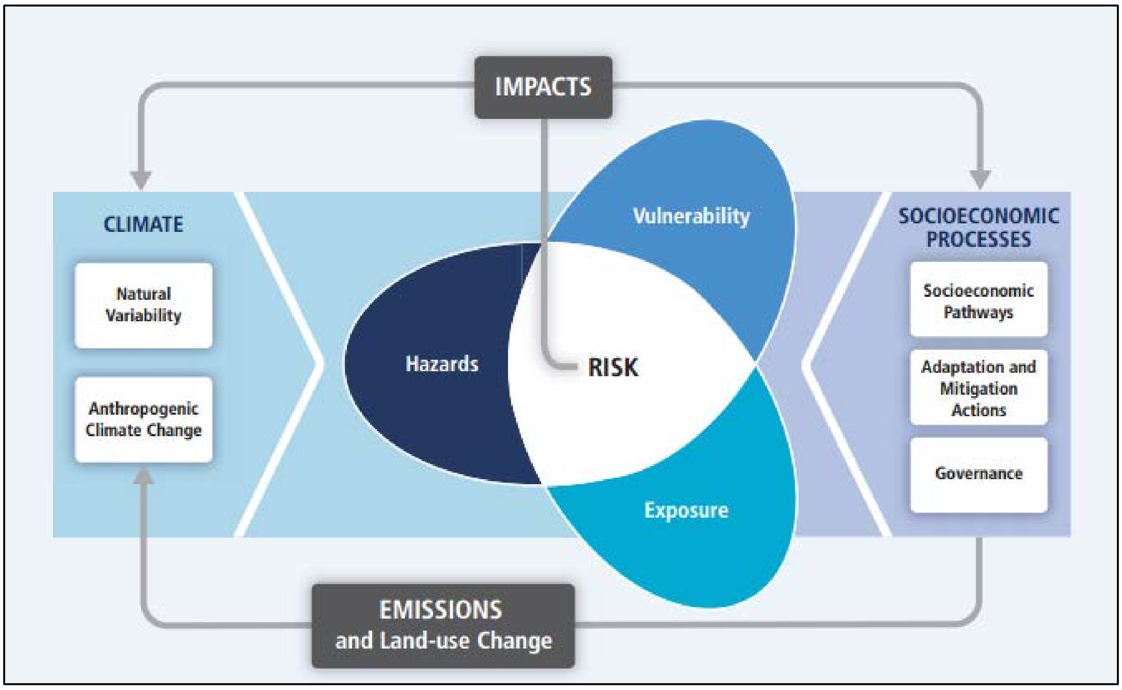


Figure 5: Risk factors for climate change in an urban context. Source: (IPCC, 2014)

Both resilience and readiness are connected to the concept of adaptive capacity which is defined by the IPCC as "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (IPCC, 2014).” This definition is further narrowed as a population’s ability to perceive risk and to avoid or lessen the negative consequences of multiple hazards they are exposed to, based on individual and household/neighborhood access to assets (Romero-Lankao, 2014). The second definition contains an important distinction, implying that individuals and households are key decision makers for adaptation, yet their abilities to respond are influenced by assets and recognition of risks.

Risks are comprised of three primary variables; hazards resulting from natural and made changes in climate conditions, exposure via spatial setting of the affected parties and vulnerabilities (IPCC, 2014). All three variables are influenced by socioeconomic conditions where lack of political representation, poverty, health and social services are indicators for high vulnerability, thus responses should be comprised of specific measures as well as generic improvements to social systems (Lemos, Agrawal, et al., 2011). Connecting this to the concept of co-benefits, the example of Klein’s M→A linkages where revenues derived from carbon taxes can be redistributed to developing countries to stimulate investment for adaptation (Klein, Huq, et al., 2007) could also be modified so that cities with major income inequalities could can take the funds derived from market based instruments (Stavins, 2001) and use it to enhance the adaptive capacities of the most vulnerable segments of the population.

Measuring mitigation and adaption against each other can pose a challenge since mitigation can be measured in terms of GHG emissions reduction, yet adaptation does not have predefined targets or quantified measurements to assess rates of success (Biesbroek, Swart, et al., 2009). Recent attempts have been made to develop a comparison based on a cost benefit analysis where GHG emissions reductions at present time have the effect of reducing adaptation costs in the future (Ürge-Vorsatz, Herrero, et al., 2014). The accuracy of this approach is complicated by a lack of data and uncertainties about severity of impacts requiring adaptation and associated costs.

2.3 Sustainability Transitions

Transition Studies is a research area in the social sciences that investigates radical shifts that change the fundamental structure of society (Loorbach and Verbong, 2012). It is a field that emerged in the 1990's to explain innovations in technology and sustainability, borrowing concepts from other fields of social and natural sciences. Researchers in this field have observed transitions from a variety of systems standpoints including sociotechnical systems (STS), innovation systems, complex adaptive systems. Grin, Rotmans and Schot (2010) identify transitions as having the following characteristics;

- They are co-evolutionary processes that require multiple changes in STS configurations.
- Transitions are multi-actor processes, involving a large variety of social groups.
- They are radical shifts from one configuration to another.
- Long-term processes that occur on a macro-level.

Transitions Studies has been used to observe a wide range of social phenomena, including changes to the energy sector, marked by a departure away from centralized, fossil fuel-based production systems with high levels of energy consumption (Loorbach and Verbong, 2012).

Investigating academic literature for sustainability transitions reveals a wide variety of analytical perspectives and models that have been proposed by researchers. Markard, Raven , et. al. (2012) conducted a meta review of journal articles in sustainability transitions and list some of the frameworks that have been developed over the last 10-15 years. A list of these has been extracted from the text and placed in the table below. The frameworks shown with underlines are considered by the authors to have the most prominence in academic literature, the lightly shaded cells contain theories more tailored toward technology dissemination, and the dark cells are more geared toward sustainability issues. The authors also make a distinction between socio-technical transitions and purely technological transitions. The socio- prefix denotes that there are changes in user practices, and institutional changes in addition to the technological aspects.

Technological Innovation Systems	Multi-Level Perspective	Strategic Niche Management	Transitions Management
Social Construction of Technology	Technology Future Studies	Actor Network Theory	Industrial Ecology
Constructive Technology Assessment	Sociology of Expectations	Evolutionary Economic Theory	Eco-Innovation
Long Waves	Reflexive Governance	Ecological Modernization	Green Management and Corporate Social Responsibility

Table 5: Theories describing various forms of transitions. Source: (Markard, Raven, et al., 2012)

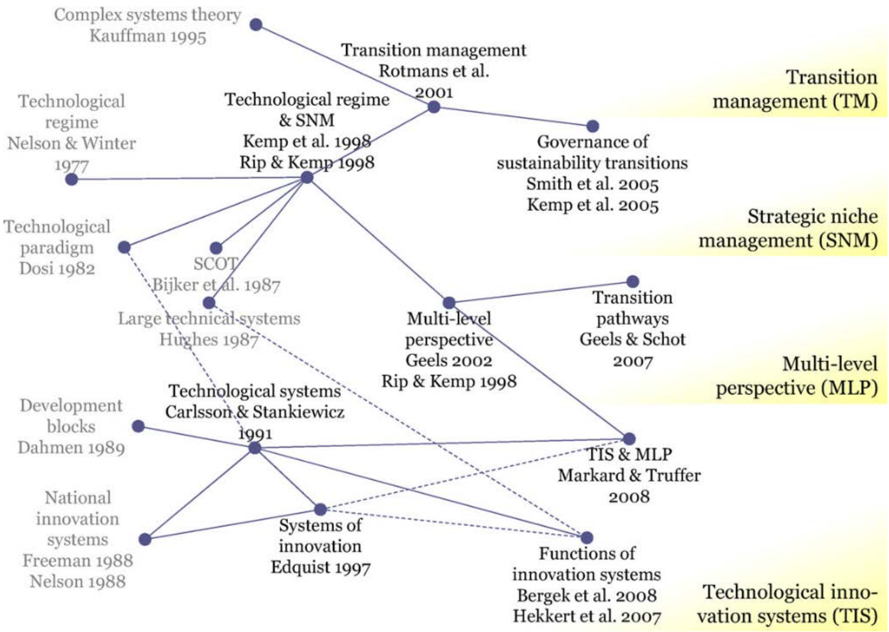


Figure 6: Timeline and linkages among prevailing transition theories. Source: (Markard, Raven, et al., 2012)

2.3.1 The Multi-Level Perspective

The multi-level perspective is a three tier model used to conceptualize dynamics within a sociotechnical system. This was originally developed as a heuristic framework to broadly conceptualize interactions supporting technological change (Rip and Kemp, 1998). Over time this model has been adopted by transitions researchers to map interactions between specific actors and influences pertaining to specific sectors such as energy, healthcare, and environment. Throughout the application of this model three tiers are ever-present; landscape, regimes and niches. These are also referred to at times as macro, meso, and micro levels. Following the identification of the three levels, visual interpretations of MLP were published in academic literature, most notably the "S" curve (Rotmans, René Kemp, et al., 2001) and a nested hierarchy represented by a sandwich of overlapping ovals (Geels, 2002, Geels and Schot, 2007).

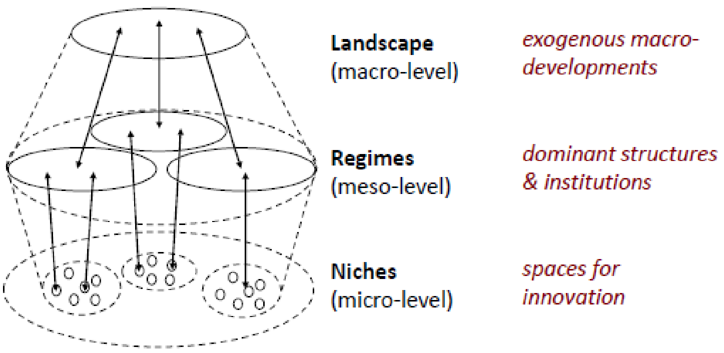


Figure 7: A visual framework for MLP in a sociotechnical system. Source: (Geels and Schot, 2010)

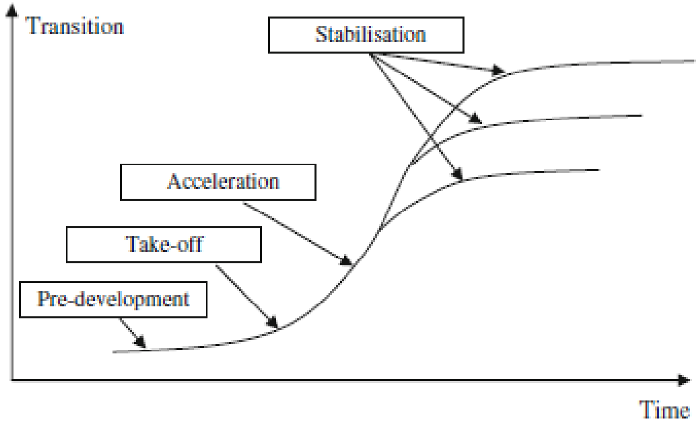


Figure 8: An "S" curve of movement of niches into the mainstream. Source: (Rotmans, René Kemp, et al., 2001)

Landscapes are the top level of the socio-technical system where pressures build and are exerted upon established organizations at lower levels (Smith, 2007, Verbong and Geels, 2010, Geels and Schot, 2007). These pressures are derived from exogenous forces that occur outside of the system that can be social, political, economic or environmental in nature (Geels, 2002). Regimes describe the dominant technologies, rules and processes existing within a STS. Niches are novel technologies or practices that operate in protected spaces, or new processes that represent a deviation from the business as usual operations found in a regime.

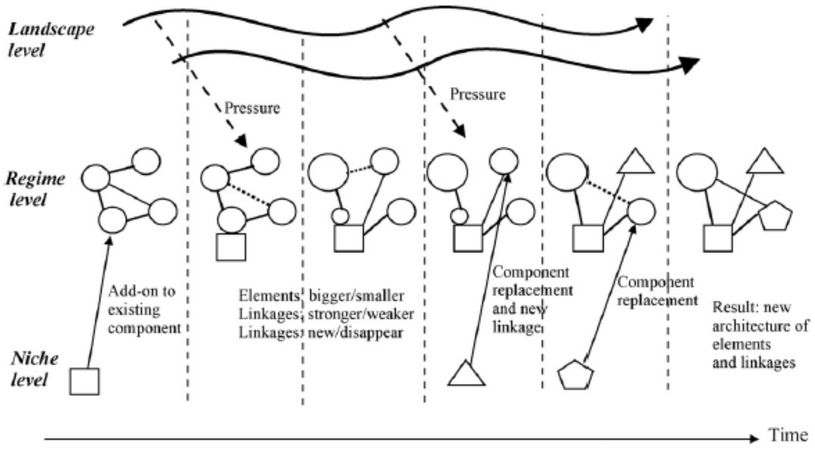


Figure 9: An illustration of hypothesized linkages in a reconfiguration pathway within a socio-technical system Source: (Geels and Schot, 2010).

Geels and Schot (2010) adapted the "S" shape model to show four transitions pathways that can be present within STS; a transformation pathway, a reconfiguration pathway, a de-alignment and realignment pathway and the technological substitution pathway. These niche innovations start off as incremental and compatible with the existing regime practices, but slowly reconfigure the architecture of the system.

Berkhout, et. al. (2012) suggest that transitions do not occur strictly because of technological innovations in niches, but also require supportive economic, political institutional and socio-cultural changes. Because the energy market is highly regulated it does not operate as an open and free market and is subject and thus requires supportive institutions creating policy guiding it toward sustainability. Firms can be the impetus for lobbying policy to create conditions favorable to innovation or they can be reluctant parties that engage in green innovation as a result of pressure from social movements and regulation (Penna and Geels, 2012).

The multi-level perspective has been used to analyze transitions over the course of decades but has sometimes been challenged for being too rigid, too focused on technological innovation and having a weak conceptualization of actor interaction within the systems (Farla, Markard, et al., 2012). Further publications point out that the some of the discussed limitations of MLP arise from researchers using the framework in a mechanical and hierarchical way for which it was not originally intended (Rip, 2012).

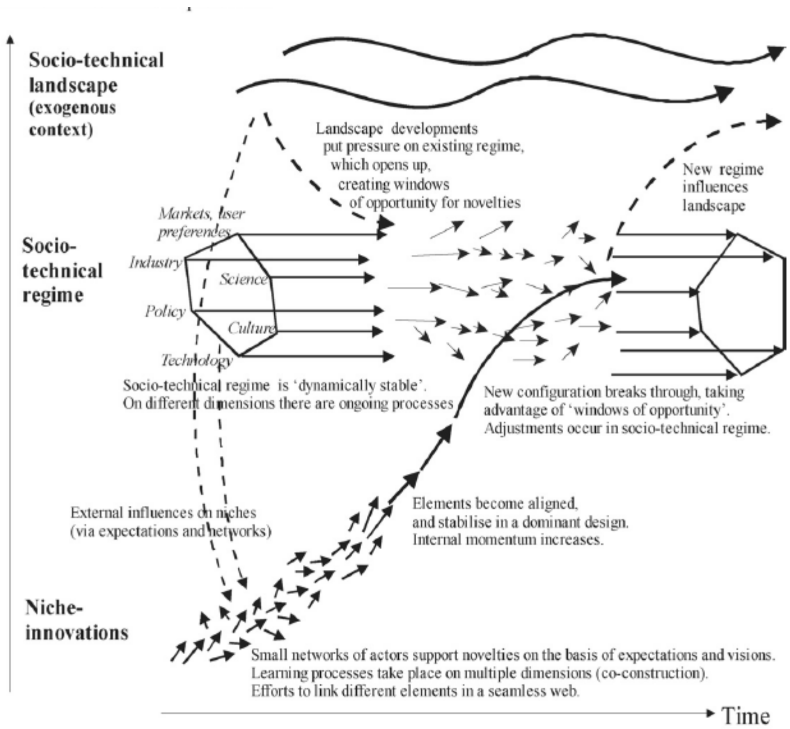


Figure 10: Hypothesized elevation of niche innovations into the mainstream regimes. Source: (Geels and Schot, 2007)

2.3.2 Technological Innovation Systems

Technological Innovation Systems (TIS) is a framework that investigates the networks of actors and institutions working together to enable the development and distribution of new products or innovations (Markard and Truffler, 2008). The TIS framework has been used to analyse sustainability transitions and also how actors proactively build up resources in networks to spur innovation and progress for sustainable energy (Musiolik, 2012).

Bergek, Jacobsson, et al. (2007) explore the functional dynamics of TIS for the purposes of identifying policy issues and allowing decisions makers to set goals for achieving innovation. A step-by-step approach for analysis is offered, as well as a framework that identifies key processes or 'functions' that influence the development and spread of new technologies. A six step process is used in this framework, where facts, actors, functions, goals and external policies are evaluated at each step of the way.

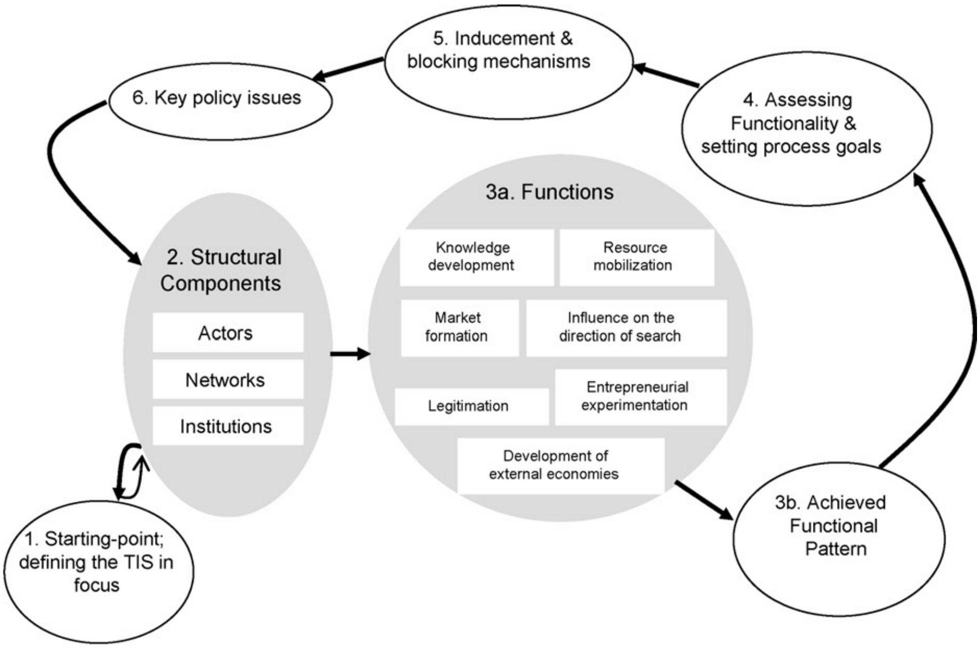


Figure 11: A framework for mainstreaming niche innovations in a TIS system. (Bergek, Jacobsson, et al., 2007)

Step	Description
1	Determine the focus by choosing between a) knowledge field or product, b) breadth and depth or c) spatial domain, depending on the desired analysis.
2	Identify actors including firms within the value chain, but also outside supporting organizations and networks that contribute to the knowledge and resource base.
3 a & b	Determine "functions". There are six categories recommended and a variety of functions suggested within each; 1) Knowledge development 2) Resource Mobilization 3) Market Formation 4) Influence on the direction of search 5) Legitimization 6) Entrepreneurial experimentation
4	Determine whether innovative project is within a growth or formative stage using the following indicators. • time • uncertainties technologies, markets and applications • knowledge on price and performance of products • small diffusion compared to potential • minimal consumer demand observed • weak or absent positive externalities
5	Examine blocking mechanisms, with comparative mapping between blockades and functional patterns. Blocking mechanisms can be internal or external in nature, dealing with weaknesses in the firm, the

	customer base or within the network of actors. An example of the mapping is shown in the diagram following this table.
6	Determining the policies and/or policy issues that need to be addressed or enhanced to promote the projects. These can be used as a response to some of the blocking mechanisms identified in Step 5.

