Assessing the relationship between city growth and electricity use over time: A comparative analysis of Chandigarh and Seattle

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Abstract

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Urbanization in developing countries will be one of several global processes that define the 21st century. The ramifications of hundreds of millions of rural citizens transitioning to urban lifestyles are multifold and highly uncertain. The state of the global climate is one particularly dubious outcome of this process, due to the expected rises in energy consumption that accompany urbanization. Still, the subsequent socioenvironmental impacts of 21st century urbanization are reliant upon decisions made by planners and policy-makers at the local level regarding the characteristics of both growing cities and newly created ones.

This thesis attempts to engender a better understanding of the relationship between common characteristics of cities and their resulting energy consumption by comparing two cities from distinct contexts. I employ a longitudinal, mixed-methods approach to analyze data for Seattle in the United States and Chandigarh in India to discern similarities and differences between both cities regarding population size, density, urban form, electricity consumption, and climate over time. In contrast to a strictly quantitative approach, I employed a mixed method research design in order to take advantage of qualitative data obtained through field observations in both cities. The result is a thorough assessment of the relationship between city growth and energy use among two cities characterized by dissimilar geographical and socioeconomic settings.

The analysis and discussion yielded several notable findings. In both cities the residential sector is the predominant categorical user of electricity, though recent growth trajectories differ. The urbanization process that is currently occurring in Chandigarh appears quite unique compared to what has ever occurred in Seattle. Climate change will impact electricity use in each city but the outcomes will differ due to geographical differences. It is possible and useful to compared seemingly matchless cities, though there are numerous methodological impediments to such a process. These findings indicate the need for mixed method research approaches that bolster quantitative analysis and contribute to a unified science of urbanization.

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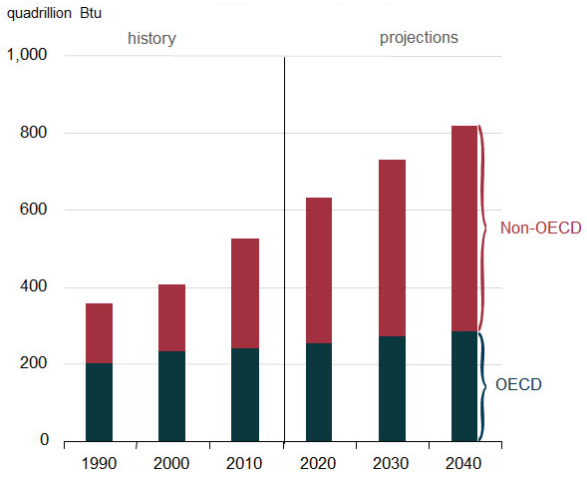
CHAPTER 1: INTRODUCTION

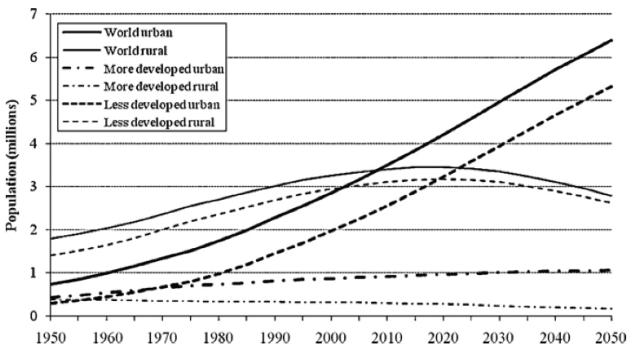
Urbanization in less develop countries (LDCs) will likely play an inordinate role in dictating the future state of global climate due to trends and projections for increased population growth and energy use in countries such as India and China. Non-OECD countries are expected to comprise the vast majority of global energy use (Fig. 1, IEA, 2013), while urban populations in the same group of countries are expected to proliferate (Fig. 2, UNDP, 2007). India will be a particularly integral actor in this process due to its large rural population and burgeoning economy. For example, the population of India without access to electricity, who live predominantly in rural areas, is greater than the total population of the United States (Wolfram et al., 2012). The latent energy demand of this rural population transitioning to more energy-intensive urban lifestyles is enormous. At the same time, around the world we see that the size and density of cities is increasing. In 1950 there was only one city in the world with over 10 million population and today there are more than twenty (Montgomery, 2010). As India and other LDCs continue to urbanize, planners and policymakers will be faced with myriad decisions regarding the size and density of both existing and newly created cities.

Fig. 1. World Energy Consumption, 1990-2040



Source: US EIA, 2013

Fig. 2. Global urban and rural growth



Source: Madlener, 2011

The size and density of cities is ostensibly relevant from an environmental perspective because of impacts on global climate change. City size influences energy consumption, thus contributing to global climate change and general environmental conditions.

> "If energy consumption of cities in Asia or Africa increases to the level of the energy consumption of Northern American cities under today's conditions (e.g. with regard to the fuel mix), an ecological collapse will inevitably be the consequences" (Mulligan, 2013).

At the same time, there is an ostensibly humanitarian importance attributed to the size of cities. As urbanization unfolds, city size will increasingly be connected to social equity and the plight of the urban poor.

> "We now face a very uncertain outcome where numerous megacities—each having more than 10 million residents—will increasingly dominate the global urban landscape and control the shape of international public and corporate relationships. Inside many of these megacities, especially in Asia and Africa, the living conditions for millions of inhabitants will continue to be very miserable by the standards of the more developed nations." (Ibid.)

Moreover, if energy demand in India follows previous patterns demonstrated by countries such as the U.S., then global temperatures may rise by more than 2° C, likely inducing a variety of significant global challenges (IEA, 2013). Therefore, the U.S. and other more developed countries (MDCs) have a stake in how India urbanizes because of the resulting challenges that they themselves may experience. For example, hydroelectric power generation in Washington State, which depends upon snowpack, may be impacted by energy use in India because greenhouse gas emitting coal power contributes to rising global temperatures. The corollary is decreased or altered snowpack, resulting in changes in river flow and hydroelectricity production (Hamlet, 2010). Although future energy demand is clearly in the hands of LDCs, the entire international community will feel the subsequent climate impacts, with certain places experiencing these consequences more severely than others.

Therefore, it is important for knowledge and experiences to be shared across borders. If urbanization is viewed as a chronological process, then the US, who is 80 percent urban,

is amongst a more mature stage of the process, while India, which is only 30 percent urban, may be just starting that process (United Nations, 2012). It has been theorized that urbanization in all cities follows an S or J shaped curve, where the growth of urban populations change at different rates over time (Mulligan, 2013). Based upon such theories, there may be ways in which cities in the US can provide insight or guidance into what is currently occurring in Indian cities.

My research question aims to explore challenges and opportunities in the energy-urbanization field by assessing the potential for comparison and knowledge transfer. I focus my research on two cities: Seattle, Washington and Chandigarh, India. Through comparing these cities I attempt to discover the following: 1) How can comparing cities contribute to a shared understanding of the relationship between city size and energy use amid a changing climate?, 2) Are there generic patterns that can be observed in seemingly dissimilar cities?, and 3) What methodological approaches are useful for developing a theory of all cities in space and time?

In order to investigate these questions, I hypothesize that as cities become bigger and warmer, their electricity use will rise as well. Moreover, I hypothesize that this relationship between city size, temperature, and electricity consumption over time in Seattle, Washington and Chandigarh, India is fundamentally different. I intend to shed light onto the evolution of urbanization and energy as a process by looking at two cities in different stages of development in order to help understand what may occur in India in the future.

Additionally, I hypothesize the existence of thresholds, where the impact of urban density and size eventually ceases to contribute to increased energy savings or efficiencies (Fig. 3). While larger, denser cities experience energy efficiencies for several reasons, I imagine that there may come a point when they experience diminishing returns as size and density continue to increase. This theory attempts to assess whether there may be an ideal range of city sizes in terms of energy efficiency. Previous research on urban metabolism uses a biological analogy to infer that larger urban agglomerations

are more efficient than smaller ones. However, I suspect that this analogy is insufficient and energy efficiency may decrease once a city becomes particularly immense.

I also expect to find a positive relationship between higher temperatures and increased electricity use because of the need for increased electricity to cool buildings as temperatures rise. In certain cases, if the fuel used to generate electricity contributes to a warming climate (ie fossil fuels), then the result may be a positive feedback loop, leading to exponential growth in electricity use and temperature (Fig. 4). Electricity generation and use begets higher temperatures due to climate change and high temperature begets increased electricity use needed to cool buildings. Yet, this relationship will likely be different in Seattle and Chandigarh because of differences in average temperatures between the two cities.

Fig. 3. Theoretical relationship between electricity use and population density

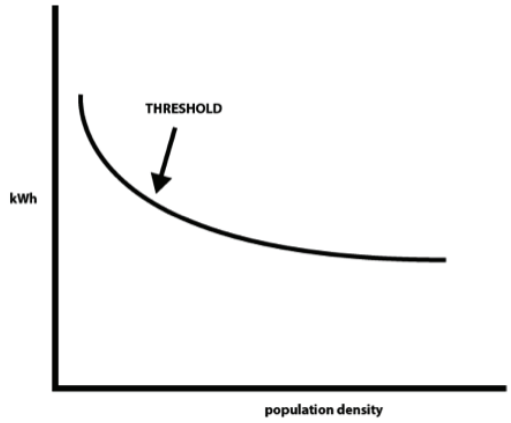
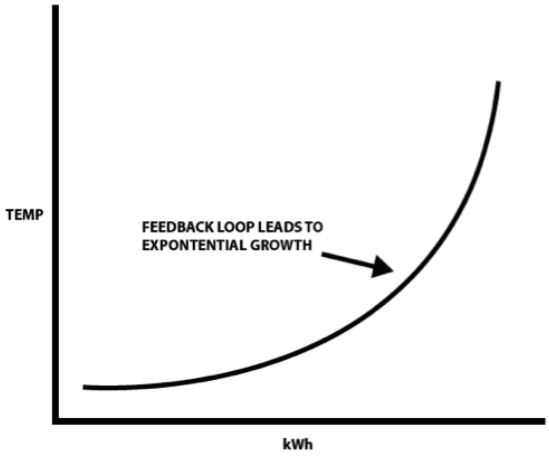