Table 6: Steps involved in agents moving innovations from niche to mainstream in a TIS system. Adapted from: (Bergek, Jacobsson, et al., 2007)

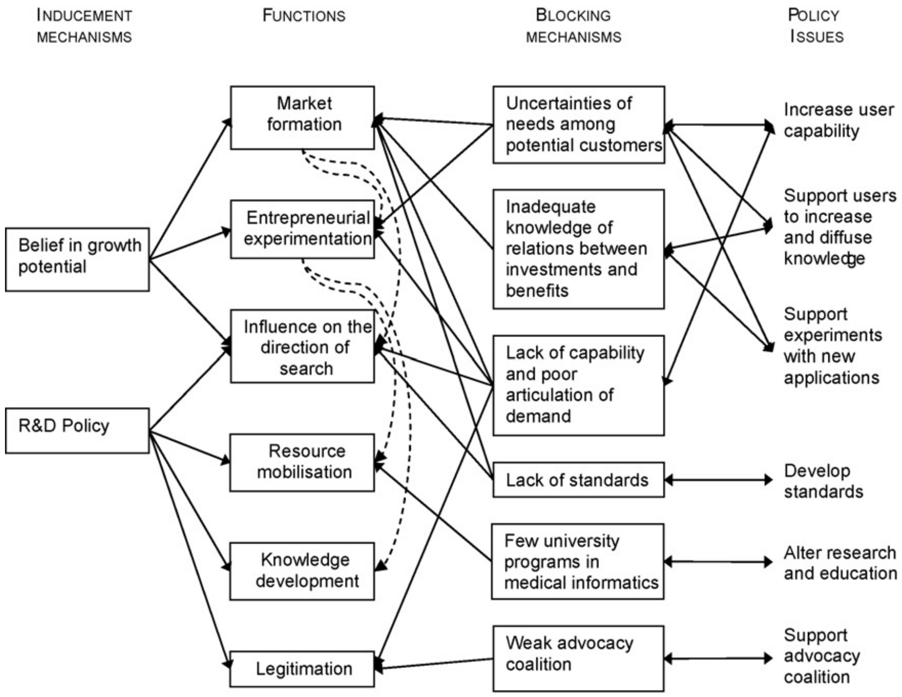


Figure 12: Barriers and blocking mechanisms for innovation. Source: (Bergek, Jacobsson, et al., 2007)

Hekkert, Suurs, et al., (2007) propose analyzing systems innovation also using functions, where the process rather than the structure of the system is used for analysis. Hekkert argues that TIS' allow for dynamic analyses and therefore add deeper context when analyzing transitions occurring at a broader level. For instance, when evaluating the growth of renewable energy in Germany, TIS allows the analyst to see that the result is not simply due to FIT's enacted at the national level, but is also the result of a highly educated workforce, entrepreneurialism, venture capital, R&D engineering firms and networks between industry, policymakers and academia.

These are all indicators that can be used for analysis under Hekkert's proposed functions of innovation systems, but he warns that so many factors can contribute to the outcome of technological innovation that mapping all of these can result in a formidable task, and only those that influence goals of the innovation system should be used. (Hekkert, Suurs, et al., 2007). According to Johnson, (2001), establishing explicit functions is an important step in establishing system borders, and creating a standardized to measure of indicators that can be used in a variety of geographic and technological contexts. Using empirical evidence, Hakkert's research team narrowed the number of functions relevant for mapping key activities down to seven functions (2007);

1. Entrepreneurial Activities
2. Knowledge Development
3. Knowledge Diffusion Through Networks
4. Guidance of the Search
5. Market Formation
6. Resources Mobilization
7. Creation of legitimacy & counteract resistance to change

The factors identified are similar to Bergek's but there are differences in the approach as well. For instance, Bergek's process follows a linear flow from step one to step six, while Hakkert's shows that multiple starting points for initiating sustainability transitions.

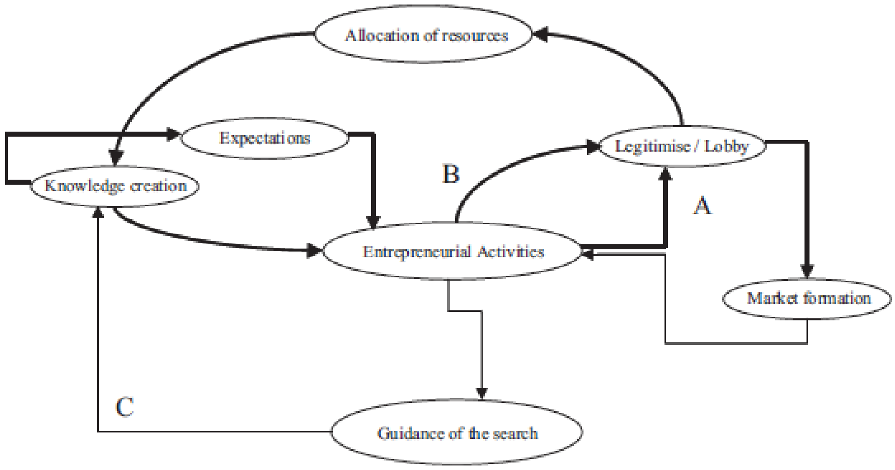


Figure 13: Framework for actor interactions in a TIS system. Source: (Hekkert, Suurs, et al., 2007)

A recurring question is whether market failures or institutional failures are responsible for the barriers to technological innovation. Jacobsson and Johnson (2000) indicate that it is a combination of market, network and institutional failures that inhibit innovation. Dysfunction within networks can arise from several hypothesized barriers shown in the table below.

Actors and markets	**Legislative failures**	**Networks**
Poorly articulated demand Established technology characterised by increasing returns Local search Processes Market control by incumbents Skewed capital markets	Failures in the educational system Skewed capital market Underdeveloped organizational and political power of new entrants	Poor connectivity Wrong guidance with respect to future markets Institutions

Table 7: Potential barriers inhibiting the mainstreaming of technological innovations in a TIS system (Jacobsson and Johnson, 2000)

Johnson's pulls from these stated deficiencies in subsequent research, identifying 8 functions to evaluate TI (Hekkert, Suurs, et al., 2007, Johnson, 2001);

1. Supply resources (capital and competence)
2. Guide the direction of search (influence the direction in which actors deploy resources)
3. Recognize the potential for growth (identifying technological possibilities and economic viability)
4. Facilitate the exchange of information and knowledge
5. Stimulate/create markets

6. Reduce social uncertainty (i.e., uncertainty about how others will act and react)
7. Counteract the resistance to change that may arise in society when an innovation is introduced
8. provide legitimacy for the innovation

Hybrid models exist as well where TIS with MLP are merged to gain an understanding of network actors within the context of the systems innovation. (Markard and Truffler, 2008)

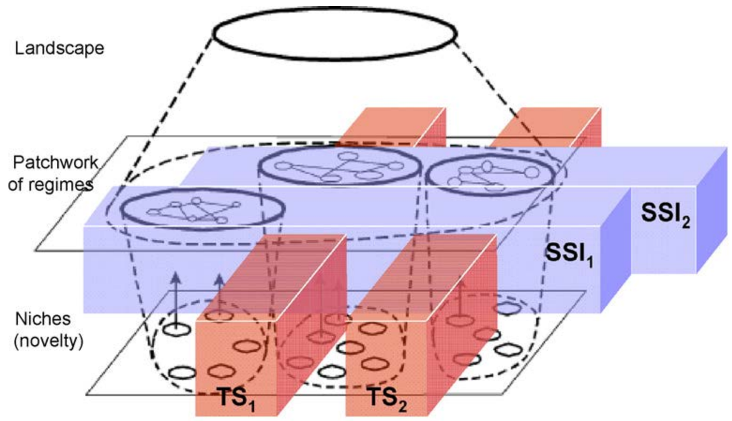


Figure 14: A merged TIS + MLP framework, where TS represents Technical Systems, and SSI represents Sectoral Systems of Innovation. (Markard and Truffler, 2008)

2.3.3 Urban & Energy Applications

The relationship between niches and socio-technical regimes in the green building industry has been investigated. Smith looked at some of the factors that separate mainstream housebuilding from eco-housing in the U.K. and two types of translations that elevate building techniques from novelties into regimes. (Smith, 2007)

Regarding regulation, Smith argues that regulation dominant approaches may not encourage deeper learning, ie. second order translations. Developers will implement the basic regulations to stay compliant, but this will not encourage firms to develop systems that adapt to pre-existing market conditions. Subsidy also relieves some of the pressures to develop technologies at lower costs that can compete with alternatives in an open market.

Studies have been conducted that investigate how institutional factors diffuse new energy technologies including one that looked at the obstacles policy makers have faced in Japan with encouraging innovation (Suwa and Jupesta, 2012). Given Japan’s reputation for technical innovation in the electronics industry the government’s challenge of contending with technological “lock-in” to fossil fuels comes as a surprise, but Suwa and Jupesta suggest that deeper policy reforms are needed to spur innovation even in developed countries (2012). Many GHG reducing technologies are experimental and are considered to be on the ‘waiting-list’ for market demand and policy to catch up. Technology lock-in can be rooted in the difficulty of delivering emerging technologies to consumers at prices competitive with existing technologies (Van den Bergh, Truffler, et al., 2011).

Bringing innovative technologies to the market over time has been conceptualized by using a “S” shaped curve that shows innovative projects moving from the R&D phase to growth trajectory and then to a stabilized plateau. (Rotmans, Kemp, et al., 2001) Suwa and Jupesta argue that sustainability innovations are not geographically limited and can be shared across space and time and applied in other countries.

Suwa and Jupesta explain that Japan chose an RPS over a Feed-in-Tariff (FIT) because the RPS required less government intervention and this was the ideological approach preferred by Japanese policy makers at the time the RPS was drafted. RPS was associated with policies adopted in the United States, while FIT was considered the European approach, which some considered to be a threat to the dominant industries that comprised the regimes of the energy sector (2012). RPS mechanisms currently exist in Italy, China, South Korea, Sweden, Norway, UK, India and 30 out of 50 U.S. States, including California (REN21, 2014).

Governmental policies used to encourage renewable energy can be targeted toward generating energy from renewable sources in the near term, and improving conditions for long-term changes in consumption. (Harmelink, Voogt, et al., 2006) The hope with RPS in Japan was that it would stimulate both immediate interest in renewables investment, and also long term interests, but this proved to not be the case and resulted in mediocre adoption of PV. It appears that the established requirements were not strict enough to pressure the regimes of the country's energy utilities to uptake new innovations. The relation of this case back to California is that policy needs to exert strong pressure on existing industries in order for innovation to take hold.

Bai, Roberts, et al., (Bai, Roberts, et al., 2010) conducted an assessment of common patterns for initiating sustainability experiments at the local level in Asia and then constructed a process-oriented framework based on common triggers, actors, linkages and pathways. This framework relied on case studies from 30 countries and evaluated not only the conditions that allowed the experiment to take place, but also the ability for these experiments to move from localized actions to mainstream policies. The triggers, actors, linkages and pathways method used in the meta-analysis pulled from earlier work by (Bai, Wieczorek, et al., 2009) where the MLP framework was adapted to include a temporal dimension.

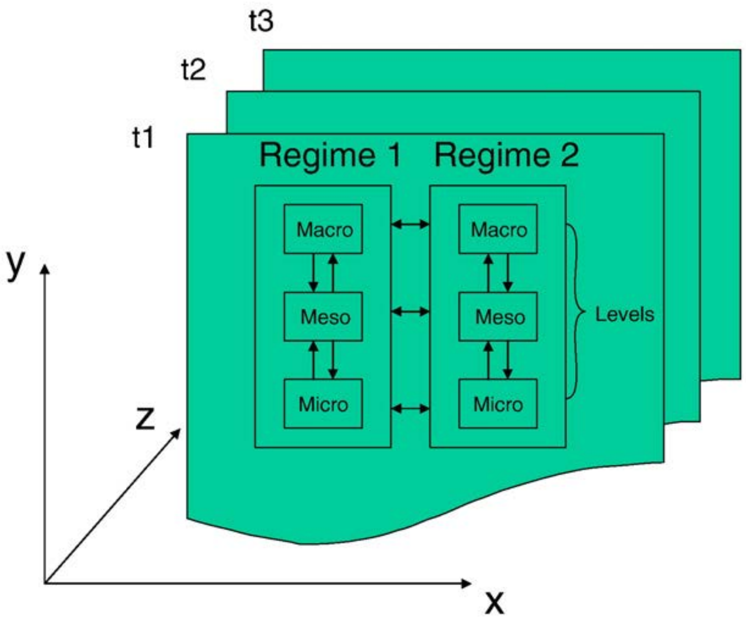


Figure 15: A framework for vertical and horizontal linkages between multiple regimes, with the inclusion of a time dimension. Source: (Bai, Wieczorek, et al., 2009)

2.3.4 Promises & Requirements

Emerging technologies within a socio-technical system can be evaluated using an analytical framework based on promises and corresponding requirements for their further development. The premise of this framework is that actors in a system set visions for newly emerging technologies, and their performance potential to solve broad societal challenges, such as climate change. Then, the promise is translated into requirements for the further concrete development of the technology. (Parandian, Rip, et al., 2012). Promises involving newly emerging technologies have dual dynamics; grand, open-ended visions that attract public interest but lack specificity on pathways for development, and promise-requirement cycles that developers engage in to create explicit steps for realizing the technology.

The diagram below illustrates the connections between the open-ended promises shown as an umbrella and the promise-requirement cycles.

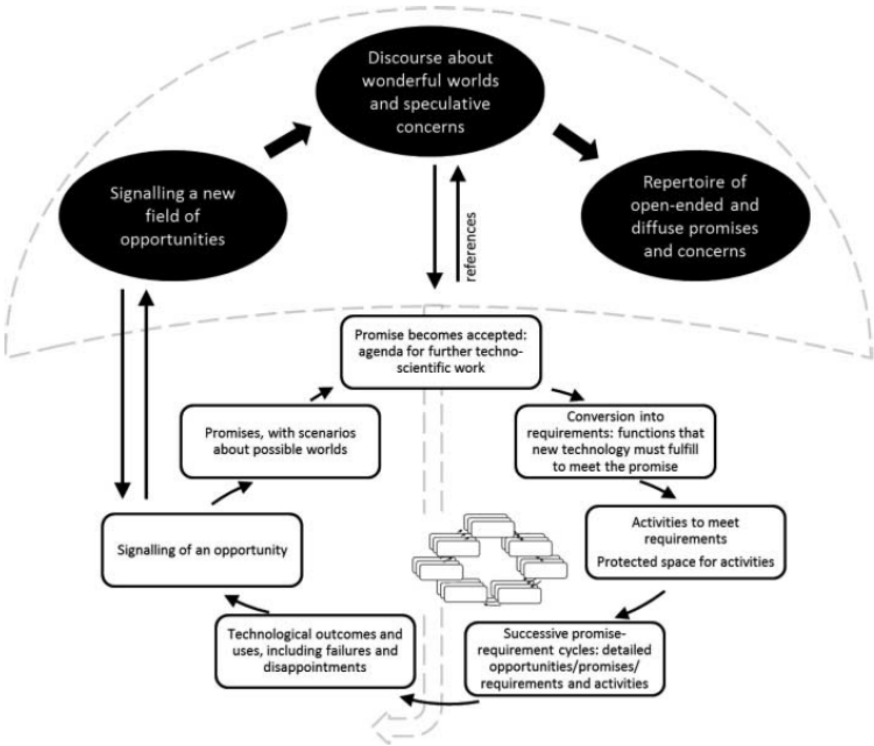


Figure 16: A diagram illustrating the dual dynamics of promises and requirements for emerging technologies. (Parandian, Rip, et al., 2012)

Often, some hype is built around an emerging technology which can encourage investment, but it can result in unfulfilled expectations if the technology does not pan out according to the narrative (Borup, Brown, et al., 2006). If the promise of the technology remains general, there may not be incentives to actually invest in further development and use, which results in a so-called 'waiting game'. Promise umbrellas and promise-requirement cycles can be observed as independent phenomena, or they can be analysed in relation to each other. When viewed together, sometimes one process with predominate over the other, for instance, the promise can be very strong with very little development occurring in the promise-requirement cycle. Or the promise-requirement cycle can be very strong, but there is less discussion about the promise of the technology to deliver benefits.

2.3.5 Complex Adaptive Systems

Like the study of complexity of cities which was adapted from the biological sciences, ZNE projects can be studied as complex adaptive systems that are influenced by the interrelationships of consumers, aggregators, agents, weather patterns, raw materials and physical infrastructure. (Rylatt, Gammon, et al., 2013). The scale of this analysis extends beyond the individual project level and includes the energy infrastructure that allows grid-connected ZNE's to import and export energy off the grid.

Complex energy systems have been mapped by researchers using models such as the MARKAL model. This model can provide a broad overview of how energy systems evolve over the course of decades but it is limited in its ability to identify specific barriers. (Bale, Varga, et al., 2014). This type of model could be helpful in high-level public documents that provide a general overview of the energy sector. Alterative models for mapping include Network Theory which energy distribution is mapped in the context of nodes, which can provide insight into the ability for multiple ZNE projects to work synergistically to achieve the climate adaptive, or "resilience" properties championed by proponents of DER's. This model could be useful in testing the supposed self-healing properties of microgrids (Rickets, 2009). ABM's or agent-based models can be used for behavioral analysis of agents within an energy system. But it's usefulness in observing individual ZNE case studies may be limited, and instead, could serve as a better tool for observing consumer behavior among utility customers.

2.4 Microgrid & Smartgrid Infrastructure

Smart grids are not merely physical infrastructure, but rather a way of configuring energy systems at the household level so there is a two way communication between the utility company and homes (Jones and Zoppo, 2014). A smart grid operates using the internet and Wi-Fi to relay information about power consumption and production to optimize the flow of electrical power across the grid, thus improving the efficiency and reliability of urban energy systems. (IEA, 2009). To enable this technology, utility companies install digital meters called Advanced Metering Infrastructure on homes that capture real-time information and transmit it to a central database. This information can be used to respond to outages, check usage, and charge variable rates during peak hours. This data with customers so that they can make more informed decisions on the appropriate times to use energy. According to Albadi and El-Saadany (2008), in advanced configurations utility companies can use the two way connection to initiate direct load demand response, where power intensive appliances can be shut down remotely. This can have the effect of saving both the utility company and the consumer money as energy intensive appliances are scheduled to operate when costs to produce energy are at their lowest. From an adaptation perspective, the more efficient distribution of energy resources through smartgrids has been hypothesized to reduce strain on the energy infrastructure resulting in a more reliable and cost-effective system (Jones and Zoppo, 2014).

Sometimes the terms smart grids and microgrids are used interchangeably, but they are, in fact, different concepts. Microgrids connect together distributed energy resources (DER's) such as photovoltaic solar (PV), wind power, combined heat and power (CHP) and other technologies produced in various locations throughout neighborhoods. They can then be used to switch a neighborhood's power between locally produced sources, energy storage systems, or an established central grid depending on conditions. (Hatziargyriou, Asano, et al., 2007) In the event of a disruption, like a hurricane, microgrids have the ability to "island" from the grid by drawing power from local or stored sources to keep power on for connected buildings throughout a neighborhood (Lasseter, 2007). Military installations, universities, schools, and hospitals, sometimes classified as MUSH's are primary candidates for this type of technology to enhance safety and security (Microgrid Institute, 2014). And with the recent increase in private and commercial buildings utilizing DERs, local communities are being considered as potential markets as well. Smart meters can work together with microgrids to control the power flowing from the local energy sources and battery storage to the main grid (Considine, Cox, et al., 2012).

As explained above distributed energy resources (DER's) create the power that is ultimately needed for a microgrid system to operate, so the mainstreaming of microgrids is predicated on DER's becoming widely available to consumers and commercial users. State and local policies have been a driving force behind creating many of the conditions that have allowed distributed energy to increase its share of overall energy production in selected markets through a wide variety of reforms in energy regulations and financial incentives. (Pitt, 2008).

2.5 Conceptual Framework

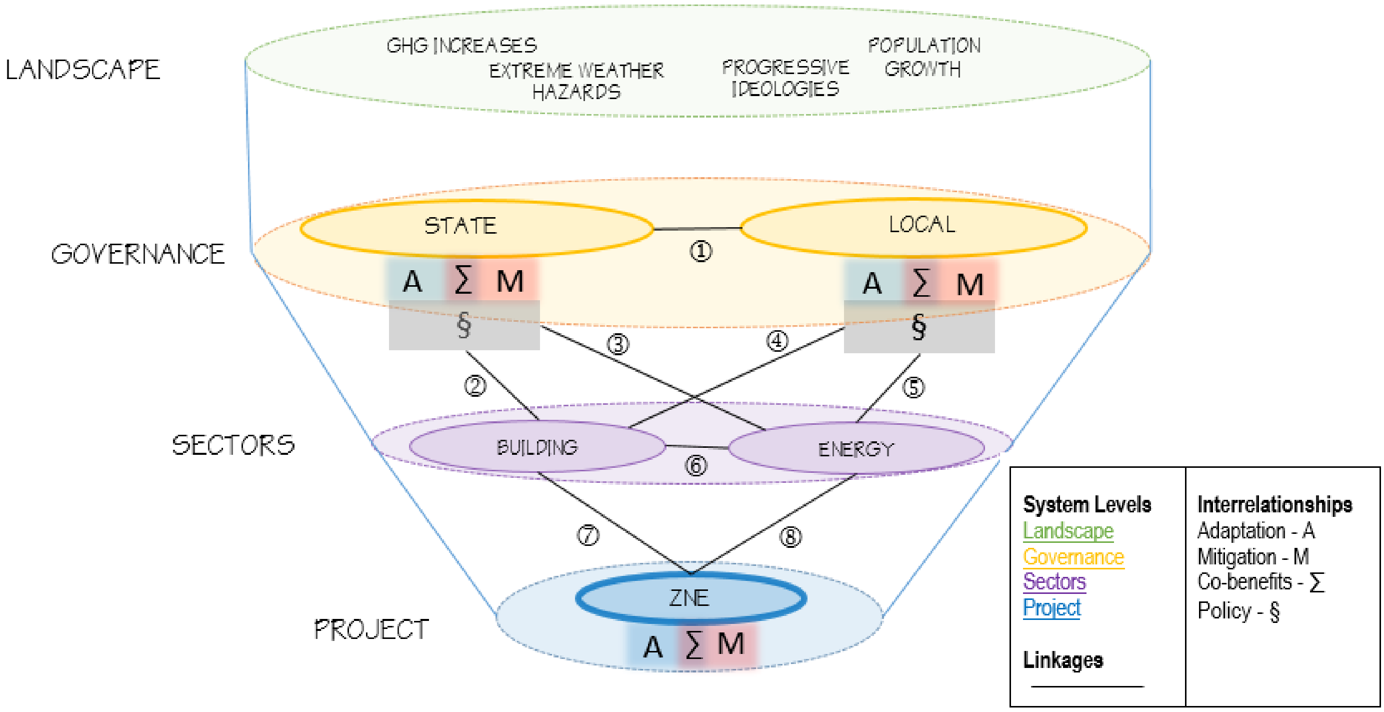


Figure 17: A conceptual framework for evaluating ZNE at multiple organizational levels. Author created with influences from several climate change and transitions models.

This conceptual framework illustrates the system of institutions, policy and roles for decision makers critical in establishing an environment for ZNE. The structure is based off the multi-level perspective (MLP) from transitions theory showing the position of various levels stakeholders within the context of societal functions (Geels and Schot, 2010) It is a model that simplifies a complex web of stakeholder interactions to illustrate key institutions involved in the process. The structure of the framework isn't hierarchical, but rather a system that works interactively to deliver a product or service that meets the expectations of a modern society like shelter and electricity.

In that way, the layered approach is like a sandwich where government agencies and industries at the regime level represent the bread and cheese – both essential ingredients that work together to create and end product. To take this analogy further, imagine the sociotechnical system as a restaurant, whose societal function is to deliver food to the public. The restaurant can function for a while offering just basic sandwiches, but at some point it will encounter pressure from competition, increased expectations from customers, fluctuating ingredient prices. The chef will need to experiment with new items on the menu or at least try some new ingredients to improve the final product all while maintaining an affordable price for most customers. These culinary experiments may not mix well with the traditional ingredients and there may be customers who don't want something new, or just don't want to pay extra for it. But out of necessity, the restaurant must continue experimenting until the right combination is found – or run the risk of operating an outdated business model that proves to be unsustainable.

This the way that I see transitions occurring, with niches being the new ingredient, landscapes being the costs, competition, but also endowment factors that allow an organization to procure new ingredients. Those who have worked in restaurants understand that the owner, the chef and the staff, don't necessarily agree on what should be placed on the menu – or if there should be changes to it at all. So internally there are conflicts that inhibit progress within the system.

With that said, the purpose of looking at systems in the context of ZNE is to identify how the push toward energy efficiency and renewables is influenced by interactions among actors. As a progressive state, California has largely accepted that changes are needed to outdated ways of building homes and providing energy and is further than most states down the creation of policy for this purpose. But almost a decade in, it is still in the experimentation phase. A host of new 'ingredients' have been introduced throughout the state, but it is unclear at this point which of these has staying power and will find their way into the mainstream. All ZNE by 2020 is one of bolder strategies that has been proposed, and whether this is something that customers will adapt to or if the building and energy sectors can rise to the challenge of filling the gaps of technical and financial know-how remains to be seen.

Landscape

The landscape is the environment that system operates within. In this section I have chosen several factors that could influence the success ZNE development. Climate change indicators like GHG increases and extreme weather are important because in theory these are the high level changes that are prompting sectors and policy makers to adjust the current trajectories of energy production and housing development. Knowledge about the issues must be accompanied by a political will of voters and legislators to support policy, and this is where progressive ideology comes into play. Development is also dependent on growing markets, capital and entrepreneurship and this is where the concepts of market based economies and growing populations come into play.

This model does not imply that ZNE is only possible when these landscape elements are present, but these are some elements that make a viable pathway in California cities.

Population Growth	Estimating the number of households and impacted and contributing to solutions.
GHG Increases	Evaluating the effectiveness of policies in reaching goals set by state and local governments.
Extreme Weather	Understanding the vulnerabilities of energy infrastructure to damage. (IPCC, 2014)
Progressive Ideologies	Moving policy from concept to implementation, combination of voter and agency participation. Readiness of social systems to undertake climate change action. (Ford and King, 2015)

Table 8: Factors influencing the landscape for ZNE development in the Sacramento region

Governance

For this research *state* and *local* governments are represented by the processes of the agencies of state government and the regional governments of the Sacramento metropolitan area. The national government was not included in the model since a comprehensive greenhouse gas reduction program has not been adopted by the U.S. federal government. This makes the California state government the starting point for climate change efforts and regulations impacting the energy and building sectors.

There are many state agencies involved with ZNE and policy creation and details of these agencies will emerge in the analysis sector, but for now these executive agencies are collectively referred to as the 'state'.

The City of Sacramento governs climate change action at the local level through its planning authority. Climate change directives authorized by the state government and modified through the city planning process to take local context into consideration along with public interaction though a scoped planning process. The measures identified in plans are then codified into specific ordinances, zoning and building codes.

Sectors

Sectors are defined broadly as the homebuilding and energy industries. These are established sectors with functional business models (Geels and Schot, 2007). From a transitions standpoint the implication is that portions of these sectors operate as regimes that perpetuate some of the negative externalities contributing to climate change and can be modified or replaced to achieve more sustainable systems (Loorbach and Verbong, 2012).

Among the pathways for these changes to occur, a reconfiguration pathway is theorized where the most beneficial aspects of emerging technologies are incorporated into the business practices of established regimes. (Verbong and Geels, 2012) This is the evolution that likely has the greatest potential to occur within the well-established sectors of energy and homebuilding, which have been chosen as the industries for analysis in the conceptual framework model.

In the model the *energy sector* includes utilities and firms that provide equipment and services for the generation, distribution and storage of energy. In the Sacramento region the utility is generally the publicly owned utility SMUD, but also includes investor owned utilities like PG&E in certain communities. In a way utilities are in-between governance and independent operators, because certain elements of their operations appear to be governed by state agencies, while others are independent.

The *building sector* is a general reference to the collection of institutions that develop residential buildings throughout the state. Although California has some of the most stringent building codes in the U.S., there is increasing pressure from state regulators to become even more efficient by 2020. The building sector is expected to work with utilities and governing agencies to incorporate new building typologies into their market offerings.

Project / Household

The project category is defined by the small sample of ZNE niche projects that have been developed in California over the last few years. The real-life ZNE examples in Sacramento share similar characteristics and will be clustered together and represented generally as *ZNE* in the model. The actors responsible for developing these projects to market appear to be a subset of the larger building industry represented at the sectoral level.

Linkages

Linkages in the conceptual framework represent interactions between actors in the system. These could come in the form of directives or sharing of knowledge. These are policy outcomes and are hypothesized based on the current understanding of the stakeholders involved with ZNE. The purpose for looking into these linkages is that the cross-sectoral interactions of climate policy (Berry, Brown, et al., 2015) may create conditions where co-benefits among stakeholders can be compounded to form systemic synergies.

Directives describe action targeted from one organization to another in the form of regulations, laws and recommendations (Bai, Wieczorek, et al., 2009, Jacobsson and Bergek, 2004). For instance, when states decide that utilities need to produce more renewable energy a state agency will pass a law requiring the utility to meet as specific target by a specific timeline.

Experiences gained from the development of niche projects are a key component of innovation uptake in socio-technical systems. (Loorbach and Verbong, 2012) Information flows between parties in an effort to achieve mutual objectives, such as in the case of the city and the utility or possibly in effort to legitimize ZNE (Hekkert, Suurs, et al., 2007) in the case of ZNE developers sharing information with the building industry. These linkages will become clearer as the specific policies and interactions among stakeholders are analyzed.

The cells in the table below correspond to the lines representing anticipated linkages in the conceptual framework;

	Receiver			
Initiator	City	Energy Sector	Building Ind.	ZNE
State	Climate Change Planning Requirements (Directive)	Renewables Portfolio Standards (Directive)	Green Building Codes (Directive)	
City			Enhanced Green Building Codes (Directive)	Climate Change Planning Measures Encouraging / Regulating ZNE (Directive)
Energy Sector	Facilitate utility's goals through city planning (Knowledge Transfer)			Energy efficiency programs & incentives for homebuilding (Directive)
ZNE		Consumer data sent to utility to improve grid management (Knowledge Tranfer)	ZNE projects create awareness in building community of design and marketability of ZNE (Knowledge Transfer)	

Table 9: Author generated table of anticipated linkages between actors in a socio-technical system for ZNE.

Chapter 3: Research Design and Methods

3.1 Research Design

This research evaluates the potential for ZNE development to address statewide and regional climate change mitigation and adaptation goals. According to the academic literature ZNE is achieved through a combination of energy efficiency and distributed energy resources linked to the existing electrical grid in various configurations. A cursory overview of the state and local governments policies pertaining to sustainable energy transitions shows a wide range of initiatives to promote DER's and energy efficiency, some with overlapping objectives. The research will be conducted using a single embedded case study looking at climate action decision making at state, local and project levels. The case is conceptualized as a sociotechnical system illustrated by the MLP inspired framework in Section 2.5.

The first and second sections of Chapter 4 will focus on the ability to address mitigation and adaptation respectively. Mitigation is indicated by GHG reductions, adaptation indicated by vulnerability and hazard reductions. Since many agencies have already taken steps to form climate policy, an ex-post analysis will be used to see where existing policies address the goals of organization at multiple levels, thus creating co-benefits. The co-benefits may result from intentional responses or may be positive externalities now recognized as benefits in retrospect. Research in climate change already identifies some areas in building and energy that have potential for ZNE co-benefits, and this information has been used to develop indicators that guide this analysis.

In the third section the connection among actors will be evaluated as linkages. These linkages can include knowledge transfers, recommended actions, statutory requirements and other forms of collaboration between parties. The linkages will then be compared to a promise-requirement cycle to see how the top down approaches filter down to actors with the capacity to influence an urban transition.

A Layered Approach

Since multiple layers of governance are being evaluated in the framework, the process for evaluating mitigation and adaptation at each layer is described below.

State

For mitigation the GHG output of the state will be assessed. The population, and housing growth between now and 2050 will be calculated. This growth will then be compared to existing models that evaluate the potential for ZNE in new housing development to reduce GHG emissions. If all new housing development in CA is ZNE starting in 2020 than comparing growth rates statewide to the ZNE reducing abilities should allow for a chart to be produced that show the GHG reduction potential of the technology over time. The results will then be compared to statewide GHG reduction targets.

For adaptation the vulnerabilities of the state to climate change impacts will be assessed. Some infrastructure vulnerabilities will be considered, particularly with regard to transmission infrastructure delivering power throughout the state.

Local
For mitigation the GHG output of cities and counties in the Sacramento region will be assessed. Projections for housing growth for the four county region comprised of Sacramento, Yolo, El Dorado and Placer counties will be calculated. The model used to assess statewide GHG reduction ZNE potentials will be scaled down proportionally to the Sacramento region. These results will then be compared to the targets set by local governments in Sacramento.

For adaptation the vulnerabilities of the local region will be assessed, including impacts to the operation of the local utility in the Sacramento region. Demand increases over the next several decades resulting from population growth and climate change factors will be evaluated. Gaps between the utility's capacity to provide energy and demand will be assessed. The role of ZNE in filling this gap will be quantified using household growth data combined with the known current capabilities of ZNE projects.

Household
For mitigation the carbon footprint of households in the Sacramento area will be assessed, particularly with electricity and natural gas consumption. The differences in performance between ZNE and other forms of DER and EE will be considered.

For adaptation, case studies of recently completed ZNE projects will be used to see how much energy each unit generates using DER's that can be placed back onto the city's grid. A discussion of battery backup systems within completed ZNE buildings will also draw attention to the potential for ZNE projects to island from grids during emergency situations.

3.2 Operationalization

3.2.1 Variables

Mitigation – M
Mitigation is defined as an intervention that reduces the anthropogenic changes within the climate system and includes strategies to reduce greenhouse gas sources and emissions. (Klein, Huq, et al., 2007) This can be measured by assessing the GHG output of sectors in MMTCO2e. GHG models are evaluated under a business-as-usual scenario, and then compared to estimates of how mitigation strategies can alter the trajectory of GHG emissions over time.

McEvoy (2006) remarks that urban areas are centers of economic activity, with high energy intensity and that mitigation responses are needed at this level to curb energy flows and minimize the ecological footprint of cities. According to Biesbroek, Stewart, et. al. (2009), when mitigation strategies occur at the local level there is a spatial planning dimension to this approach that can be used as a 'switchboard' for linking together mitigation and adaptation at the local scale, and this is where the presence of the city government's general plan, climate action plan and ordinances come into play.

Adaptation - A
The Intergovernmental Panel on Climate Change's fourth assessment report established a definition for climate adaptation that is used for this research. Adaptation refers to systemic social and environmental modifications in response to actual or expected climatic changes, which minimize harm and enables benefits to be achieved. More specifically the types of adaption are anticipatory and planned responses (Klein, Huq, et al., 2007). An adaptive capacity dimension can be added to the concept which includes increasing the ability of individuals, groups, or organizations to adapt to changes and make decisions that transforming abilities into actions

(Adger, Agrawala, et al., 2007). In the energy sector adaptive capacity is measured in the 'resilience' of the system, or its ability to absorb shocks which arise from demand spikes and fluctuations in fuel costs, among other variables (Molyneaux, Wagner, et al., 2012). Increasing the diversity of energy sources such as the incorporation of distributed energy resources into the grid and reducing demand are two strategies for improving the resilience of the system (Jones and Zoppo, 2014)

Co-Benefits - ∑

There is growing interest in investigating how mitigation and adaptation can be merged into single "win-win" actions (McEvoy, Lindley, et al., 2006). Among the interrelationships between mitigation and adaptation actions are ancillary benefits, or co-benefits that can help cities achieve their sustainable development goals (Klein, Huq, et al., 2007). Co-benefits are the positive externalities and synergies that result from climate actions, in contrast to trade-offs which are the negative externalities (Biesbroek, Swart, et al., 2009). While the effectiveness of mitigation strategies can be monitored in terms of greenhouse gas reductions but measuring the success of adaptation is much more complex since there is no consensus among academics on standardized approaches (Biesbroek, 2009). But since it has been established in the preceding paragraphs that 'resilience' can be measured by the introduction of alternative energy modes and demand reductions, evidence of whether resilience has been achieved can be identified using quantitative metrics (Ürge-Vorsatz, Herrero, et al., 2014).

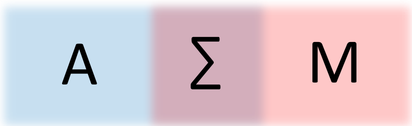


Figure 18: Intersection of adaptation and mitigation with co-benefits present at the confluence.

Co-benefit interrelationships can sometimes span multiple sectors (Berry, Brown, et al., 2015) and this can be seen in ZNE where a nexus exists between the building and energy sectors, since the GHG emissions calculated are the result of electricity production in the energy sector. Within these sectors stakeholders act as decision makers creating policy that influence sustainable energy transitions along multiple scales of vertical governance (Loorbach and Verbong, 2012, Geels and Schot, 2010, Bai, Roberts, et al., 2010). With actors, institutions and networks comprising the structural components needed for technological innovations, ie. ZNE, to gain traction (Bergek, Jacobsson, et al., 2007, Hekkert, Suurs, et al., 2007) decision making with the municipal government, utility and project levels are included as multi-level stakeholders, and subsequently analyzed within the research subquestions.

Since co-benefits are the sum of benefits between Adaptation (A) and Mitigation (M), they are visually represented in the conceptual framework using the ∑ symbol at the point where A and M overlap. Literature shows that at times the balance between mitigation and adaptation is asymmetrical, where one value is the preferred goal and serves as an entry point for the other variable to be achieved (Klein, Huq, et al., 2007). Since California is the most populated state in the second highest greenhouse gas emitting country and has a relatively mild climate, it is expected that the policies will primarily be tailored to GHG reduction with adaptation occurring as an ancillary benefit.

3.2.2 Operationalization Table

Variables	Indicators	

Mitigation	State targets for GHG reduction in the energy and building sectors. Projected reductions to statewide GHG emissions through policy intervention. GHG Benchmarks GHG Reduction targets in local planning Utility requirements for GHG reduction ZNE policy's contribution to GHG reductions.	What are the projected GHG emissions for state? What portion of GHG emissions are from the housing and energy sectors? Have GHG reductions through DERs been quantified at the state level? Have GHG reductions through EE been quantified at the state level? Have GHG reductions through ZNE been quantified at the state level? What are the GHG reduction targets for cities in the Sacramento region? What is the GHG footprint of the average household in Sacramento? How does ZNE's carbon reduction potential compare to other technologies encouraging energy efficiency and DER's? What is the share of GHG reductions possible from the implementation of ZNE in Sacramento?
Adaptation	Modelled statewide climate change hazards. Regional climate change hazards Projected demand increases from climate change hazards Vulnerability of energy infrastructure to climate change. Estimated GHG reductions through energy efficiency programs. Output of ZNE buildings	What are the most critical climate change hazards in California through 2050? What are the climate change vulnerabilities for the Sacramento region? What is the expected increase in the number of 100+ F temperature days in Sacramento during the summer? How are these climate change hazards expected to impact energy infrastructure throughout the state? How much is energy consumption expected to increase? How much will energy demand increase in the Sacramento region as a result of increased temperatures? Is there a gap between projected energy consumption and demand in the Sacramento region? Using case studies as examples, what are the energy demand reduction potential of individual ZNE projects?
Building Sector	Housing growth Population growth	What is the current size of California's residential housing sector?

	Current size of residential real estate market in California. Projected growth of residential real estate in California. Statewide population growth through 2050. Green building requirements	What are the projections for the demand of residential development between now and 2050? How much California's population expected to grow between now and 2050? How many people are there per household throughout the state?
Linkages	Knowledge Transfer between actors Policy directives to an pursue action Discourse about wonderful worlds and speculative concerns Open-ended promises and concerns New opportunity fields Innovation in protected spaces Determination of protocols for mainstreaming Waiting Games	How technical information is shared between ZNE developers, the building industry, and decision makers that policy at the state and local levels? Is ZNE a required or an elective requirement for new residential development after 2020? Have policies been proposed that setting a framework for actions to be undertaken by other entities? Are firms rising to the challenge of delivering the technology that is being championed? Do agencies have regulatory authority to require DER and energy efficiency from homebuilders?