Fig. 4. Theoretical relationship between temperature and electricity use



In general, I expect to find both fundamental differences and similarities between the relationship between population growth and energy use in Chandigarh and Seattle. Even if I control for certain variables, such as income or energy supply, there are likely a range of other core differences between the two cities that will influence electricity usage in dissimilar ways. At the same time, I theorize that there may be aspects of electricity consumption that are similar between them, due to characteristics that are inherent to nearly all cities and urbanization processes. This last theory pertains to an ancillary purpose of this paper, which is to assist in the development of a science of cities, which coalesces the myriad processes and disciplines that comprise urbanization,

into a distinct theory and methodology (Solecki, 2013). While much recent research on this topic takes a quantitative approach, in this paper I use utilize a mixed methods approach, which presents quantitative data in conjuction with observations obtained from field research. The result is a more nuanced assessment of energy-growth patterns in each city, which benefits both theory and provides practical lessons for planners and policy makers. Assessing how cities have grown and used energy in the past will help us better understand what may occur in the future, as well as help guide planning decisions today. As global climate change and demographic growth unfold, such research is necessary to engender the development of cities that are sustainable in the most fundamental way; they consume energy resources in a manner that will allow future generations to do the same.

SUMMARY

Following the introduction, this paper has five parts. Chapter 2 provides a summary of previous literature on this subject. For instance, existing research generally indicates a negative relationship between population density and energy use but a positive relationship between total population and energy use. Additionally, as climate change unfolds, there are indications that higher temperatures may alter energy use in cities, with changes in the need for heating and cooling electricity in buildings. Chapter 3 outlines the methodology of this thesis, in which I employed a mixed methods approach, combining non-experimental and comparative research to test the hypotheses. More specifically, I take a case study approach to investigate the enumerated research questions. Methodologically, I first analyze energy-growth patterns over time in Chandigarh, India and Seattle, Washington separately and then compare the findings against each other. Chapter 4 presents an analysis of the data that were gathered. I utilize descriptive statistics to analyze both quantitative and qualitative data that I gathered from various governmental administrative bodies and acquired from other research resources. Chapter 5 discusses the analytical outcomes and places the results in relation to previous theory and literature. Chapter 6 concludes the paper by summarizing the key findings, limitations, and future research.

CHAPTER 2: LITERATURE REVIEW

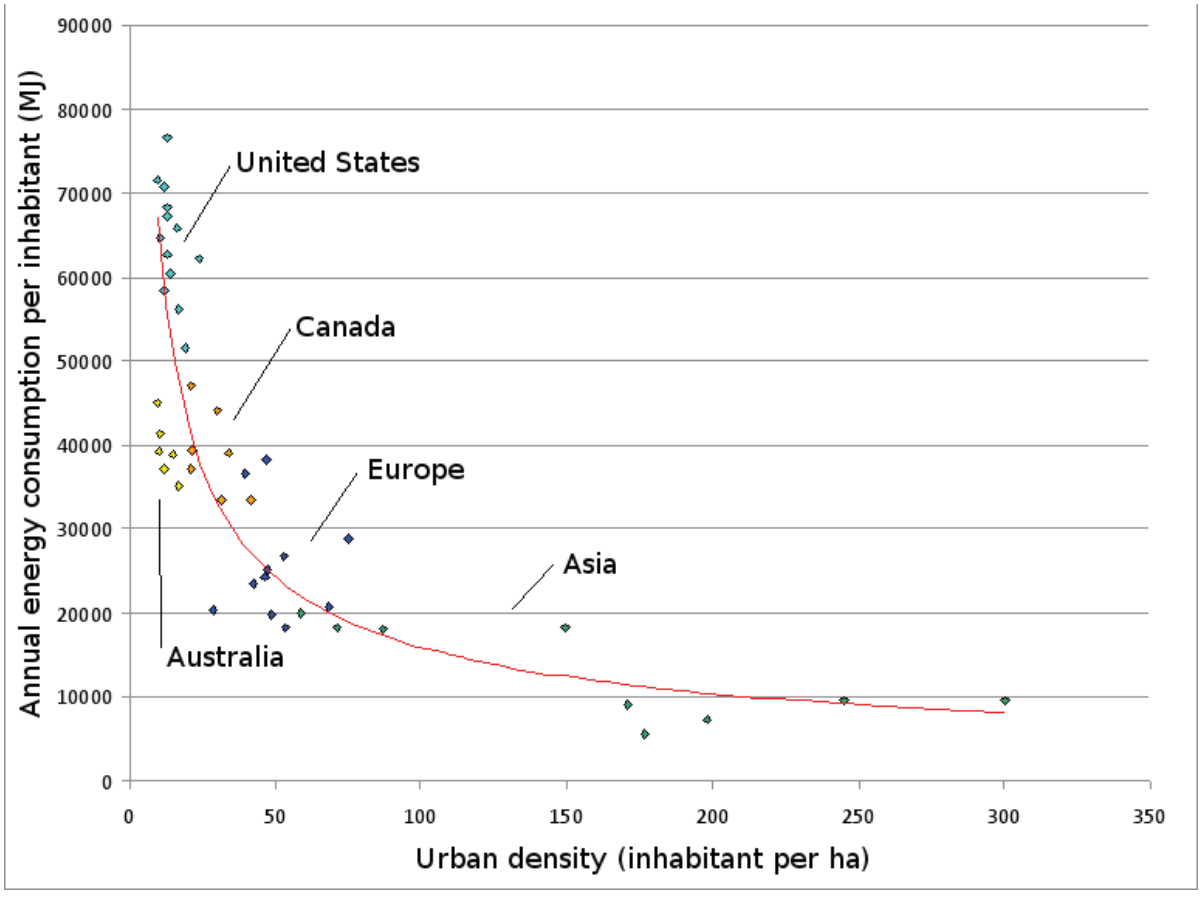
This chapter explores existing research on the relationship between energy use and city growth over time among cities of distinct origins. Subsections include density, urban form, access to electricity, economics, climate change, and urbanization science & evolution.