Table 10: Author created table of research variables, indicators and questions for data collection and analysis.

3.2.3 Data Collection Methods

Data collection methods will include interviews, observation and secondary data. Interviews will be used primarily to ask questions related to qualitative indicators and will be structured at the city level, semi-structured at the utility and project levels. The sample selection will be purposive; quota at the city and utility levels snowball at the project level where limited information is available on the residents of the ZNE projects.

Interviews will be arranged with stakeholders that have had direct involvement with the mitigative and/or resilience benefits within the energy system. At the city level I will reach out to interview individuals who are experienced with creating land use plans that address interrelationships, co-benefits and synergies in the municipality, or as a consultant to the municipality. For the utility, I will interview individuals who have been involved with energy efficiency and sustainability programs. At the project level, I will reach out to interview the developers of ZNE projects to understand their perspective on the benefits and challenges of ZNE.

Secondary data will be used primarily to gather information on indicators requiring hard numbers (ie. greenhouse gas MMCO2e, kW reductions). Also if studies were conducted prior to the policy formation that informed decision makes on the impacts of mitigation or adaptation measures this will be researched and incorporated as well. The secondary data will be complimented by the interviews. For example, in the in the utility sector adaptation has many quantitative metrics that can be used to evaluate the resilience of the energy system. But much of this data is technical and could be misinterpreted without an in-depth understanding of complex energy systems. Conclusions gleaned from the data can be cross checked in the with the expert's responses to verify the accuracy of the interpretation.

Secondary data is typically available through agency websites, appendices to approved planning documents, in publicly available technical reports. Based on a cursory review of the city's

Climate Action Plan and General Plans, much of the information used in the adaptation and mitigation decision making comes from studies initiated by the state government. A high level of transparency is generally found in state and local governance, where all decision making with potential environmental impacts is subject to public disclosure and review under the California Environmental Quality Act (CEQA).

Observation of the completed ZNE projects will be conducted in the form of field visits to completed on in-progress projects. Field visits will be helpful in seeing how the design of projects contributes to the carbon reduction.

3.2.4 Reliability and Validity

In terms of reliability, the small pool of interviewees combined with secondary data and empirical observation is a reasonable approach for conducting this research since the population of completed ZNE projects in urban environments in quite limited in California and beyond. Keeping the size of the research focused on actors within a geographically constrained system is an advantage in that it allows a greater level of detail to be investigated at each level, the type of detail that is needed to gain better insight in the evolution of niche innovations.

For validity, keeping a sharp focus on the theme of energy and renewable energy uses in the context of ZNE housing will assist with creating a sound analysis. Diligent efforts will be made to isolate the programs of each level's decision making to these themes. For instance at the city planning level, an analysis of energy efficiency can overlap with other sectors like water that are beyond the scope of the system that this research intends to analyze. Reduced water use in buildings may have an impact on the amount of energy that the city uses to pump water throughout the municipality, but this opens up a discussion about the urban water sector which moves away from the intent of the research question. The utility's program also includes over 50 initiatives all related the cause of improving energy use among the citizens of Sacramento. Care will be given to selected data only from those initiatives that are anticipated to have a bearing on the outcome of residential ZNE projects. Avoiding digressions should keep the analysis tight resulting in higher overall validity in the research findings and conclusions.

Chapter 4: Results and Analysis

4.1 Mitigation

An ambitious goal for Zero-Net Energy has been set – all residential development in California to be ZNE by 2020 (CPUC, 2011). A market assessment of the ZNE landscape shows that 16 ZNE buildings have been constructed to date in California and additional planning is needed between now and 2020 to create an environment that allows ZNE to be successfully integrated in to all new residential development (Pande, Goebes, et al., 2015). In June 2015 a Zero-Net Energy Action Plan 2015-2020 was released by the California Public Utilities Commission and the California Energy Commission outlining a framework for ZNE development in the state (CEC and CPUC, 2015) This plan describes ZNE goals as being supportive greenhouse gas reduction goals at the state and local levels through AB32 and local climate action plans. The plan does not quantify GHG reduction potential of ZNE beyond 2020, but states that, "connecting ZNE goals to GHG reductions identified in (local) Climate Action Plans could assist local governments to more easily implement elements of this plan" p.23 (CEC and CPUC, 2015). This section will look at how ZNE connects to the state and local mitigation planning.

4.1.1 Regional Growth

For assessing the level of GHG reductions occurring as a result of ZNE, an estimation needs to be made about the growth of residential real estate development in Sacramento. Historic data that shows average number of residential units permitted in the Sacramento metropolitan statistical area between 1995 and 2014 (US Census Bureau, 2014). Based on this data, the current level of annual residential building permits issued in 2014 was 4,159 down from a peak of 22,832 in 2003, with an average of 11,153 permits per year over the 20 year span.

After several years of high growth between the late 1990's and early 2000's the Sacramento real estate market was severely affected by a recession between the years 2007-2009 and beyond. It is now slowly recovering, but is nowhere near its previous rate of growth. A report released on the demand for housing units in the city between 2013 and 2021 that shows a projected growth of 58,386 new housing units over an 8 year period (SACOG, 2012). The California Department of Finance's Demographic research unit shows that between 2015 and 2020, 31,385 units to be added county-wide during that period for an average of 6,277 housing starts per year (CA Department of Finance, 2015). This is a less optimistic figure for housing growth in the region,

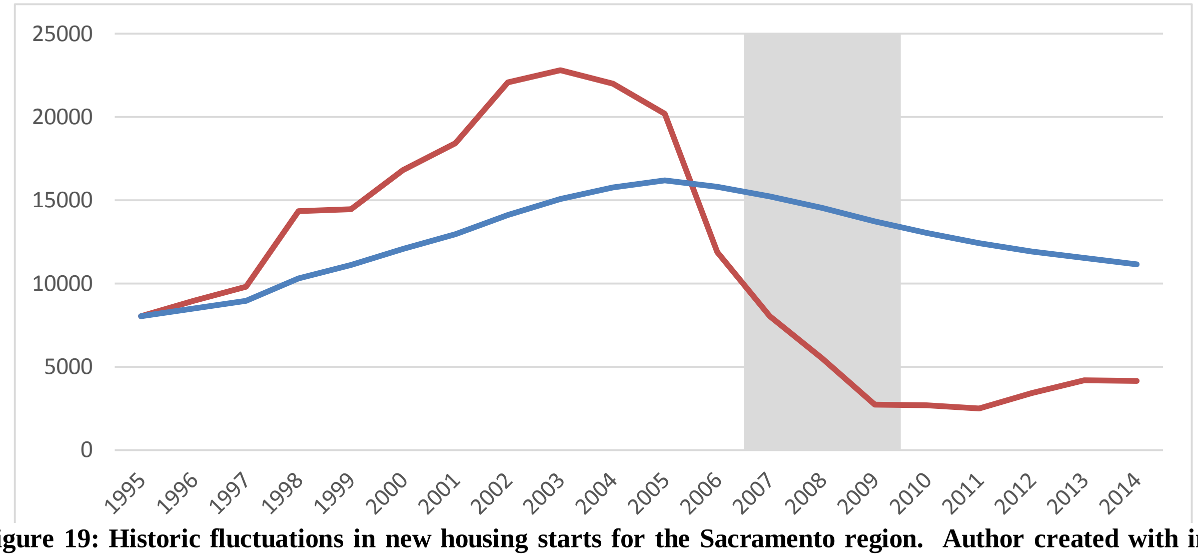


Figure 19: Historic fluctuations in new housing starts for the Sacramento region. Author created with input from SACOG and the US Census Bureau.

considering that area covered by the county is 965 square miles, compared to the city's 98 square miles (US Census Bureau, 2014).

Projected housing growth in the Sacramento region will be estimated using data from the California Department of Finance, combining forecasts for the four counties that comprise the Sacramento region; Sacramento, Yolo, El Dorado and Placer counties. Using the simple formula below the projected number of new homes per year between 2015 and 2030 can be estimated for each county. TH = Total new projected homes in a given 5 year period, PNH = Total number of homes in the previous 5 year period, HG = Housing Growth within the 5 year period and AHG = Annual Housing Growth.

$$TH - PNH = HG$$

Figure 20: Formula for calculating periodic housing growth

$$\frac{HG}{5} = AHG$$

Figure 21: Formula for reducing periodic housing growth to annual housing growth

	California		Sacramento County		Placer County		El Dorado County		Yolo County	
	TH	HG	TH	HG	TH	HG	TH	HG	TH	HG
2015	13236154		543829		144999		72857		74496	
2020	13864699	628545	575214	31385	156676	11677	76535	3678	78328	3832
2025	14449955	585256	605088	29874	168038	11362	80248	3713	82426	4098
2030	15021712	571757	634231	29143	179222	11184	83388	3140	86209	3783
Avg.		595186		30134		11408		3510		3904

Table 11: Projected housing growth state wide and the four county Sacramento region between 2015-2030.

The projected new homes data from the CA Department of Finance ends at 2030, but census data is available showing the total population growth for each county between 2035-2050 (CADF, 2014). The projected population figures can be divided by the known number of persons per household in 2030 to approximate the number of households that will be needed for accommodation based on the 2030 trends of persons per household in each jurisdiction. It is important to note that the household estimates shown above were calculated using household populations opposed to total populations to account for transient populations. For years 2035-2050, the total population was adjusted using a ratio between the total and household aggregate populations, for 2030, the last period where data is available [household population projection at 2030 times 100 divided by total population at 2030]. In the formula below TPP = Total Projected Population, HR= Housed Ratio, PPH= Persons Per Household based on 2030 rates, PNH = Total Number of Homes in Previous 5 year period, HG = Housing Growth per 5 year period.

$$\left(\frac{TPP*HR}{PPH}\right) - PNH = HG$$

Figure 22: Formula for projecting 2030 – 2050 Housing

Using this formula the following table was created showing the growth of housing over five year periods for the state and four counties of the Sacramento region;

	California			Sacramento County			Placer County		
	HP	PPH@2.87	HG	HP	PHH@2.68	HG	HP	PPH@2.47	HG
2030-35	44,745,772	15,590,861	569,149	1,794,072	669430	35199	472984	191491	12269
2035-40	46,198,832	16,097,154	506,293	1,881,467	702040	32610	504378	204201	12710
2040-45	47,510,322	16,554,119	456,965	1,957,091	730258	28218	533270	215899	11697
2045-50	48,689,194	16,964,876	410,757	2,014,080	751523	21265	560774	227034	11135

	El Dorado County			Yolo County		
	HP	PPH@2.4	HG	HP	PPH@2.7	HG
2030-35	203794	84914	1526	247682	91734	5525
2035-40	206240	85933	1019	255428	94603	2869
2040-45	206448	86020	87	264928	98121	3518
2045-50	205135	85473	-547	272807	101040	2918

Table 12: State and four county household growth projections between 203502050. Author generated through extrapolation of county and statewide population growth projections.

The regional housing growth for each 5 year time period is determined by combining the housing growth totals for each time period as shown in the graph below.

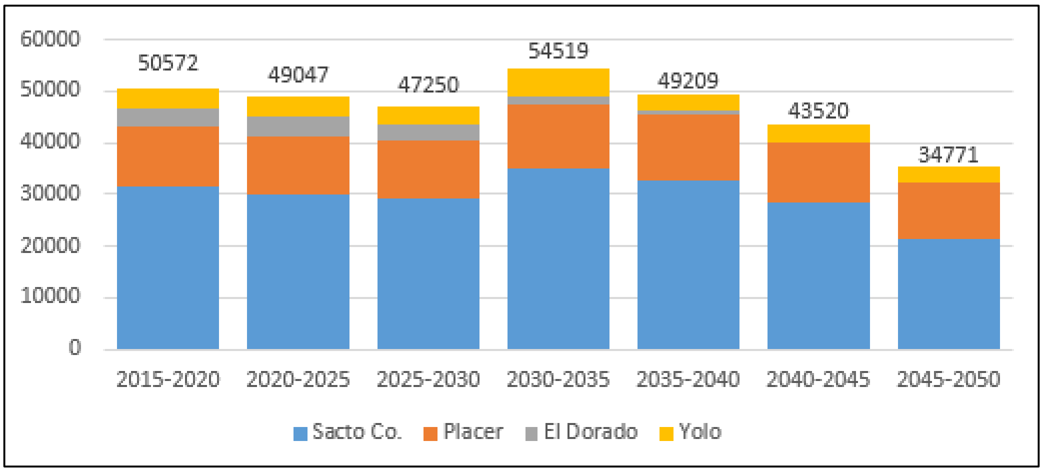


Figure 23: Estimated regional housing starts in Sacramento in five year intervals. Author created.

California's projected number of new houses is shown in the chart below. The housing growth for the Sacramento region is expressed as a percentage of California's total. This proportion of the Sacramento region's estimated housing growth will be important for calculating GHG emissions in the next section.

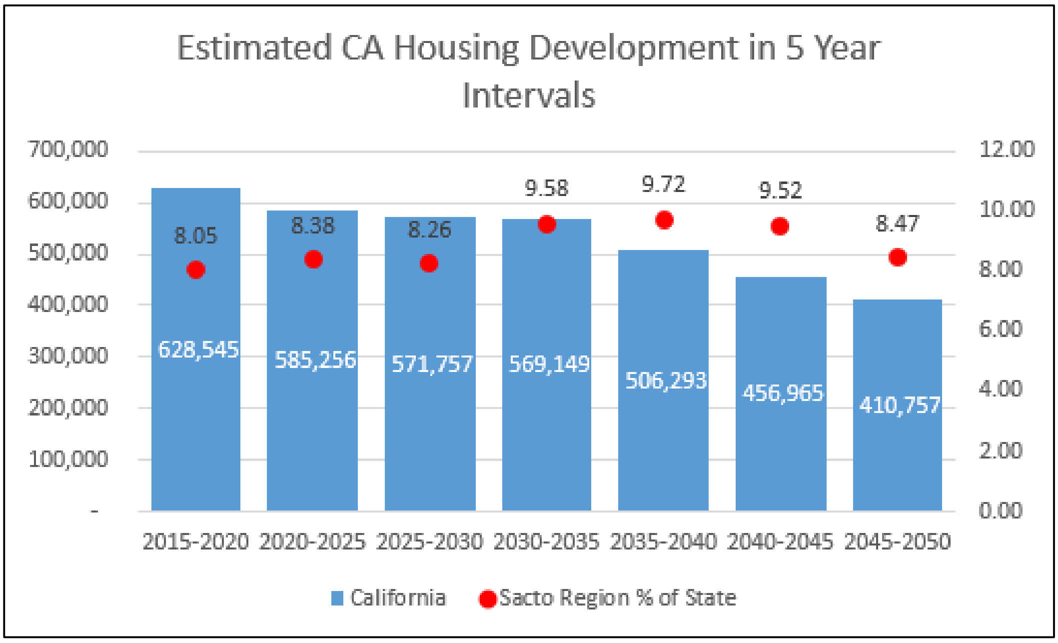


Figure 24: Estimated California housing development 2015-2050 in five year intervals.

4.1.2. ZNE GHG Quantification

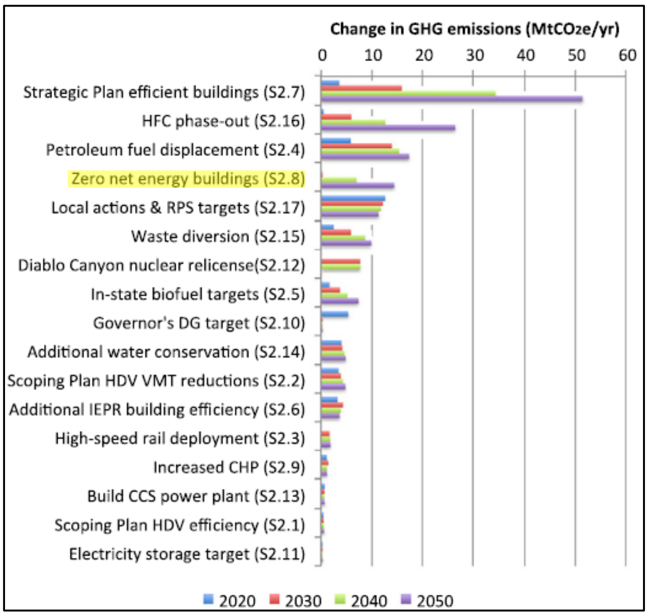


Figure 25: Scenario 2 of the CALCAPS Model, where ZNE is weighed in comparison with other uncommitted policies over the course of three decades. Source: (Greenblatt, 2015)

The dilemma of quantifying GHG reductions in overlapping mitigation programs is addressed by the CALGAPS model developed by the Department of Energy and Lawrence Berkeley National Labs. This model looks at ZNE in the context of other energy efficiency reducing policies at the statewide level and applies a sensitivity analysis to estimate the proportional share of GHG mitigation per program (Greenblatt, 2015). Three scenarios were analysed in the application of this model ranging from committed, uncommitted and speculative. ZNE fell under the scenario of uncommitted policies, grouped together with the CEC's energy efficiency strategic plan. ZNE was defined and modelled based upon the CPUC's ZNE Action Plan which includes only new residential development, not retrofits. Predictably, the ZNE Action Plan's focus on new residential construction gave it less impact in the near term than energy efficiency which includes retrofits of existing buildings. The study found that statewide ZNE policy could reduce the state's GHG output annually by:

2020 – 0 MTCO$_2$e/yr (start) 2030 - .2 MMTCO$_2$e/yr

2040 - 7 MMTCO$_2$e/yr 2050 – 14.4 MMTCO$_2$e/yr

CALGAPS models the rate of GHG reduction per year at the start of each decade throughout the state. Assuming the GHG reduction rates follow a linear curve through each decade period, statewide GHG reduction from ZNE for five year periods can be plotted as followed:

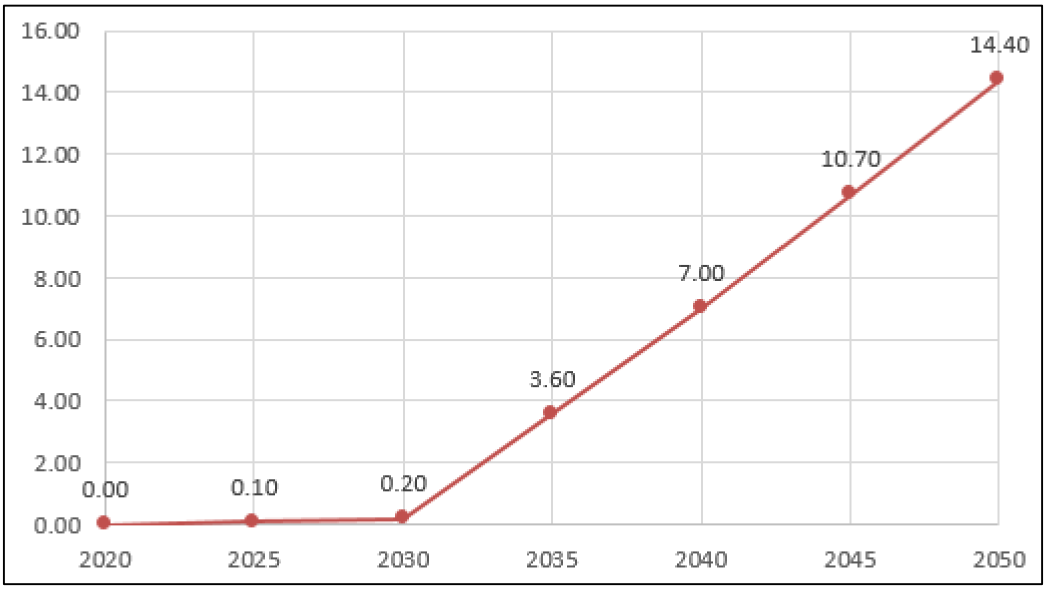


Figure 26: Plotted GHG reduction potential of ZNE statewide in five year intervals based on CALGAPS model. Author interpolated using data from (Greenblatt, 2015)

For evaluating ZNE the CALGAPS model looked only at new residential housing development, not ZNE retrofits. A challenge with using this model to evaluate ZNE emissions in a regional context is that is that the five year periods of measurement and the scale of million metric tons versus metric tons do not provide a high level of granularity. This is particularly noticeable in the period between 2030 and 2035 when ZNE jumps from having only 200 MTCO2E to 3.6 MMTCO2E. However, accepting that predictive models for climate change have an inherent level of uncertainty and this is the only model that has attempted to evaluate ZNE in the context of other California policies this model will suffice for purposes of a regional evaluation.