DENSITY & URBAN FORM

The initial challenge of assessing the relationship between city size and electricity consumption is deciding upon how to define density. There are a variety of density measures that are based upon the ratio of people to buildings, people to area, and buildings to area. Moreover, these definitions differ throughout the world. In terms of buildings, net density often includes only the parcel or excludes certain uses, while site coverage is simply the ratio of the building footprint to the total parcel area (Forsythe, 2003). Yet, due to differing definitions around the world, there is no consensus regarding the definition of net versus gross density (Cheng, 2009, Churchman, 1999). Another density measure is Floor Area Ratio (FAR), or plot ratio, which is defined as the built floor area on all floors in a building, divided by the plot area. FAR is often considered the most unambiguous measure of density (Forsyth, 2003). Others argue that we should examine spot densities rather than average densities to achieve a better understanding of how density is actually manifested at the street level (Churchman, 1999). In the US, low density is commonly characterized as 25-40 dwellings per hectre (DPH), medium density as 40-60 DPH, and high density as over 110 DPH (Cheng, 2009). In the US, urban is defined as census blocks that have population density of at least 100 people per square mile or surrounding census blocks with an overall density of at least 500 people per square mile (Young, 2012). It is also useful to understand the range of density levels currently present in regions around the world. At 439 people per square mile, the Netherlands is the most densely populated country in Europe (Churchman, 1999). Transit oriented development (TOD) has been defined as 44 DPH, with 62-123 units per hectare for up to three story apartment buildings (Churchman, 1999).

A plethora of studies have looked at the relationship between energy use and population growth over time by employing energy quite broadly and aggregating all fuel types into one variable (Al-mulali et al. 2013). Thus, these studies incorporate transportation energy use into their model and generally find a negative relationship between population density and energy use (Newman & Kenworthy, 1999). More people in a defined space leads to increased economic activity in those areas, thus reducing the distance and required energy for people to travel to work and for the exchange of goods. Increased density also increases the viability of mass transportation, which uses energy more efficiently than the personal automobile. For instance, population densities above 30 persons per hectare have been shown to increase the use of public transportation (Churchman, 1999). In sum, the rule of thumb is a negative relationship between density and energy consumption; as the quantity of people in a defined space increases, the total amount of energy consumed will decrease (Fig. 5).

Fig. 5. Density and energy consumption



Source: Newman and Kenworthy, 1999

The relationship between density and energy consumption becomes more complicated when energy is partitioned into different fuel types. For the purpose of this paper, electricity is the fuel type of interest. When electricity alone serves as a proxy for energy use, transportation becomes less influential in dictating the relationship between density and energy. Nonetheless, depending on the city, the public sector may consume significant electricity for mass transportation. For example, Seattle is in the process of expanding its' electric powered light rail system. Moreover, the use of electricity for transportation may be influenced by the adoption of electric automobiles, which are plugged in to the grid and draw power from residences, offices, or charging stations throughout a city. In sum, the established literature on the relationship between energy and density has been dominated by the incorporation of transportation energy use into theoretical models. When electricity consumption is isolated, transportation becomes less relevant, and several other variables become more important.