Since the Sacramento region's new housing growth as a percentage of the statewide total was calculated in Section 4.1.1., a ratio can be applied to the GHG reduction curve above to determine the share of the statewide projected GHG reduction that would occur at the regional level. The four county Sacramento region has a percentage of growth that ranges between 8-9% of the state's total new housing growth depending on year. The County of Sacramento's range is between 5-6% depending on the year. Plotting these calculations in the graph shown on the following page provides some estimations of GHG reducing potentials. A drop the rate of GHG emissions can be observed starting in 2045. This result occurs because of a decreasing overall rate of population growth projected to occur in California around the middle part of the 2040's.

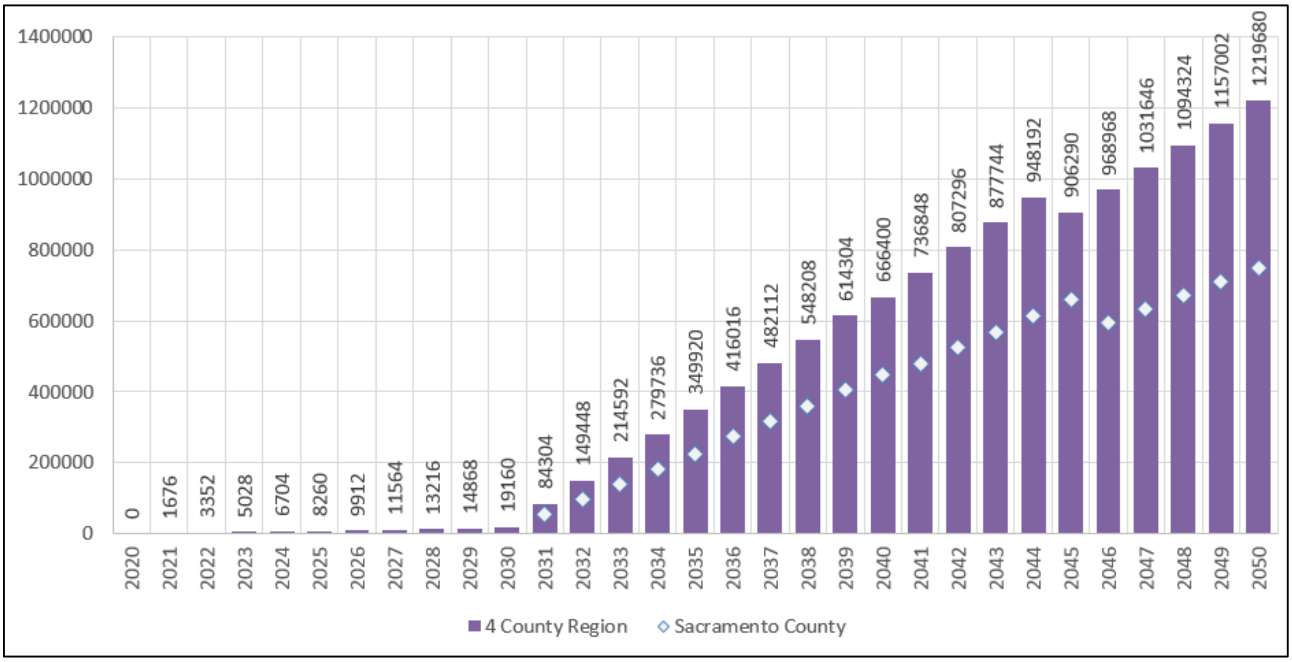


Figure 27: Annual estimated MTCO2E reductions from new residential ZNE housing development in the Sacramento region consisting of Sacramento, Yolo, Placer and El Dorado Counties from 2020-2050. Author generated.

4.1.3 GHG Reduction Targets in Local Planning

State

In 2006 the Global Warming Solutions Act, or AB32 was signed into law by governor Arnold Schwarzenegger ordering state agencies to reduce statewide carbon emissions 25% to 1990 levels by 2020. The task of implementing AB32 program was delegated to the California Air Resources Board, who inventory and monitor statewide greenhouse gas emissions categorized by economic sector. Based on this inventory a cap-and-trade carbon credit system was introduced with the goal of reducing the GHG outputs of polluting industries in the state and incentivizing research and development for carbon reducing technologies. Through this program a carbon market credit has been created that provides a financial motivation for organizations to attain GHG reductions. Over time the thresholds continue to narrow, providing greater pressures and incentives as the state moves towards its 2020 goals.

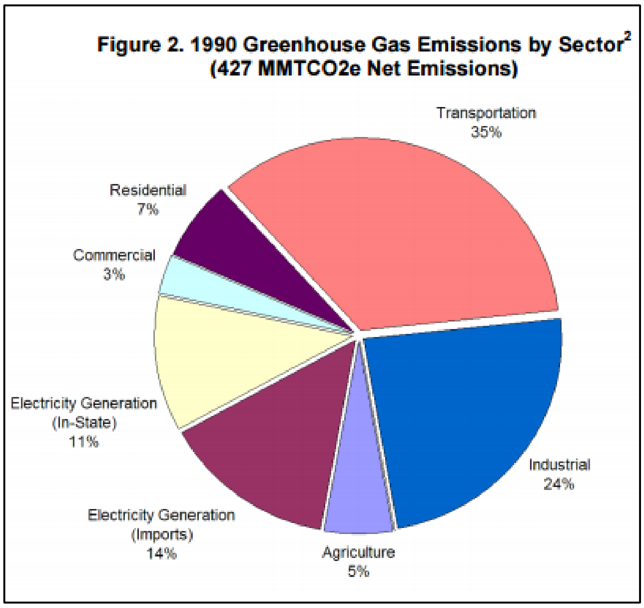
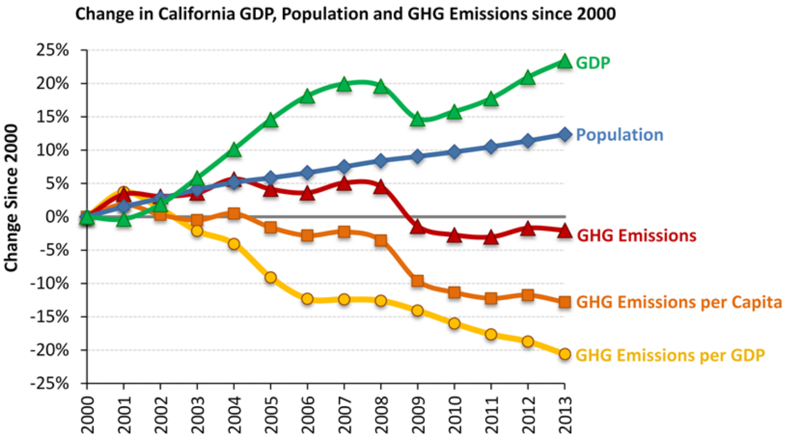


Figure 28: Baseline GHG emissions at 1990 levels. 80% reductions from these measurements targeted by 2050. (Rogers, 2007)

Available on CARB's website is a wide variety of secondary data showing the contribution of sectors to GHG emissions, targets, and progress toward achieving this goal. Because ZNE is slated to take full effect beyond 2020 and AB32 commences in 2020, there is a temporal mismatch between CARB's GHG analyses and projected reductions from ZNE development. Further executive orders from the governor's office extended the targets for California's GHG reductions to 40% below 1990 levels by 2030 (E.O. B-30-15, 2015) and 80% below 1990 levels by 2050 (E.O. S-3-05, 2005).

A staff report form CARB shows the 1990 baseline level of 427 MMTCO2e annual emissions statewide with residential buildings and in state electric generation comprising 7 and 11 percent of this total, or 29.89 and 46.97 MMTCO2e respectively (Rogers, 2007). For an 80% drop by 2050, GHG emissions would need to drop 341.6 MMTCO2e across all sectors, and 23.91 MMTCO2e in residential buildings and 37.57 MMTCO2e in the energy sector if evenly distributed across sectors. Reductions in carbon emissions have varying potentials in each sector, so reaching an 80% reduction goal may entail greater reductions in specific sectors and less in others.

Statewide, California is already trending toward aggregate greenhouse gas reductions, and since 2000 GHG emissions have dropped in nominal and per capita measures even in the midst of state GDP and population growth (CARB, 2015) Since peaking in 2001, GHG emissions have dropped by 23% in 2013, with major gains in the latter part of the period coming in-part from the introduction of utility-scale and distributed renewable energy into the mix (CARB, 2015). Between 2012 and 2013 rooftop solar like the kind that would be used in ZNE developments increased by 31% offsetting increases in fossil fuel generation derived from hydropower losses and nuclear decommissioning in 2012.



Metric	Associated 2013 Value
GDP	2.05 trillion (2009 $)
Population	38.2 million
GHG Emissions	459.3 $MMTCO_2e$
GHG Emissions per Capita	12 metric tons CO_2e per person
GHG Emissions per GDP	224 metric tons CO_2e per million dollars

Figure 29: Combined growth and GHG emissions indicators annually since implementation of GHG reduction policies beginning in the early 2000's. Source: (CARB, 2015)

In addition to AB32 an executive order and statutory law followed in 2011 establishing a Renewables Portfolio Standard (RPS) to the state's energy utilities (Senate Bill SBX1-2, 2011). This RPS imposed a requirement that energy utilities operating in the state a requirement that 33% of energy be derived from renewable sources by 2020. This standard was targeted toward investor owned utilities with oversight from the CPUC. The governor also announced that GHG for 2030 include an increase of the renewables portfolio standard from 33% to 50%. This has not been enacted, but legislation in the state senate is pending (SB-350, 2015). According to an interviewee from a local utility, these standards are mandatory for IOU's, but POU's like SMUD also incorporate these renewables standards into their operational planning (SMUD, 2012).

Beyond 2020, there is not much planning at the state level that has occurred in terms of setting GHG reduction goals for specific sectors. Specifying exactly how much GHG reduction for residential and energy to meet this goals is still something that needs to be decided by policy makers. Some researchers have attempted to create models that chart a pathway for achieving goals in specific sectors such as PATHWAYS and CA-TIMES, but these have not been translated into any planning or policy directives at the state level (Yang, Yeh, et al., 2015, E3, 2014).

With undefined pathways for GHG reductions in 2030 and beyond, a sectoral approach for estimating how ZNE may contribute to reaching the state's goals in the long term cannot be accomplished. ZNE is product that includes both energy efficiency and energy generation and therefore does not easily fit into the categories that CARB is using for estimates under the AB-32 methodology. For instance, the residential category is defined primarily by natural gas consumption at the household level. The energy sector is defined by in-state and imported energy generation. What is known however is that the 1990 baseline level is 427 MMTCO2e, so reductions of 171 and 341 MMTCO2e per year will be needed to meet the 40% by 2030 and 80% by 2050 targets. ZNE, based on the estimates in section 4.3.1 ZNE would contribute to .11% in 2030 and 4.2% of these goals in 2050.

The use of natural gas and in-state power will vary depending on the technology used and also how the state ultimately defines ZNE. According to one interviewee from a state energy agency, the state is still deliberating which definition of ZNE to adopt, and developers of ZNE are still determining what the best configurations of heating and photovoltaics to reach ZNE. This is consistent with literature review in Chapter 2 which states that use of natural gas in homes can be influenced on how ZNE is defined, and also the choice of technologies (Torcellini, Pless, et al., 2006). According to another interviewee with insight into the design aspects of ZNE, rooftop solar panels are limited by cost and also the amount of space available on roofs. The efficiency and cost of solar rooftops, and energy storage integration may improve and alter the potential for communities to generate energy. The uptake of this technology, not just in new residential building but in commercial and retrofit applications will play a significant role in the ability for the 2030 and 2050 targets to be met.

The takeaway from this information is that even at the project level, design choices and technological advancement have implications for which sectors of the economy benefit in terms of GHG consumption, and these deep uncertainties make it difficult for agencies to forecast which sectors will lead the way in meeting these goals. This explains why agencies like CARB are constantly monitoring GHG reductions in sectors, and adjusting policies based on the most recent available information.

Local

A climate action plan was published in 2012 by the City of Sacramento that proposed greenhouse gas reduction targets from 2005 benchmarks of 15% by 2020, 38% by 2030 and 83% by 2050. In this plan energy for residential, commercial and industrial buildings is cited as accounting for 42% of the total GHG emissions in 2005 (Sacramento Climate Action Plan - Final Draft, 2012). Sacramento's plan includes both mitigation and adaptation measures with themed strategies. Some of the objectives illustrated in these strategies clearly describe some of the attributes of ZNE, although this type of technology is not explicitly mentioned. Measures include working with developers, residents and SMUD to promote energy demand management and conservation, increase energy efficiency in and new and existing buildings and increase renewable energy generation and use. This section of the plan states that the city's efforts to promote renewables and require new construction to be as efficient as possible will assist with moving the community closer to achieving zero net energy in all new construction by 2030.

Action #		2020 (MT CO_2e/yr)	2030 (MT CO_2e/yr)	2050 (MT CO_2e/yr)
Energy Efficiency Strategies				
3.1.1	Energy Improvements Through Community Education	5,594	6,442	8,138
3.2.2	RECO (Option 2: building permit trigger) [1]	3,193	6,742	13,839
3.2.4	CECO (Option 2: building permit trigger) [1]	50,071	79,804	91,830
3.3.1	Energy Efficiency Through Increased Residential Density	8,474	25,894	88,983
3.2.1	Commercial PACE Program	18,225	18,225	18,225
3.2.3	Rental Housing Energy and Water Efficiency Program (Option 2) [1]	32,887	64,269	113,212
3.3.2	CalGreen Tier 1 Energy Efficiency in New Development	30,535	81,428	183,214
3.4.1	Solar Installations in New Residential Development	71,134	129,354	245,795
3.4.2	Solar Installations in New Commercial/Industrial Development	1,717	2,862	5,152
3.1.2	SMUD Smart Grid	69,215	79,498	100,064
3.1.3	SMUD & Tree Foundation Shade Trees	1,507	1,507	1,507
3.2.5	Small Commercial Energy Efficiency Pilot Program	1,219	1,219	1,219
3.2.6	SMUD Home Performance Program	1,964	1,964	1,964
3.4.3	SMUD Residential Greenergy	38,037	38,037	38,037
	SMUD Commercial Greenergy	32,434	32,434	32,434
3.1.4	SMUD Appliance Rebates	3,597	3,597	3,597
	SMUD Lighting Rebates	46,015	46,015	46,015
	SMUD Electronics Incentives	9,406	9,406	9,406
	SMUD Custom and Prescriptive Lighting Incentives	17,956	17,956	17,956
	SMUD Multi-Family Retrofits	2,410	2,410	2,410
Subtotal (Energy Efficiency Strategies)		*445,590*	*649,062*	*1,022,995*

Table 13: GHG Reduction Strategy for City of Sacramento Climate Action Plan. Source: (Alling, Walters, et al., 2012)

In the appendix of Sacramento's Climate Action Plan twenty policies are mentioned that are projected to reduce GHG emissions in the city through 2050. The GHG reduction table in this section shows some of the anticipated reductions from programs that are being offered within the City of Sacramento. Some of these programs have overlapping themes with ZNE, such as energy efficiency and DER's.

Looking though this prospective it can been seen the ZNE in new residential buildings is pushing efficiency and DER's in local settings where building standards have already seen improvements over time and are continuing to improve. At a sectoral level, the City of Sacramento's Climate Action Plan quantifies the GHG reduction potentials of energy efficiency and distributed renewables as 39,009 MTCO2e/year by 2020 but does not go beyond 2020.

The plan estimates that through the listed measures the city would be able to surpass its 2020 goal of 15% GHG reductions compared to the 2005 baseline. But beyond 2020 there are deficits between the measures that the city can include in its plan and the number of GHGs that would need to be reduced in order to match the state's targets. The plan states that these goals could be achieved through new innovations and technologies over the coming decades. Considering that ZNE is not included as a measure in this plan, this technology indeed could be a key to achieving these targets. The table below outlines the gap between the measures outlined in the plan and the target reductions consistent with the governor's executive orders at the state level (E.O. S-3-05, 2005, E.O. B-30-15, 2015).

Year	Reduction from 2005 Levels	Business as Usual Forecast MTCO2e	Reduction Target MTCO2e	Reduction Potential MTCO2e	Gap MTCO2e
2020	15%	4,835,677	3,470,753	3,464,526	-6,227
2030	38%	5,337,689	2,545,219	3,546,486	1,001,267
2050	83%	6,347,864	694,151	3,913,324	3,219,173

Table 14: City of Sacramento Climate Action Plan GHG Reduction Targets. From (Sacramento Climate Action Plan - Final Draft, 2012)

The County of Sacramento also has a climate change action plan that like the city's plan targets 15% reductions in GHG emissions by 2020, but does not set targets for decades beyond this. The plan does not apply GHG reduction target to specific sectors, but does have measures that are expected to assist with reducing carbon emissions. Incentivizing solar installations and enacting a green building ordinance to encourage energy efficiency in new developments are listed among the priority items.

Placer, Yolo, and El Dorado Counties do not have comprehensive climate change mitigation plans, but adopt best practices for sustainability planning through specific initiatives, cooperation with regional planning and on a project specific basis through compliance with the Sustainable Communities Climate Protection Act (SB-375, 2008)

The intent with this data gathering was to be able to compare the ability for ZNE to reduce GHG at the local level, but with housing growth data only available at the county level and county plans not quantifying sector specific GHG reductions beyond 2020, a direct comparison between ZNE and county planning cannot be made. What can be deduced from this data however is that the largest city within the County, the City of Sacramento, acknowledges that their current measures will fall short of meeting targets beyond 2020 and that new innovations are needed to meet this goal. As discovered in the previous section, ZNE has the potential to reduce GHG countywide by 748,800 MTCO2e/year by 2050 and a portion of this will occur within the city limits of the city of Sacramento. Although this cannot be narrowed down to specific figures, it is reasonable to conclude that the 3.2 MMTCO2e gap for 2050 will be lessened to some degree by the shift toward all ZNE housing within the city of Sacramento.

As mentioned in Section 3.2.1, the local utility SMUD is a quasi-government organization, operating as a company, but managed by a locally elected board within the County of Sacramento. So in addition to providing electricity it also creates policy that influences how that energy is generated and delivered. Through these powers the organization adopted a goal of reducing GHG emissions go 350,000MTCO2/year by 2050, or 10% of 1990 levels. This aggressive goal, and the desire to be a trendsetter in the provisioning of clean energy has driven much of the utility's support for high energy efficiency and DER's in housing according to an interviewee involved with the organization.

Household

According to two interviewees, California currently has some of the most restrictive energy efficient building codes in United States, and this results in new homes that are more efficient than their predecessors. The California Energy Commission estimates that through the introduction of energy efficiency codes starting in 1978, more than 250 MTCO2e have been mitigated.

This is an important consideration because it illustrates that ZNE's in new buildings have different GHG reduction profiles than retrofits of existing homes. An interviewee explained that efficiency in homes can be measured in using a standard called HERS, Home Energy Rating System. This system uses a multitude of indicators to evaluate efficiency of buildings on a scale from 0-250. ZNE buildings, being the lowest on the spectrum are rated 0. New homes meeting the minimum building requirements can expect to receive a score of around 100, while older housing constructed prior to energy efficiency integration into building codes can range from 101-250 (CEC, 2011, RESNET, 2013) A builder interviewee states that the cost to achieve energy efficiency rises as the HERS scale approaches 0 in a manner consistent with the law of diminishing returns.

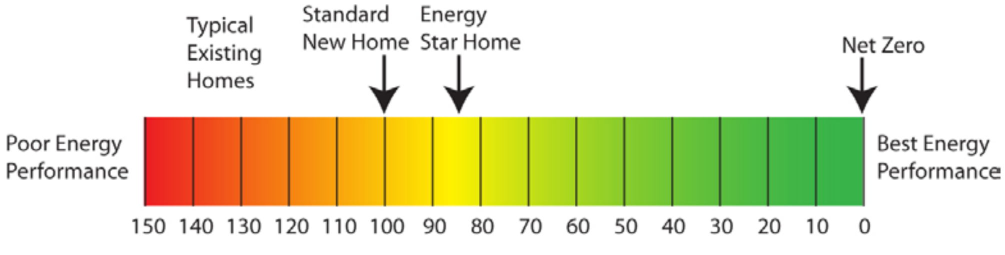


Figure 30: HERS Energy Efficiency Index. Source: (RESNET, 2013)

As mentioned in the literature review there are several ways to define ZNE, and it appears that the definition from California agencies has evolved since the rollout of the Big Bold Energy

Efficiency Strategy in 2008. The current push is for a Time Dependent Valuation that determines ZNE state based upon the time of day when electricity is fed back onto the grid. Based on the responses of interviewees, the current method of compensating homeowners with DER's is based off a system called net metering. This system does not take into consideration whether energy is generated during peak hours when it is needed most. The shift to a Time Dependent Valuation will give more weight to homes that generate power during peak hours. In the future TDE can be optimized using battery storage systems that feedback produced energy during optimal hours (Jones and Zoppo, 2014). Legislation is currently underway to modify metering rates to reflect time of use starting in 2018 (A.B. 327, 2013) potentially providing greater financial incentives to households who have invested in DER's through ZNE buildings or otherwise.

ZNE Ready buildings are also another category of homes that can be developed in cities. These are homes that are highly energy efficient, but do not have DER's attached yet (CEC and CPUC, 2015) and it is estimated that there are 6,654 of these types of homes already existing throughout the state (Pande, Goebes, et al., 2015). Near ZNE homes are those that are designed with high energy efficiency but lack sufficient onsite renewable generation to offset consumption over the course of a year, and it is estimated that 4,984 homes fall into this category statewide. Sometimes buildings that are constructed with the intent of achieving ZNE fall into the Near ZNE category after their energy use is monitored once residents move in. Such is the case with one of the local ZNE projects in the Sacramento area, the UC Davis West Village Complex discussed in section 4.2.3.

ZNE is equated with carbon neutral lifestyles, but electricity and gas represent only a portion of the greenhouse gas footprint of the average household in Sacramento. Profile of GHG emissions per household are available through an online tool called the CoolClimate Network (Jones and Kammen, 2014). Using this tool, the total annual GHG emissions per household in Sacramento is 39.4 MTCO2e per year for each household with 2.44 MTCO2e/year from electricity use and 2.47 MTCO2e from natural gas. ZNE households replacing natural gas powered appliances with high efficiency electrical systems and utilizing DERs would assist with reductions in the natural gas and electricity categories.

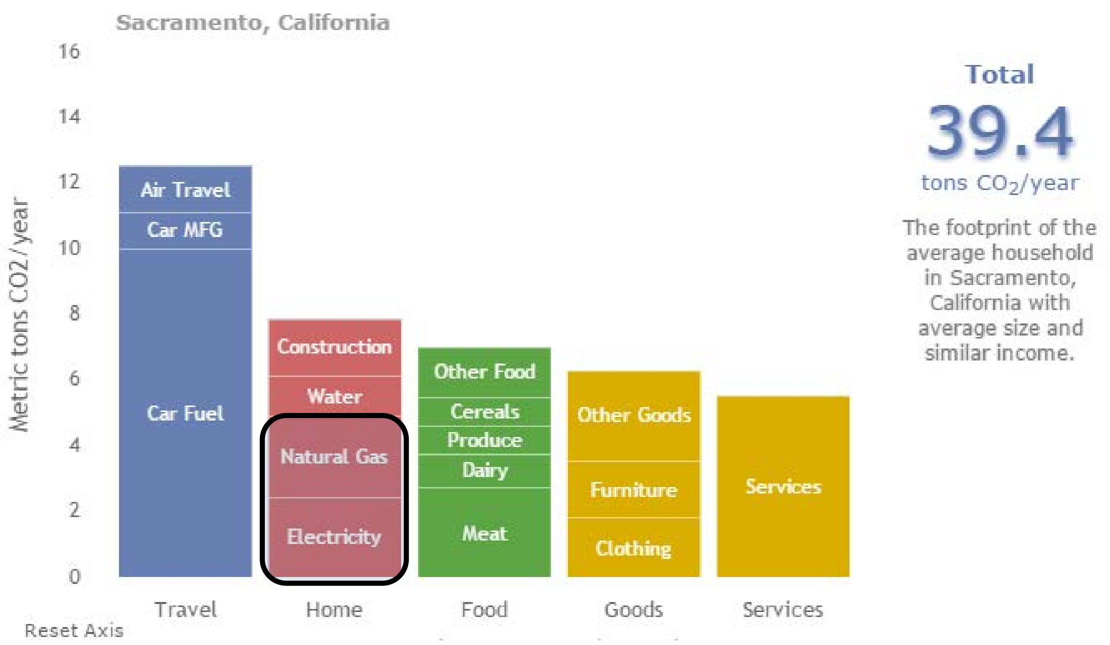


Figure 31: Average household GHG emissions in the city of Sacramento. Source: (Jones and Kammen, 2014) via http://coolclimate.berkeley.edu/

4.2 Adaptation

4.2.1 Climate Change Hazards & Vulnerabilities

Climate change planning is occurring in response to some vulnerabilities of the current system to climate change threats. In California models have been created and incorporated into studies that evaluate what climate changes are imminent. According to one interviewee involved with municipal climate change planning, both extreme heat and extreme flood events are possible scenarios in California, with both events receiving attention in planning. Heat increases, droughts, and wildfires are seen as a chronic long-term issue, while floods and storms are an acute but potentially catastrophic event. According to a report prepared for the CEC threats to energy generation and transmission posed by climate change come from a broad mix of coincident climate impacts, including frequent heat spells, winds, drought, fires, and flooding (Sathaye, Dale, et al., 2012).

ARkStorm

When inquiring about Sacramento's most critical climate vulnerability during interviews a local planner emphasized flooding. With California currently in a protracted drought, and much of the literature focusing on heat and drought impacts it was difficult to imagine flood inundation being among the most pressing issues. But then I recalled the flood events of 1997 and 2005, which until now seemed a distant memory. And looking at studies on flooding in the region revealed that these type of events are not as uncommon as one would expect.

In 2011 the US Geological Survey published a report evaluating the potential impact of an ARkStorm in California (Jones, Cox, et al., 2011) . In this report the event is described as a superstorm combined with flooding and landslides having the potential to cause $400 billion in property damage and $325 in lost productivity. Flooding in the Sacramento area and delta of the San Francisco Bay would result in the evacuation of up to 1.5 million residents. The probability of this extreme event happening each year is low – about .2% each year for the most apocalyptic scenario, 1% per year for a less extreme event. But this type of event is not unprecedented, it has occurred at least seven times since 200 A.D., most recently in 1861-1862 where winter rains persisted for 45 days, flooding the central valley to create an inland sea 32km wide by 400km long, p. 2. According to geologic evidence this flood was among the mildest in comparison to the six events that preceded it.

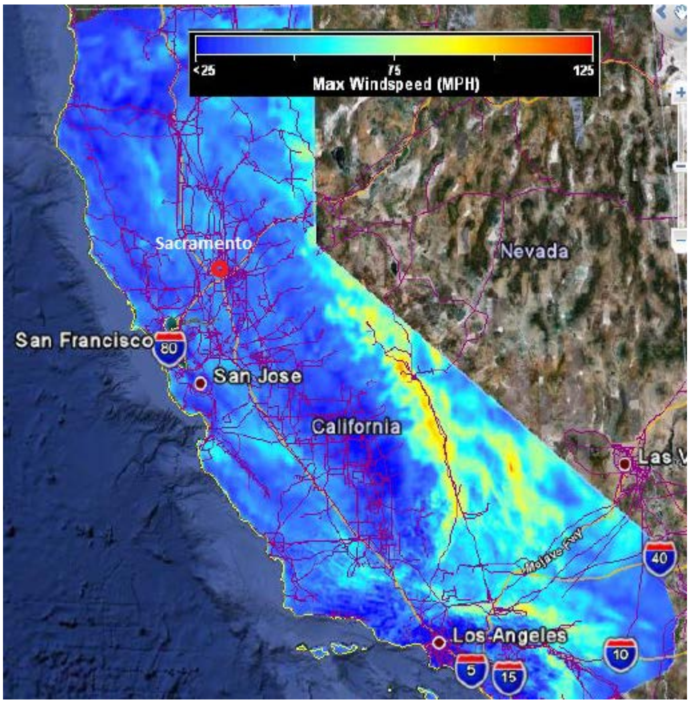


Figure 32: Projected wind speeds from ARkStorm event with major electrical transmission lines shown in red. Adapted from USGS report. (Sathaye, Dale, et al., 2012)

The USGS report looks at the impact of an ARkStorm on housing and energy infrastructure within the state. In the energy sector, transmission lines are vulnerable to winds exceeding 75 miles per hour. Modelling shows that an ARkStorm would generate wind gusts at this level that could cause transmission damage. A closer look at the mapping shows that this vulnerability is generally concentrated on the east side of the Sierra Nevada Mountains. According to the grid mapping from the California Energy Commission this would impact the Path 65 500 kV Pacific Intertie supplying imported power from Oregon hydropower plants to the Los Angeles Metropolitan Area (Sathaye, Dale, et al., 2012).

In peak operation this interstate direct current line supplies up to 3,100 MW of power to nearly three million households in the Los Angeles region (ASEA Brown Boveri, 8/9/2015). A disturbance to this line could create challenges for grid management in southern California, but it is not clear from the available data whether this would have a ripple effect of cascading failures to cities in the north of the state like Sacramento. Apart from large transmission lines, USGS assessment also mentions that the most common cause of power interruption within American cities after major storms is from damage to transformers and wooden crossbars. This can occur at windspeeds as low as 45 miles per hour, which are identified in pockets throughout the state on the projected wind speed map. From empirical observations, these wooden poles are extremely common in established neighborhoods throughout the city of Sacramento.

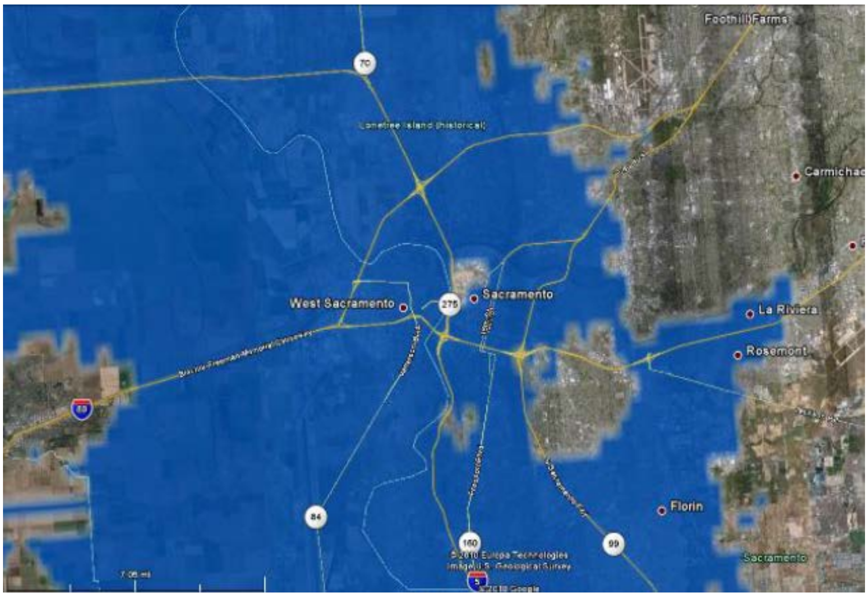


Figure 33: ARkStorm projected flood map for the Sacramento area. (Sathaye, Dale, et al., 2012)

The second condition of an ArkStorm with severe impacts on the electrical grid is flooding. This threat is potentially more impacting to the grid in the long term, because floods can damage to substations that serve large populations and take several days to restore and several months to fully repair, p.37. A map shows that Sacramento has at least six substations in the immediate vicinity that would be affected by major inland flooding. Eight resilience measures are included in the report, ranging from improved mobilization and coordination to hardening physical infrastructure. None of the proposed measures includes the use of DERs, a surprise given the research showing microgrids as a possible solution to storm resilience (Lasseter, 2007) and the proposed use of these technologies for storm protection within other US states such as New York (NYSERDA, 2014).

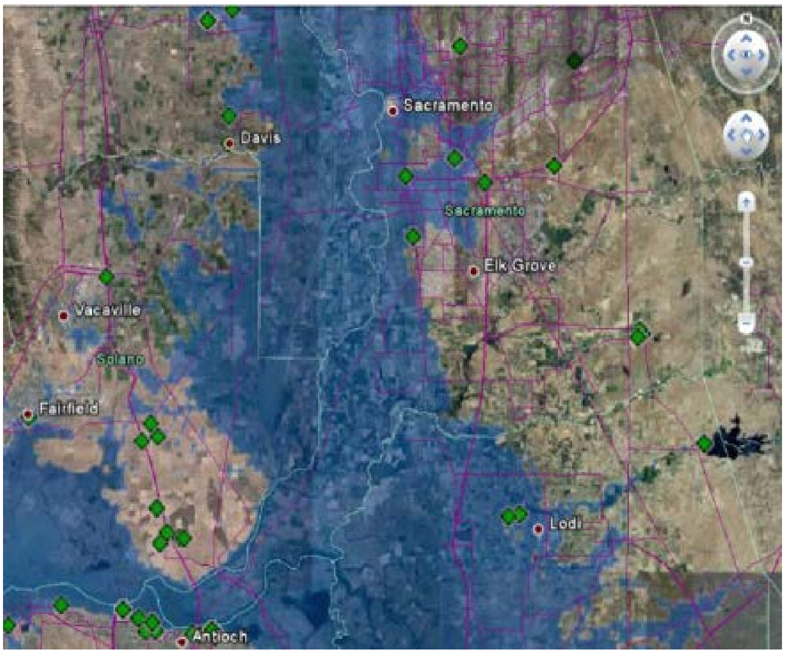


Figure 34: ARkStorm Flood map showing affected substations in the Sacramento metropolitan area. (Sathaye, Dale, et al., 2012)

Temperature Increases

According to the California 2009 Statewide Adaptation Strategy, higher temperatures are a hazard that will create significant impacts on the state's electrical infrastructure (CNRA, 2009). While floods and storms are acute shocks to the system, higher temperatures are longer-term trends that increase warmth of the state in both cool and currently warm regions. In the Central Valley where Sacramento is located, temperatures occasional exceed 100 degrees F (37.7 C) in the summer, sometimes for consecutive days. The frequency and intensity of these heat waves are projected to increase in the coming decades according to several climate change models. In the table below are the findings of studies that have modelled the projected growth in temperature statewide and specific to Sacramento.

Source	Findings
(Hayhoe, Cayan, et al., , 2004)	Increase of 3°-5° F in state-wide average temperature by 2030s and up to 9° F for summer average by 2050s under high emissions scenario
(Drechsler, Motallebi, et al., 2006)	Summer daily maximum temperatures would increase by 2.2°–7.6° F by 2035–2065
(Mastrandea, Tebaldt, et al., 2009)	Extreme temperatures currently estimated to occur once every 100 years would occur annually under high emissions scenario
(Ostro, Rauch, et al., 2011)	Statewide changes in annual average temperature of 1.9° F in 2025 and 4.6° F in 2050 would translate to 2,100 to 4,300 excess deaths in 2025 and 6,700 to 11,300 excess deaths in 2050
(Miller, Jin, et al., 2007)	Extreme heat days could double in inland cities like Sacramento. 17% chance of experiencing statewide electricity deficits during high temperature summers.

Table 15: Conclusions from models of temperature increases in Sacramento. Sources: (CEC PIER, 2015, Sacramento Climate Action Plan - Final Draft, 2012, SMUD, 2012)

(Cayan, Tyree, et al., 2009)	Comparing 1961-1990 baseline averages with 2070-2090 projected averages, Sacramento shows a shows 3.6°F (2.0°C) increase in the low emissions scenario, and 6.3°F (3.5°C) under high emissions.

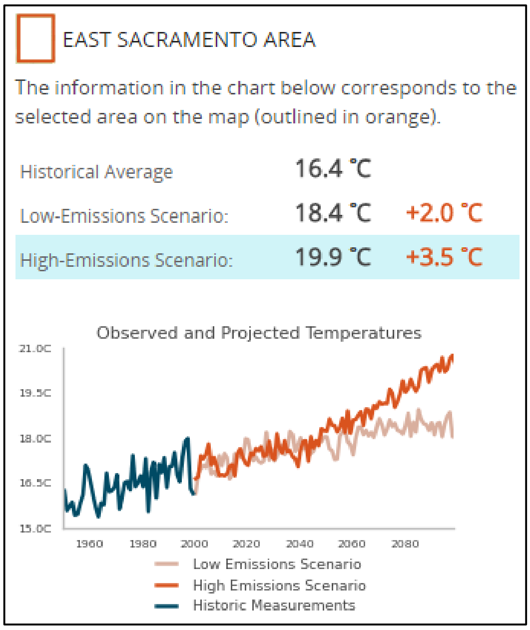


Figure 35: Projected temperature increases for the city of Sacramento through 2100. Source: (CEC PIER, 2015)

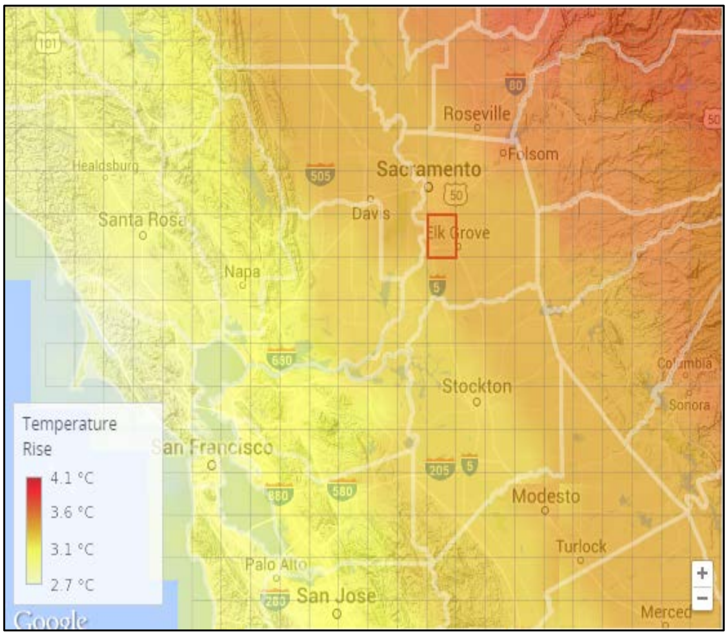


Figure 36: Heat map of regional temperature increases through the end of the decade (CEC PIER, 2015)

These temperature increases are expected to have impacts on the operation of the local utility's power grid (Cayan, Tyree, et al., 2009) estimates that increases is in temperatures between 2012 and 2099 could cause a 6% drop in the efficiency of thermal power plants and a corresponding drop in plant output during high temperature events. An additional 7% decline in transmission capacity by the end of the century would also accompany these reductions.

SMUD released a report on the readiness of its operation in response to these temperature changes (SMUD, 2012). In this report it is indicates that average measures of annual temperature increases may be misleading because it can underestimate the spike of energy demand in summer months when air conditioning is used. This increased demand also coincides with losses of efficiency created by heat.

The increased temperatures in the central valley also coincide with reduced precipitation throughout the year. This shift in hydrological patterns could reduce hydropower production. This is particularly important for Sacramento's electric utility SMUD, who produces around 23% of its total energy from hydropower. Changes in the seasonality of snowmelt, and reduced snowpack will all have the potential reduce the availability of water available for downstream release and thus hydroelectric power generation (Madani and Lund, 2010).

4.2.2 Pathways for Vulnerability Reduction

Returning for a moment to Chapter 2, two pathways were identified that could improve climate resilience in energy – demand reduction and alternative physical configurations for electrical systems. After a review of data, the emphasis for adaptation in energy transitions in California is geared toward demand reduction. Alternative physical configurations like microgrids are a very small part of climate adaptive strategies at the moment. In theory it is possible for clusters of ZNE buildings, or Community ZNE to be linked together using battery storage to create a microgrid but real world examples of this were not found. The microgrid examples that can be found are in commercial settings like SMUD's headquarters which is a retrofitted office building and at the campus of the UC San Diego, typical institutional settings found under the MUSH classification.