It is also important to consider that measurements of population density should not be viewed in a vacuum, but rather in relation to the relative size of a city. For instance, using CO2 emissions as a proxy for energy use, Fragkias et al. concluded that while emissions decrease with increased density, the benefit of added density is less important than the overall size of the metropolitan area (Fragkias et al., 2013). While only using a sample of cities in the United States, the corollary to that study's results is that large urban areas are only slightly more efficient than smaller ones. Another study indicates that high-density cities use less electricity per capita than low-density cities but with an important caveat (Lariviere & Lafrance, 2009). From a sample of Canadian cities, the authors found that if a city characterized by 1000 people/km2 increased its density to 3000 people/km2, then the electricity use per capita would only increase by 7%. Compared to the relationship between gasoline consumption and density, the savings or efficiencies from increase density on electricity use is relativel minor. Others have argued that sustainable development, which incorporates electricity use with several other variables, should include densities of 30-35 DPH. Steemers suggests that European cities have approached optimum levels of density because they have achieved

moderate energy use under moderate densities, while maintaining a high quality of life (Steemers, 2003).

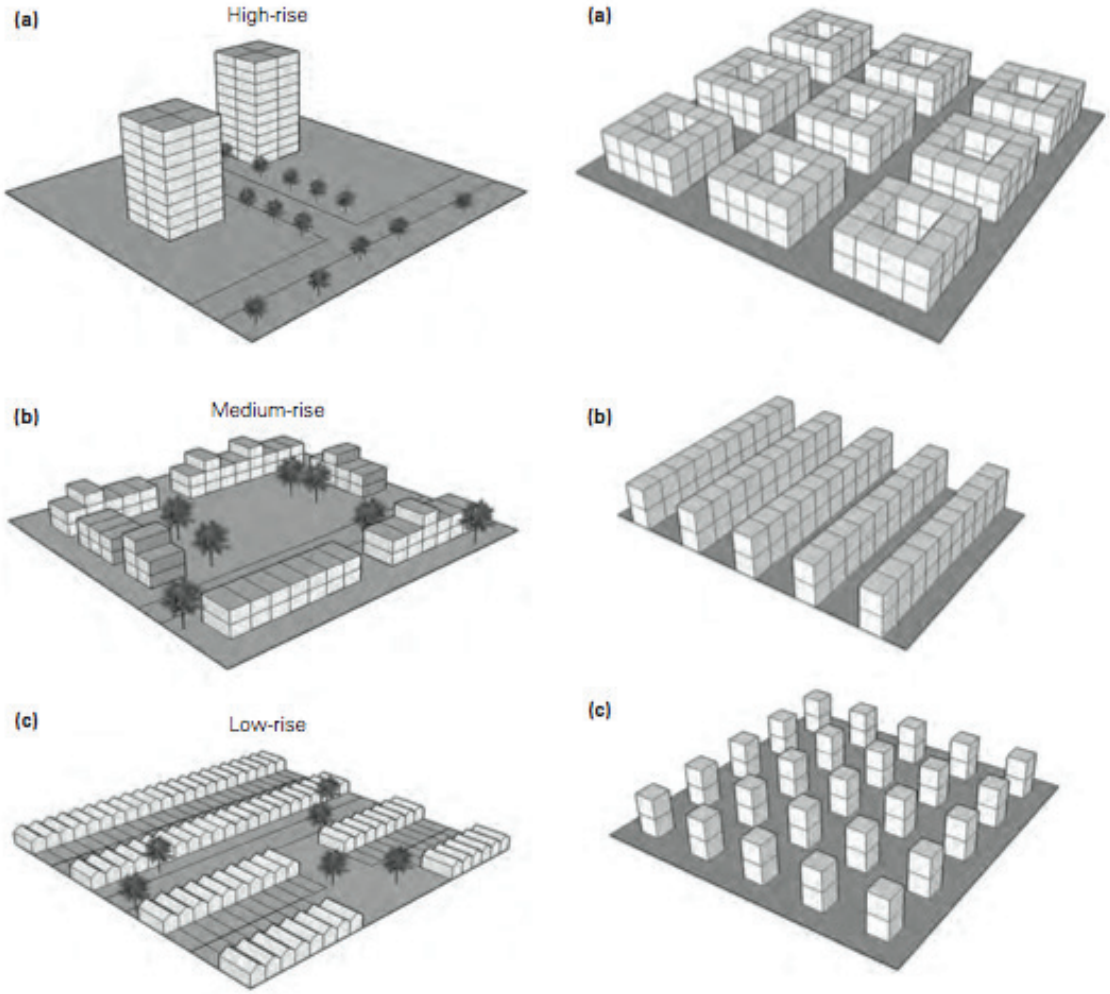
Buildings are the predominant users of municipal electricity use, but the general relationship between urban form and electricity use is complicated and equivocal. Residential buildings in particular are a predominant energy consumer, as they account on average for 30% of total energy use in countries around the world (Swan, 2008). Buildings designed at higher densities are generally associated with smaller residential areas, which reduces energy for heating and cooling. High density can also engender energy efficiency because it allows the sharing of resources (Steemers, 2003). For instance, shared walls in high rise buildings, compared to detached residences, reduce the amount of building heat loss and total energy consumption (Clarke, 2013). Moreoever, higher densities may also enable the viability of larger-scale energy efficient systems, such as combined heat and power systems (CHP) (Cheng, 2009). Yet, there is an indication that CHP is viable at densities ranging from 37-250 DPH, indicating a wider range of potential applications, depending on discount rates and energy prices (Churchman, 1999). Lastly, higher densities are also more economically profitable and this allows more money to be invested in using energy efficient building materials (Churchman, 1999).