Demand reduction and microgrids pathways occur at different scales. For instance, demand reduction happens at the building level and is multiplied over many communities to achieve improved resilience of the energy system as a whole, microgrids occur at the building or neighbourhood level and their benefits remain within this context. When microgrids are implemented in a public facilities or multi-unit residential they can serve as a hub for communities and emergency response efforts. But according to an interviewee familiar with battery storage technology, there are more efficient and cost effective ways to implement microgrids that serve the community in disasters than photovoltaic solar panels and battery backup systems. Diesel generators can be used at a fraction of the cost and are effective so long as there is a fuel supply that can last over several days during a storm event. But this type of configuration would not have the same greenhouse gas reducing properties as solar plus battery backup system. Also since the Sacramento region is most likely to experience heat waves and demand peaks than a .2% annual chance of a one-off ArkStorm, demand reduction is generally the focus for energy sector resilience as opposed to addressing major storm and flood threats.

Filling the Energy Gap

Based on discussions with state energy regulators, greater demand is projected in the state through 2050 and the existing energy infrastructure is inadequate to support these increases. This creates a gap between generation and demand that must be filled by new energy sources. This is a statewide issue that both investor owned utilities and publicly owned utilize must address. In Sacramento SMUD has modelled this gap, showing its growth annual through the mid part of this century. In an interview with the utility it was discussed that the types of energy that will be used to fill this mix are unknown at this time, but DER's will likely play a role. The dark green section of the graph below represents the state required RPS, which utility scale renewables projects will assist with achieving. But there are still needs beyond this requirement. SMUD's integrated resources planning strategy indicates that by 2030 2,600 GWh per year of renewables will be needed beyond RPS requirements to meet local demand (Shelter, 2010). Energy efficiency efforts are also shown by this graph, which is also important because ZNE contains a high level of energy efficiency in its design. How much ZNE will impact this graph will depend on how widespread ZNE adoption becomes, not just in new residential development, but also in retrofitted buildings and commercial applications.

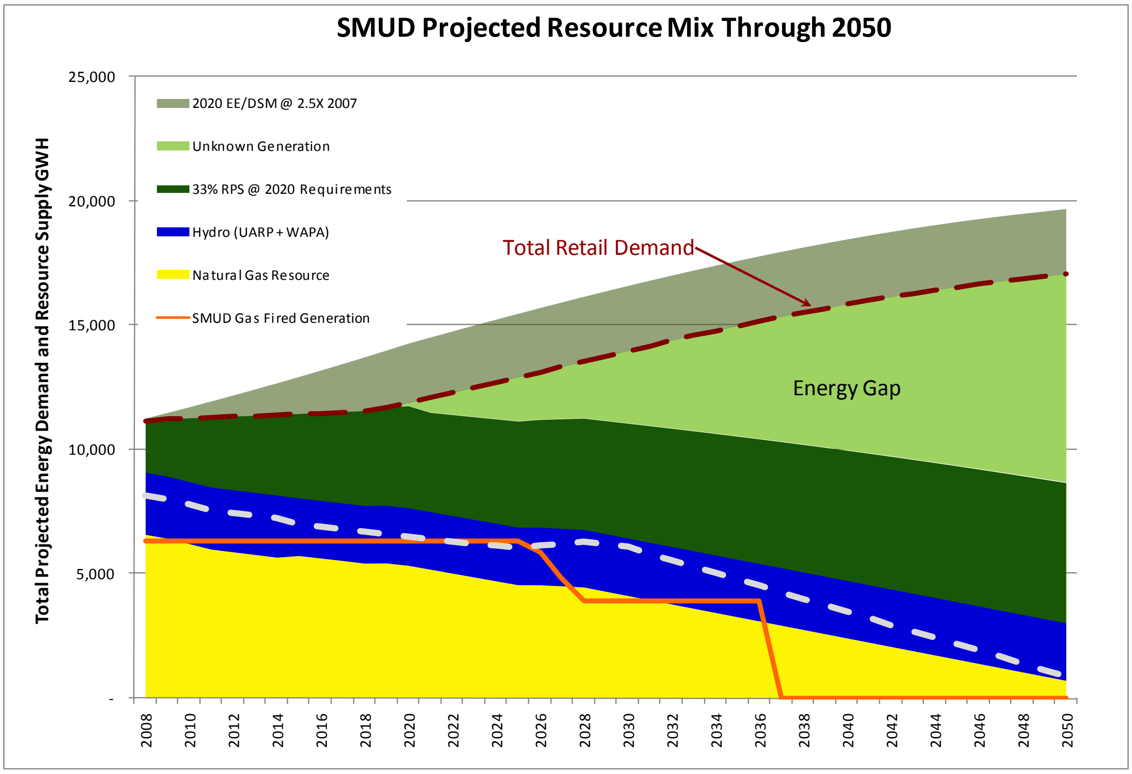


Figure 37: Energy generation mix for SMUD's service district through 2050. Note the gap between anticipated demand and the available generation options. Source: SMUD (Shelter, 2010).

The growth in energy demand represented in the above graph is influenced not just by natural growth in the region, but also increased seasonal usage exacerbated by temperature increases arising from climate change (SMUD, 2012). The orange line represents natural gas co-generation plants that expected to be decommissioned. These co-gen plants can be operated longer if they are switched to renewable energy resources like biofuels according to a planner within the organization.

Utilities will need to invest in new generation sources to fulfil this growing demand, not just to accommodate increased peak use, but also to account for losses that occur when generation equipment is exposed to higher temperatures for prolonged periods. These investments will cost money whether it involves upgrading existing infrastructure, procuring energy from out-of-state, utility scale renewables, or DER's from ZNE type households. Financial incentives that benefit DER adopters include net metering and feed-in-tariffs for DER producers. Starting in 2012 SMUD initiated a feed-in-tariff scheme to provide greater financial incentives for DER use, but this program was capped off at 100 MW and as of 2015 has met its quota (Resolution 13-08-01, 2014).

How much can new residential ZNE development fill the gap of SMUD's projected increases in energy demand in the Sacramento region?

The gap represented in the above graph begins in 2020 and grows through 2050, and coincidentally this is the same time period that ZNE residential development is expected to take effect according to the CPUC's ZNE Action Plan. It is also the same time period that estimations of GHG reductions and housing growth in the state and the Sacramento region were calculated in section 4.1. In the next section, 4.2.3, case studies of ZNE projects operating the Sacramento area are profiled, which include kWh outputs of single family homes with PV and battery storage systems. Knowing these figures, along with SMUD's energy gap represented in GWh allows for a rough estimation of how much ZNE, if applied in all new residential development can help fill this void based on the current capabilities of PV and lithium-ion battery storage technology.

Each single family home in the recently constructed 2500R project has an output of 11.64 kWh per unit (DOE, 2013). kWh is a way of measuring energy that takes the capacity of the battery (4.5 kW per unit) and multiplies it by the time it takes to deplete from fully charged to empty (2 hours and 35 minutes). If we assume that a PV unit charges the battery to its maximum capacity during the day, and then fully unloads its energy between 4pm and 7pm when energy is no longer being captured from the sun and urban energy demand is at its peak, then in theory around 11.64 kWh could be put back onto to grid each day per household. If this process could occur each day throughout the year in a sunny region like California, then a household with PV and batteries could supply about 4.249 MWh of energy per unit throughout the course of the year. Each subsequent year new ZNE homes would be introduced into the Sacramento market to increase the number of energy producing homes.

In the chart to the right, annual new residential construction in Sacramento County is shown in column two. Data from Sacramento County is used because this is most closely aligned with SMUD's service district. The formula for evaluating annual housing growth is shown in Figure 21. Each year the new housing is multiplied by 11.64 KWh and added to output from the previous year creating a running total. The MWh is then converted to GWh.

Two data sources from SMUD can be used for comparison, the chart in Figure 37 which provides a visual approximation of the energy gap by year (but is unfortunately not accompanied by actual GWh figures) and the integrated resource plan which provides and a hard number and year – 2,600 GWh needed by 2030 (Shelter, 2010). The year 2030 is highlighted in the table to the right. Of the 2,600 GWh that will be needed in 2020, 280.7 GWh could be expected to come from new ZNE residential homes in Sacramento based on the current technology found in 2500R.

Of course this is a rough estimation, the daily and annual output of DER homes fluctuates based on a variety of conditions, batteries are not always used to their full capacity each cycle to prolong lifespan, and the performance of batteries and solar panels will undoubtedly change between now to 2030 and beyond. But this is an attempt to verify to some extent whether ZNE can help with filling energy gaps created, in part, by growing demand due to increased temperatures brought on by climate change.

Year	New Res. Sac. Co.	MWh Total	GWh/ Total
2020	5975	25385	25.4
2021	5975	50771	50.8
2022	5975	76156	76.2
2023	5975	101542	101.5
2024	5975	126927	126.9
2025	5829	151692	151.7
2026	5829	176457	176.5
2027	5829	201222	201.2
2028	5829	225987	226.0
2029	5829	250752	250.8
2030	7040	280663	280.7
2031	7040	310573	310.6
2032	7040	340483	340.5
2033	7040	370393	370.4
2034	7040	400303	400.3
2035	6522	428012	428.0
2036	6522	455722	455.7
2037	6522	483431	483.4
2038	6522	511141	511.1
2039	6522	538850	538.8
2040	5644	562829	562.8
2041	5644	586808	586.8
2042	5644	610787	610.8
2043	5644	634766	634.8
2044	5644	658745	658.7
2045	4253	676815	676.8
2046	4253	694884	694.9
2047	4253	712953	713.0
2048	4253	731023	731.0
2049	4253	749092	749.1
2050	4253	767161	767.2
Assumptions:			
KW per unit:			4.5
KWh per unit:			11.64
Annual KWh per home			4249
Annual MWh per home			4.249

Table 16: Potential annual energy output of ZNE residential development in Sacramento County.

Upon investigating some of the barriers to ZNE transitions a question emerged – if DER equipped buildings become mainstreamed, won't this have the effect of disrupting the functional business models of the energy sector? Utilities are being expected to tell their customers to consume less of their product, produce their own energy and then pay their customers for bringing power back onto the grid. All of this occurring at the same time that utilities are needing to pay for expensive upgrades to aging or climate vulnerable infrastructure. Under these circumstances companies would typically need to raise prices to offset these increased costs and a dwindling customer base. But rates are not determined by most utilities, they are governed by the CPUC. A report released by the CPUC showed that in 2012 DER's in residential and commercial applications throughout the state cost IOU's $245 million, and this is projected to increase to $1.1 billion by 2020 as more buildings adopt solar energy (Seybert, 2013).

Some options are being proposed to ease the burden of DER's on utilities. According to an interviewee, the cost of upgrading energy systems to increase capacity, harden the grid for climate resilience and fund net metering could be offset by user fees for prosumers, who use the grid to feed-in excess power but aren't paying for the system's maintenance and expansion. Proponents of the renewables industry argue that this would create a disincentive for household conversions to solar (Sommer, 2014).

Toward the future utilities will need to balance DER integration into the existing grid from both a technical and financial perspective, but the optimal mix between proven methods of generation and distributed generation has not been determined. This is area of research that requires further investigation according to the utility, and at the time of this writing is being actively explored by energy experts. (Fine and Robinson, 2015).

Household Level

Per experts in the building industry ZNE buildings in new homes have added expenses that make them more expensive to develop than traditional homes, and the costs become exponentially higher the closer that buildings come to achieving ZNE. Valuation, or estimating how much property values improve as a result of being ZNE status is still a work in progress (Pande, Goebes, et al., 2015). Knowing the long term added value of ZNE would assist with obtaining financial resources that amortize the cost of ZNE upgrades over a long term. But estimating values is moving target, since it has not been definitively established how net metering or FIT rules will be structured to provide annual revenue streams to prosumers. Investment in DER's for homeowners often involves a cost benefit analysis that must result in net positive financial benefits within a reasonable timeframe. Uncertainties about the ability for ZNE systems to generate the revenues to offset upfront capital expenditures may serve as a deterrent to consumers.

Utility	**Monthly Bill**
SMUD	$93.93
Roseville Electric	$113.95
Los Angeles Dept.of Water & Power	$120.53
Modesto Irrigation District	$136.63
Southern California Edison	$143.94
Pacific Gas & Electric	$154.44
San Diego Gas & Electric	$166.62

Table 17: Monthly average residential electrical bills in California at 750 kWh per month in January 2015 Source: (SMUD, 2015)

Aside from receiving money through net metering and FIT schemes, there is also potential savings from reduced electrical bills. Throughout California electricity bills are typically in excess of $120 per month for an average household. But SMUD emphasizes that it's electrical bills are among the lowest in the state at $93.93 per month. So the potential to reduce electrical costs in is actually lower in Sacramento than other jurisdictions in the state. But expectations about reduced bill must also be contrasted with CPUC's explanation in the ZNE Action plan, that ZNE does not necessarily mean zero bill. Over promising the cost savings of ZNE and under delivering could cause the technology to develop a bad reputation so the CEC recommends that the technology should be promoted as one that delivers a host of benefits independent of cost savings, including reduced pollution, comfort and building functionality p. 13. Accurately portraying the benefits and limitations of ZNE is important because a market transformation will be driven in part by consumer awareness that creates demand for the product from builders (Pande, Goebes, et al., 2015).

Lowering utility bills however may allow populations on fixed incomes, like the elderly, to run air conditioning at the summers, which are expected to become hotter for more consecutive days in Sacramento. By allowing this option, elderly populations which are typically the most vulnerable to heat waves could better adapt to climate conditions at a minimal cost, thus improving the adaptive capacity for a specific segment of the population.

4.2.3 Case Studies

UC Davis West Village

Figure 38: Images of the UC Davis West Village housing complex with DER PV Solar equipment

The UC Davis West Village is a 663 unit apartment complex serving 2,000 students of the University of California, Davis 20 minues west of the City of Sacramento. The project has been designed to create a framework for addressing the technical, financial and regulatory barriers in residential project striving to reach ZNE. The U.S. Department of Energy, California Energy Commission and the California Public Utilities Commission provided grants to fund research related to this public-private partnership ZNE project.

The multi-unit complex was developed with the intent to be ZNE, but fell short of reaching ZNE goals by 13% in its inaugural year between 2012-2013. In a one year period the UC Davis west village generated 2,981 MWh of electrical which was right on par with the amount modelled. It consumed, however, 3,412 MWh which was 22% more than modelled.

Design aspects were cited to be a contributing factor in the annual report, but a more influential factor was the consumption patterns of students, which were underestimated in earlier models. Adjusting consumption patterns in buildings that perform below ZNE could allow poorly performing buildings to reach ZNE status (UC Davis, 2013).

What is obvious from this reading is that ZNE is not just plug-and-play, but there is flexibility in how buildings can move in and out of a ZNE designation based upon design and the behaviors of occupants. This links back a theory in sustainability transitions from Shove, who observed that the social norms occurring within buildings exert influence on the pathways to energy transitions (Shove, 2012). Further based on interviews, the introduction of storage technologies could have the ability to tip the scale of homes teetering on the borderline to ZNE status. This scenario is actually being played out in the UC Davis West Village Complex where the project's design team has partnered with Honda to develop a load balancing systems that utilize an electric vehicles lithium-ion battery to optimize the power consumption of a highly energy efficient and DER equipped residential buildings (Honda Motor Co, 2015).

The project also shows signs of being a community ZNE project as discussed in Section 2.1.3. Energy is generated not only from rooftops of individual units, but also over parking structures and bicycle lanes, providing shade from the intense summer heat while powering the multi-unit apartment blocks.

2500R Street

Constructed in late 2013, 2500R is an infill residential development project that has reached ZNE status, and has done this by combining solar PV with battery storage. The project consists of 34 residential units priced at around $350,000, a typical going rate for new townhomes in the downtown Sacramento area. Each of these units has a rooftop PV storage system with an output of 2 kW mated with a battery storage system of 4.5kW (DOE, 2013). The project was built in a collaborative effort with the local utility SMUD, who donated $450,000 in smart grid equipment from who wanted to use this community as a research tool for how ZNE fits into their system.

The homes proved to be popular sellers, and some residents that moved into the homes reported that their energy bills had been reduced to zero in the first few months of ownership (SMUD, 2014). Part of this saving was attributed to SMUD placing some of the units on a separate time-of-use rate, providing greater incentives for managing power consumption and generation at peak hours. This management was automated through a system developed by the smart grid manufacturer Sunverge, with a digital console in each unit showing real time data to homeowners when the savings is occurring. At an additional cost of $25,000 per unit for the battery plus PV system, the investment was not inexpensive, but according to the developer these prices are expected to go down in the future making the investment even more justifiable. Based on the success of this project the developer is considering another larger project in the core of Sacramento that would continue to build on the relationship with SMUD.

Figure 39: 2500R Street Project. 34 units of residential infill w/ PV and battery storage, and interactive display panel accessible from tablets and mobile phones.

4.3 System Interactions

4.3.1 Actor Linkages

The information in this section are insights into the ZNE development process compiled from interviews with various actors involved with ZNE processes.

1. State Government ←→ Local Government

Within the Sacramento region, the city of Sacramento has the most well developed Climate Action Plan in terms of goal setting, and integrating both climate mitigation and adaption. The plan itself indicates that its objective is dual purpose to address both GHG reduction and improving the resilience through 2050. The plan mentions that its mitigation targets were inspired by planning occurring at the state level namely, AB-32, SB-375, EO S-3-05. With adaptation, the plan was created to following in the footsteps of the State's 2009 Climate Adaptation Plan.

In terms of prompting efficiency in the building sector, Sacramento's CAP defers to Title 24 building codes developed by state agencies, indicating that Tier 1 building standards which are 15% more efficient than required level to become mandatory for new residential development in the future.

In discussions with two interviewees about the motivations to pursue climate adaptation at the state and local level, there is apparently a financial incentive for local governments to participate in adaptation planning from the national government. This funding is predicated on developing a Hazard Mitigation Plan. These plans generally focus on responses to acute impacts like flooding, but could also be a window of opportunity for jurisdictions who do not have comprehensive adaptation goals to pursue action. This especially applies to cities where addressing climate change planning is low on the political agenda. The County of Sacramento has a multi-hazard mitigation plan which predates the State Climate Adaptation plan by five years. The City of Sacramento's CAP makes reference to this plan, including a measure to raise public awareness of climate hazards. This public awareness goal could present an opportunity to advocate for technologies like ZNE which improve the resilience of the city's energy infrastructure and minimize heat exposure though passive building designs.

Sacramento's CAP also calls for the creation of an Interagency Adaptation Team to work with state agencies and neighboring jurisdiction to share data, review infrastructure design and ensure that local plans are kept up to date with the latest science. In the CAP it is stated that the city's target is all new construction to be ZNE by 2030. This includes both residential and commercial development. But the State's ZNE action plan states that residential should become ZNE by 2020 – a decade before the stated target of the city's plan. Through an interagency adaptation team, the city would have a forum for discussing these type of inconsistencies and make adjustments to its planning to stay congruent with the state's goals.

2. State Government ←→ Building Sector

The CEC is involved with updates to title 24 building standards that require efficiency in building standards and updates to these standards occur in three year intervals. The latest update occurred at the end of 2013, and the next will take place at the end of 2016. 2013 was a major update with the effect of increasing efficiency in new residential homes by 25% over 2008 standards. Over the next few years default building standards under Title 24 are expected to become even more stringent to ramp up progress in building techniques that will move toward ZNE.

The CEC and CPUC jointly administer pilot projects that provided financial incentives for builders interested in piloting energy efficiency and DERs under the umbrella of the Go Solar initiative. This program has a budget of $3.3 billion and a goal of up to 3 GW of distributed energy statewide for homes. $400 million of this is targeted toward new residential development under the CEC's New Solar Homes Partnership. According to an interviewee, in the decision making for the ZNE Action Plan representatives from the building industry provided feedback on the feasibility of achieving the goals. These forums focused on addressing technical and financial issues.

3. State Government ←→ Energy Sector

Rate setting for IOUs are regulated throughout the state by the CPUC. The involvement of CPUC in the affairs of IOUs is a tradeoff – regulatory oversight in exchange for exclusivity in specific markets. The CPUC prevents price gouging that can occur when a handful of organizations control the production and distribution of energy. In its role of supporting ZNE, the CPUC has taken steps to move toward decentralization of energy resources.

As a POU SMUD is not required by the CPUC to have renewables portfolio standard, but since the utility's goal is to be an innovator they have set targets to reduce GHG emission consistent with what the IOUs are required to provide. SMUD is part of a regional climate collaborative in cooperation with CEC, PUC, SACOG, Water Agencies, City, County & Local Governments.

The CEC has a different role, it is tasked with developing programs that support legislated mandates. The CEC is a large agency with over 600 employees that the implements energy policy for the legislative and executive branches of the state government. When a statute or an executive order is passed, it is up to the CEC to plan and implement the measures. Their concern is not explicitly with addressing climate change, but rather with implementing.

The state is at the helm of influencing ZNE development throughout the state. Programs like CEC's EPIC provide a funding source for utilities and builders to conduct building science evaluations and initiate pilot programs.

4. Local Government ←→ Building Sector

According to an interviewee involved with land use planning, local plans in California are generally more specific than other states, avoiding "fluffy" objectives and goals, for those that are more direct and prescriptive. There can be a competitive component to local planning, cities can try to top each other by instituting more rigorous green building standards. There are alternative standards than are sometimes used by cities to assess the efficiency performance of homes. For instance LEED is the standard that the US Green Building Council uses, CalGreen is used by the state, and Greenpoint ratings from the non-profit Build It Green are used by some cities for green certification.

5. Local Government ←→ Energy Sector

Attempts are being made to "standardize" permitting for DER's and standards are being developed to increase interest in energy efficiency standards for local governments.

SMUD participates climate collaborative in cooperation with CEC, PUC, SACOG, water agencies, City, County & Local Governments.

6. Energy Sector ←→ Building Sector

A number of Performance Based Initiatives seek to encourage PV solar and storage applications. Currently developers must only build out and show that they have strategized for reducing carbon emissions. Once the project is built out, there is limited accountability for ensuring that expected long term GHG reductions have been achieved. Other programs include New Solar Home Partnership program and "buydowns" which are subsidies for home retrofits.

7. Building Sector ←→ Household

Consumers are attracted the prospect of lowering energy bills and green building becomes a selling feature that can add value to homes.

Creative financing is being discussed. The high upfront costs from adding solar and energy efficiency into new development, (estimated by one interviewee to be somewhere around 60k) can be amortized over a longer term since the operating costs of energy efficient units is lower over the life of the building. Green Appraisal addendums are being used to determine increased value of energy efficiency and DER's in residential construction, thus justifying some of the additional costs.

According to one source larger homebuilders are often in a better financial position to experiment with innovation in new home building as their ability to absorb risks are higher with larger projects, especially with the availability of incentives coming from state programs like EPIC.

8. Energy Sector ←→ Household

According to two sources during interviews consumers will drive growth for ZNE and there is a need public education to convey the benefits of energy efficiency and renewables. Renewables are sometimes perceived as expensive additions to homes, but as prices decline a messages needs to be conveyed that these technologies are affordable to many households, not just high income. Through leasing programs with third parties and incentives provided from utilities, the costs of initial investments can be offset.

The growth of electric vehicles may actually increase the need for utilities to provide power at night as electric vehicles are charged in people's garages. Also electric vehicles are being explored for their ability to help balance loads when plugged in and charging, assisting with load balancing from a utility's standpoint.

4.3.2 Promises & Requirements

While the government forms policies that outline pathways for emerging technologies, the private sector and researchers respond with their own protocols and internal policies for bringing the technologies to a mass market can be conceptualized as requirements, which was described as part of the promise-requirements cycle in Section 2.3.4. This section explores how a diffuse, and open ended promise of ZNE influences the development of a critical component of energy efficient and DER homes – lithium ion battery storage systems.

DER's found within ZNE buildings are comprised of a variety of technologies, which are expected to improve in efficiency and cost over the next several decades. An adjunct component to DER systems that is anticipated to enhance the transition to sustainable energy is lithium-ion battery storage. When Solar PV is placed on the rooftops of buildings, the power from this can only be used during hours where daylight is present. When batter storage is attached to PV (or any DER source for that matter) energy can be captured and stored for later use in the home or fed back onto the grid during peak hours when energy demand in cities is at its highest. This is called load balancing. Battery storage is also described as a key component of a microgrid system that could be used to island buildings in the event of an outage caused by extreme weather conditions, thus having an integral role in climate change adaptation for vulnerable populations.

Battery storage and its relationship with ZNE development appear to fit the profile of a technology influenced by dual dynamics of promises as described in Chapter 2. Major expectations are being placed on the potential for this technology to achieve mitigation and adaptation, but at the current moment batteries are still undergoing the process of improving their performance to meet these envisioned benefits.

The Umbrella Promise

The ZNE Action Plan describes energy storage as a critical component to ZNE and the management of grid impacts, but the promise of battery storage extends back even further in policy making. The ZNE Action Plan addresses one of four programmatic goals set by CPUC's CA Energy Efficiency Strategic Plan (CPUC, 2011). These goals are described colloquially as the state's *Big Bold Energy Efficiency Strategies* that are expected lead a holistic, market transformation using energy efficiency, energy conservation, demand response, on-site storage, renewable generation, and advanced metering p.46. In 2011, CEC's PIER released a strategic analysis study for energy storage in California by 2020. In this, the vision for energy storage systems in the state were described as follows:

> *"The proliferation of residential PV systems and… an increase in zero net energy buildings have the capacity to fundamentally change the characteristics of the 2020 market for energy storage. Customers can potentially use behind-the-meter energy storage systems, particularly batteries, to capture and balance electricity from on-site renewable sources. They may also*

be able to use their battery systems to participate in power markets by providing grid services when not in use. Meanwhile, large-scale adoption of electric vehicles will likely drive down battery costs for lithium ion batteries as manufacturers increase production to meet demand and will provide opportunities for energy storage to lessen the stress on the distribution system from increased delivery of electric power. Vehicle owners in 2020 or sooner may be able to sell or otherwise recycle used batteries for second-use applications, such as providing distributed storage opportunities for the grid. They may also be able use their batteries to supply power to the grid often termed as vehicle-to-grid applications to offer ancillary services to utilities." (CEC PIER, 2011) p.42

Within this assessment new opportunities for investment are signalled and there is discourse about the positive way in which batteries can meet the big, bold strategies established by the CPUC.

The promise of energy storage was further elevated in the policy discourse following Superstorm Sandy October 2013 when electricity was disrupted in Manhattan, New York City for a prolonged period. Policy makers at state and federal levels responded with funding and discussion about the need to make buildings "island" from the grid during emergencies, possibly through augmenting Solar PV systems with battery backup to create microgrids within the city and in other parts of the country (Lacey, 2014, Cuomo, 2014)

While photovoltaic solar in California grew at a rapid pace between 2011 and 2014, systems that included battery storage were generally limited to a handful of demonstration projects, operating in a protective space of research and government funded programs. A 34 unit affordable housing project with PV and battery storage was able to be brought to the Sacramento market in 2014, as described in the case studies section, but this is just one project among a total of 5,805 applications for new PV solar system in the state in 2014. If battery storage units are integral components of ZNE systems as suggested by the ZNE Action Plan, more pilot programs, affordable prices, and reliability will be needed to reach the target of 151,342 new ZNE homes by 2020.

Promise-Requirement Cycles

According to an industry publication there are at least 43 firms that are active in the development of battery storage systems, and these firms each have products at various stages of development. (Shahan, Z., 2015) Some of these are start-up companies, others are divisions of major corporations. One of the most visible of these firms is the California based electric car company Tesla, who announced in April 2015 a venture launch a battery storage product for residential and commercial applications using the same technology found in electric car batteries. This announcement captured the attention of the media who hailed the firm's entry in the market as a disruptive game-changer, with the ability to bring clean energy to a mass market. It also boosted public awareness of battery storage and reinforced the promise of low carbon futures envisioned by California policy makers.

But Tesla and other actors involved with battery storage R&D still need to further develop requirements needed to overcome the economic, regulatory, grid interconnection, cost-cutting and technological barriers cited in reports by the US Department of Energy (Bhatnagar, Currier, et al., 2013). The high capital cost of battery storage combined with limitations for end users to recover investments through revenue compensation mechanisms are cited among the top challenges that will need to be remedied through additional research and regulatory reform. Also the performance and reliability of the batteries to endure repetitious energy charging in household applications will also require further improvement. (Fuhs, M., 2015).

In terms of promise-requirement cycle, some initial steps have been completed. The signalling of opportunities and promises were described in the section above. Industry accepted this challenge in 2009 forming the California Energy Storage Alliance, now with 70+ members advancing the role of energy storage in the electric power sector through policy, education, outreach, and research.

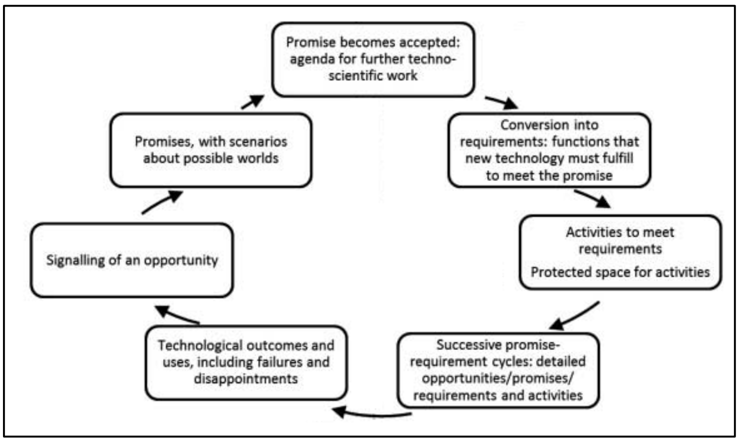


Figure 40: Promise-requirements cycles in technological innovation (Parandian, Rip, et al., 2012)

An interview with a battery producing firm on its growth strategy in the storage market revealed a more cautious approach to market entry than the hyped media portrayals of a regime disrupting venture. The company's strategy was tempered with an awareness of the barriers present with the technology, and a steady timeline for rolling out its products. It was explained that markets where feed-in-tariffs are established, such as in Germany, are generally more conducive for battery storage compared to the flat energy rate and net metering utility models currently present in California.

The CPUC study described in the umbrella section provided some foreshadowing about the ability or willingness for utilities to take on the challenge of integrating energy storage to the grid. For instance, the report says that CEC should partner with utilities to develop plans for DER and energy storage p.166, but then later states that utilities strongly oppose setting targets for energy storage because of costs and interests in other technologies p.177. It is also assumed that manufacturers will be able to rise to the challenge of creating more affordable batteries, but cautions that the technology is in direct competition with inexpensive natural gas that may or may not increase in price toward 2020, 183. Four years have elapsed since this study was conducted and natural gas remains inexpensive due to excess supply brought on by advances in natural gas mining techniques, ie. hydraulic fracturing or fracking.

There is evidence that changes to utility business models are underway that would create more incentives for battery products. In late 2013, the CA legislature passed an energy storage procurement mandate requiring IOUs to plan for the incorporation of 1.5 GW of storage capacity into their operations by 2020 (AB 2514, 2013). Rulemaking for changes to rates and compensation to support DER grid integration are being considered by the CPUC, but it is unclear whether these changes will be made soon enough to ride the current wave of optimism surrounding the technology.

In the promise-requirement cycle, technologies may not pan out to the scale or purpose originally intended in the promise, but still provide an increase in knowledge about the application of the product. By the time that these lessons are learned, however, the market and research may have shifted its attention to another emerging technology. In the case of ZNE, the concept of ZNE-ready homes seems to imbed some flexibility that would allow for future integration of DER's as technology improves. A ZNE ready home is designed to be highly energy efficient, and can be easily retrofitted to accommodate solar panels and battery backup systems. This designation builds a potential market for firms to continue pressing on to improve the cost, reliability, and grid integration even if these requirements are not currently met.

Dynamics

The umbrella promise for energy storage is part of a broader agenda of a low carbon market transformations promoted by the state government. Since it has been demonstrated that ZNE can be achieved without battery storage technology, the technology's proliferation could enhance but does fully control the outcome of achieving the big, bold energy efficiency strategies set by the state.

Large firms like Tesla, GE and Samsung that are diversified into the electric vehicle market can hedge their bets on storage by continuing to earn revenue in automotive markets, while investing in R&D that improves the performance and production costs of batteries for both applications. When, or if, the kinks are worked out of the utility business models making the consumer investments in batteries more economically feasible, then these firms are in a prime position to ramp up production to meet demand.

This is an important point because industry's rise to the challenge of creating battery backup systems places some of the responsibility of requirements back on the agency that created the promise – the CPUC. In addition to establishing strategies for energy efficiency and renewables the CPUC also regulates rate structures for utilities. With the technology and production capacity now available, adapting the business models of utilities is now the focus for reducing bottlenecks to bringing battery storage to the market.

What relevance does this have to ZNE? It means that if climate change mitigation and adaptation are possible through ZNE transitions as identified in earlier sections, the scale of effectiveness is predicated in-part by policies also that advance supplemental technologies. This supports the assertions of transitions researchers (Berkhout, Marcotullio, et al., 2012) that elevations of niches require supportive economic, political institutional and socio-cultural changes alongside technological innovations.

Chapter 5: Conclusion

The purpose of this research was to understand whether ZNE brings mitigation and adaptation co-benefits to state and local planning or policies for climate change. The quick answer is yes, there is evidence of benefits achieved at multiple levels. However, there are also variables like technology progression, regulations and market growth that will likely influence the degree in which these objectives are achieved. Under the main research question, subquestions were created to guide the research and these are addressed here with brief explanations of the findings.

What statewide climate change mitigation and adaptation co-benefits are achieved in policies supporting ZNE in California?

Statewide ZNE shows the potential to reduce GHG emissions progressively between 2020 and 2050. Researchers have already made attempts to quantify the role of ZNE among other climate change programs implemented at the state level (Greenblatt, 2015). This research is based on the assumption that all new residential development in the state will be ZNE by 2020. At the state levels ZNE if carried out to its full capacity it is estimated to bring about 14.4 MMTCO2e reduction per year by the mid part of his century. In terms of meeting carbon reduction goals the state has set reduction goals from 1990 levels to 25% by 2020, 40% by 2030 and 80% by 2050. When compared to modelling that evaluated ZNE's ability to reduce GHG emissions isolated from competing state policies, the program would support total reduction goals by .11% in 2030 and 4.2% in 2050.

From an adaptation standpoint California is vulnerable to both flood and drought events in the future, and these will have impacts on the infrastructure throughout the state as identified in the CA Climate Action Plan. While statewide vulnerabilities are evident, measures addressing these appear to be carried out at a more localized level consistent with the assessments of Wilbanks, Leiby, et al. (2007) who observed that adaptation planning has a local, bottom-up emphasis.

What regional climate change mitigation and adaptation co-benefits are achieved in policies supporting ZNE in Sacramento?

For mitigation, greenhouse gas reduction was the primary indicator. Using population projections for the Sacramento region, GHG reductions are expected to become noticeable around 2030, and then rapidly increase toward the middle part of the century as increasing numbers of the region's housing stock become ZNE. At a local panning level ZNE is not explicitly addressed as a potential technology in the City of Sacramento's plan, but DER's and energy efficiency both components of ZNE are listed at potential solutions for GHG reduction and adaptation.

When it comes to adaptation, vulnerabilities to heat and flooding are the two greatest threats to energy supply in the Sacramento region. Extreme floods have a low probability but would be devastating beyond the just the electrical system. Heat increases have a greater likelihood and will reduce the efficiency of energy systems while increasing peak demand, especially during the summer. Wildfires and droughts will also have some direct impacts on transmission lines and hydropower production.

ZNE's primary function in addressing these impacts is to reduce the amount of power consumed by households during peak hours and also to help utilities balance loads from on-site energy being placed back onto the grid. The local utility in Sacramento has identified a gap between generation capacity and what will be needed by 2050, and ZNE buildings with their distributed energy components may have a role in filling this gap. Through projections of Sacramento's housing growth and what is currently known about the performance of ZNE buildings, it was demonstrated that ZNE could fill in the local utility's energy deficit by 280 GWh or 10.8% in 2030.

In households ZNE has the ability to decrease carbon footprints by eliminating the consumption of fossil fuel sourced energy and natural gas that are commonly found in standard homes. ZNE has a significantly smaller carbon footprint than the average household.

Two affordable, multi-unit ZNE-type projects are operating in the Sacramento region show that the projects are able to be incorporated into everyday types of housing. The lifestyles of occupants of these homes has a determining factor how much energy reduction and savings is capable within a ZNE home. Residents who diligently monitor their energy use reap the most cost savings, although energy bills in the Sacramento region are already among the lowest in the state. For vulnerable populations, including the elderly, the decreased cost of air conditioning through high efficiency appliances may assist with climate change adaptation at the household level.

What are the linkages between actors engaged in developing ZNE?

When looking at ZNE from a transitions perspective, ZNE is the byproduct of several technological innovations converging into a novel building typology. This is brought into production through a complex network of linked actors. Government agencies in California have grand visions for sustainability and addressing climate change, but implementation will rely on established industries adapting their business models and raising consumer awareness about the social and environmental benefits of low carbon housing.

The premise of co-benefits relies on the principle that single actions can fulfil two or more desired outcomes, resulting in win-win scenarios. But in the case of ZNE policy, there are not just single actions, but multiple actions occurring at different levels of governance that enable ZNE. Further, the ability to evaluate the effectiveness of ZNE mitigation and adaptation is made possible by established climate change plans at the state and local level that set targets for GHG reduction and have quantified the impacts of climate change on sectors. On a regional scale the comprehensiveness of climate change plans vary – larger cities and counties in California tend to have more complete assessments of GHG emissions and climate change vulnerabilities. Some cities and counties do not have well developed climate change plans, leaving room for improvement.

Next Steps

This research answers some questions, but raises some new questions that could be excellent for additional research.

> How much ZNE can utilities absorb into their operations per year to fulfil demand and legislative requirements while maintaining a profitable business model?
>
> What are the trade-offs or negative externalities that arise out of ZNE development?
>
> Could ZNE Action Plans be used in growing cities of developing countries to fill the gap between energy supply and demand brought on by urbanization and/or climate change?
>
> What impacts do retrofits of existing buildings to ZNE have on mitigation and adaptation?

When first reviewing some of the plans associated with DER and energy efficiency I was initially surprised by the lack of quantification backing up claims that proposed technologies could bring sustainability to cities. If greenhouse gas could be reduced by PV and battery storage systems, or there were household cost savings involved with energy efficiency, I wanted to know exactly how much would be reduced or saved. But in climate change planning there are many moving parts;

models are constantly being revised, technologies are updated, consumer behaviors fluctuating – and these dynamic variables create complexity in evaluating causation between the introduction of a new technology and meeting climate action targets. But the exercise of quantifying adaptation and mitigation for ZNE in this research, as broad as these estimations may be, have served the useful function of identifying some potential goal achievement at state, local and household levels. The calculations used to achieve these estimates can be refined in the future and expanded to include more variables as details emerge about the rate of ZNE adoption, the performance of DER equipment, and the ability of utilities to enact feed-in tariffs and absorb DER's into the grid.

As methods for quantifying the effectiveness of impacts of ZNE and other technologies improve, it is still advised in the meantime for cities and regions to include at a minimum DER, EE or ZNE ready buildings as strategies for sustainability in their housing and energy sectors. As one planner interviewee described to me, integrating sustainability into local planning is like a general doctor screening a patient, a handful of vitals are evaluated and if there are critical needs more detailed testing and prescriptions are considered. To take this further, climate adaptation and mitigation are two of the vitals that should be screened in an evaluation of any urban plan, DER's and EE are two practices that cities could recommended in their plans generally to keep GHG's and energy consumption in check. In the event that the screening reveals a city is particularly vulnerable to climate change impacts or polluting then more intensive forms of DER and EE can be evaluated for inclusion, like ZNE and microgrids. These require more testing, calculation, coordination with multiple actors to become feasible. Some of these remedies require experimental 'medicines' like lithium-ion battery storage that are expensive today but will become more affordable as more 'patients' adopt their use. Through these preventative measures state, city and regional governments can sustain the health of their populations and assets amid the vexing challenge of climate change.

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