Previous research also demonstrates the importance of urban geometry, where building overshading and solar gain can influence building energy use (Ratti, 2005). For instance, passive solar building design attempts to optimize solar gain by specified building siting, orientation, layout, and landscaping, in order to mitigate energy used for interior space heating and cooling (Madlener, 2011). Steemers cites a one third increase in heating energy for an urban house compared to a greenfield house when considering the potential for passive solar design (Steemers, 2003). Yet, achieving energy savings from passive solar design is challenged by higher urban densities, where high-rise buildings create shade and prevent solar gain (Ibid.). High-density also poses challenges to active solar demand, such as photovoltaics, which also relies upon solar access for energy production. Additionally, high building density may reduce

the available ground area for vegetation and trees, which help purify and cool urban areas, resulting in increased urban heat island effect (Ibid.). The urban heat island effect is a phenomenon in which areas with significant impervious surface land-cover absorb radiation from the sun, which increases the ambient temperature of those areas compared to adjacent areas (Young, 2012). The result is warmer urban temperatures, which influences energy consumption patterns.

Contrary to popular belief, urban density is not synonymous with high-rise skyscrapers because density can be manifested in a range of different urban forms. Depending on the arrangement of buildings and design of buildings, the same density can be achieved on the same area of land (Fig. 6, Cheng, 2009). Yet, there are likely population density

Fig. 6. Same Density in Different Urban Forms



Source: Cheng, 2009

thresholds, where at a certain level of population it may be impossible to arrange and design buildings in a way that enables energy efficiencies. Therefore, when assessing the relationship between population density and electricity use in different cities, it is useful to consider how each city's urban form may influence it's level of electricity consumption.

ACCESS TO ELECTRICITY

Intuitively, access to continuous and reliable energy supplies will impact city electricity consumption, regardless of the urban form. When supply infrastructure is inadequate, or when demand outpaces supply, shortages may occur, resulting in lower total electricity consumption. As cities get bigger, demand for electricity increases, yet total consumption will rise only if supply increases as well. For instance, In July 2012, two energy blackouts affected a large swath of northern India, including Chandigarh, leaving close to a billion people without power – the largest such occurrence in human history (ESI, 2013). Such events reflect burgeoning household electricity demand as more and more people move into cities. For India in particular, studies have looked at how individual household electricity demand is influenced by factors such as income, prices, household size and other household specific characteristics (Filippini & Pachauri, 2004). The results indicate that households living in larger Indian cities show significantly higher electricity consumption than those living in cities with less than 1 million inhabitants.

This finding suggests that larger cities are characterized by more developed markets and electricity infrastructure and have continuous access to electricity and other technology that increases household electricity consumption. Reliable electricity infrastructure in larger cities may influence electricity consumption, while illegal access to electricity in large cities may be relevant as well. Populations in informal settlements create illegal hookups to the electrical grid and influence electricity consumption while not being officially accounted for in population estimates. This occurrence is common in Indian cities, including Chandigarh.

ECONOMICS

The movement of people from rural to urban areas entails both a structural shift in the economy from low-energy intensity agriculture to high-energy intensity production of commodities, as well an increase in the consumption of energy intensive commercial products by rural-to-urban migrants (Madlener, 2011). Assessing the relationship between city size and energy use is difficult, partly due to the challenge of disentangling the relationship between energy use and economic growth. There are several prominent theories regarding the relationship between economic growth and energy use. The feedback hypothesis indicates biodirectional causality, where electricity consumption causes economic growth AND economic growth causes electricity consumption (Solarin, 2013). Conversely, the conservation hypothesis infers unidirectional causality from economic growth to energy use. Lastly, the neutrality hypothesis states no causality between the two variables whatsoever. (Cowan, 2014). In India in particular, Cowan found no causality in any direction between electricity consumption and economic growth, which may be a result of the countries unpredictable energy supply system (Ibid.).

More generally, the Environmental Kuznets Curve (EKC) can help shed light on the potential relationship between economic growth and environmental conditions (or energy efficiency) over time. Originally developed by Kuznets and Simon (1995), the EKC theorizes an inverted-U shaped relationship, where a country will initially industrialize and experience high levels of environmental degradation, followed by a sharp decrease in environmental harm as increased incomes raises environmental stewardship amongst the population (Ibid.). One argument embedded within the EKC theory is that economic growth fuels innovation in environmentally benign technologies, including those that increase the energy efficiency of cities. Though the EKC is generally interpreted at the country level and in relation to environmental pollution, it provides another theoretical framework in which to help assess the relationship between changes in energy use and economic growth over time. Additionally, the 'rebound effect' represents the theory that over time increased energy

efficiency may decrease the price of electricity, which will actually increase overall levels of consumption because people can afford to pay for more total electricity (Turner, 2013). Similar to the EKC, the rebound effect provides a useful economic theory in which to assess the determinants of urban electricity use over time and to help disentangle the impact of economics from other pertinent variables.

CLIMATE CHANGE

The Intergovernmental Panel on Climate Change (IPCC) recently released their Fifth Assessment Report on global climate change, indicating that global temperatures will continue to rise to levels that may disrupt human activities (IPPC, 2014). Rising temperatures may theoretical beget increased electricity consumption because of the need for additional air conditioning in buildings. Yet, at the same time, rising temperatures may decrease electricity consumption in locations that require significant indoor heating. Therefore, it is uncertain how exactly rising temperatures will generally impact electricity use in cities in general because of how variations in regional geography influence consumption patterns. For instance, cities in higher latitudes may consume more energy for heating buildings compared to cities in the tropics, which may allocate a greater proportion of electricity for air conditioning (Lankao, 2009).

Several studies have looked at climatic impacts on electricity use in diverse geogrpahical settings. For instance, there are indications that climate change may impact Seattle through increased average temperatures and extreme heat events, leading to increased energy demand for cooling (City of Seattle, 2014). In China, Asadoorian indicates a positive feedback between temperature and electricity demand (Asadoorian, 2008), while Considine developed a model in the US that suggested that warmer climate may slightly reduce energy demand (Considine, 2000). The high temperature, high electricity theory implies a feedback loop for countries in lower latitudes, where rising global temperatures due to climate change beget increased electricity requirements for air conditioning. If that air conditioning electricity is produced using fossil fuels then this will further increase temperatures and the result

will be a positive feedback loop where temperatures and electricity consumption rise exponentially.

URBANIZATION THEORY

In order to better understand the intricate relationship between energy use and urban growth over time, new theoretical and methodological approaches should be considered. For instance, there have been recent calls for a unified science of urbanization (Solecki, 2013). This science of cities, or urbanization science, would assess the possibility of identifying fundamental laws of the urbanization process, such as its origin, development, organization, emergent properties, and connections to other processes. An urbanization science may be comprised of at least three core components; 1) a framework that identifies the basic components of urbanization across cohorts of cities, 2) empirical evidence that supports urbanization as a unique system, and 3) demonstrated relationships between urbanization and other Earth systems (Ibid.).

The study of complexity and cities is one example of a recent contribution to an urbanization science. Complexity theory points to the potential existence of certain universal characteristics that can be applied generically to cities of all size, location, and stage of economic development. Central to complexity is the idea of emergence, where the interaction of myriad actors' actions produces singular utcomes that are distinct from the behavior of the individual actors (Samet, 2013). Scaling analysis has been of particular interest to those studying urbanization science. Scaling can be defined as how certain characteristics (eg electricity use) change in relation to the overall size of the system (eg urban population density). The presence of a scaling characteristic means that the relationship between several variables is the same over a wide range of system sizes, indicating potentially universal characteristics of cities. Several recent studies have indicated the existence of near universal relationships between city population size and other variables, such as innovation (Bettencourt et al., 2007). By looking at a large sample of cities, another study identified this scaling effect between population size and NO2 pollution (Lamsal et al., 2013). As population increases, NO2 pollution will

increase at the same rate, regardless of the context and location in which a city resides. Other research has indicated the existence of generic mechanisms and properties of city size and CO2 emissions (Fragkias, 2013).

Additional research has contributed to an urbanization science by comparing cities to biological systems. Urban metabolism is a widely used concept that theorizes how cities work as a system of inputs and outputs that are analogous to energy use in biological systems. In terms of efficiency, Klieber's Law states that larger animals consume proportionately less energy than smaller animals, inferring that they are more energy efficient (Fragkias, 2013). Therefore, if cities are characterized by a type of urban metabolism similar to what exists in the ecology, then larger cities may be more energy efficient than smaller cities. Using another biological analogue, the Allee Effect hypothesizes that increased population density infers increased fitness and therefore increased likelihood of survival (Kolbert, 2014). It is unclear whether this effect observed in biological systems can be applied to urban systems. Although there have been recent developments in urbanization science, more work is needed, especially on population scaling to assess whether larger cities are more or less efficient than smaller ones (Marcotullio, 2013).

Similiarly, adjacent research has focused on how cities change over time rather than on their characteristics at one point in time. The result is an attempt to discern how all cities may or may not conform to generic chronological growth patterns. Cities throughout the world are characterized by different sizes, which are the result of historical growth trajectories. Yet, it is possible that cities are characterized by generic evolutionary mechanisms and should be viewed as objects evolving within systems over time (Swerts, 2014). Based upon this theory, we can identify trajectories of population growth in cities. Northam first suggested a theory of urbanization evolution in the form of an S-shaped curve with three chronological stages of urban population growth: 1) initial, 2) acceleration, and 3) terminal (Mulligan, 2013). Traditional stage theory of economic growth helps to explain the characteristics of the urbanization curve. Initially, primary economic activities are dominant and urbanization is slow. Urbanization then

accelerates as industrialization occurs. During this expansionary second phase, there is an exodus of people from rural to urban, which creates an inital concentration in city population. Finally, urbanization slows as an economy is characterized by tertiary economic activities such as personal services. This last stage may be characterized by suburbanization (Samet, 2013).

It is generally understood that cities within the same urban system follow similiar patterns of growth, but the similarities between the growth patterns of cities among different urban systems is less certain. Over time, cities are generally understood to grow from the bottom up, with their first and second 'natures' determining the extent of development at a particular location (Samet, 2013). Such bottom up growth occurs relatively randomly, in constrast to to being the outcome of direct government intervention. This first nature includes geographical variables, such as navigable rivers or useful natural resources, which enables an initial settlement. A city's subsequent development is then dependent on second natures, which includes implementation of technology for a variety of basic purposes including infrastructure, defense, and communication. Institutions will alter the the evolutionary trajectory of a growing city unit through designed interventions, interrupting the random components that propel city growth (Ibid.)

Similar to historic patterns of urbanization, there are patterns of electricity consumption that we can observe over time. Parikh notes that residential electrification today is proceeding much more rapidly than it did in the past within earlier industrialized economies, resulting in presently exaggerated demands for electricity (Parikh, 1995). At the same time, the author intimates that new technologies are arising today, not available to the initially industrialized nations, which may help accommodate rapidly increasing present energy demands. Given the uncertainty of myriad variables that impact changes in electricity consumption, predicting future patterns is problematic.

SUMMARY

TOPIC	AUTHOR	KEY CONCEPTS
Economic growth	(Cowan) (Solarin) (Turner)	EKC, Rebound Effect, directionality of causality
Climate	(Asadoorian) (Considine) (Paul) (Hamlet)	Geographical impacts on electricity consumption
Energy Use	(Newman & Kenworthy) (Al-mulali) (Churchman) (Madlener)	Negative relationship between density and energy use
Density	(Cheng) (Steemers) (Churchman) (Forsyth) (Laviere & Lafrance)	Net vs. gross density, problem of comparison, Density in relation to total size
Urban form	(Clarke) (Ratti) (Steemers) (Cheng)	Density in multiple forms, overshading, solar gain
Science of cities	(Bettencourt) (Fragkias) (Solecki) (Lamsal) (Fragkias) (Mulligan) (Samet)	Complexity, urbanization science, scaling, urban metabolism, urbanization curve

CHAPTER 3: METHODOLOGY

This chapter describes the methodology I employed for investigating the manner in which city size and energy use change over time. The research design is a mixed methods approach and employs comparative case study analysis with descriptive statistics. Broadly, the research design is structured to first assess the relationship between several chosen variables in two case study cities separately and then compare the results against each other. The result is an assessment of the similarities and difference that may exist between the two cities.

CASE STUDIES

My research design is structured around case studies of one city in the United States (Seattle) and one city in India (Chandigarh). These cities were chosen due to convenience, familiarity, and access to data. Because I work and study in Seattle, I have insights and access to data that does not apply to other cities in the US. I chose Chandigarh because I had the opportunity to reside there during a three-month study program in the winter of 2014. As a result, I had a unique opportunity to pursue the collection of otherwise inaccessible data and was able to draw insights through field observation that would not be possible remotely.

The methodology employs case study comparison, rather than experimentation, as the principal method of theory testing. Comparative analysis juxtaposes geopolitical entities to assist in testing hypotheses or revealing similarities and differences between different systems. Although experimentation may be possible in limited circumstances within urbanization science, it is usually impractical because it requires establishing a control and experimental groups (Peters, 1998). For instance, it would be practically impossible to observe two identical cities and perform an intervention on one while holding the other constant. Rather, comparison is used because urbanization is a process that requires descriptive richness, within complex and often unplanned settings (Peters, 1998). Comparative case study analysis is useful because it espouses specification

over generalization. When attempting to identify universal characteristics between outwardly unique cities, comparison is a useful first step. Once initial theories are tested through comparative case study, the sample can be expanded to include more cities and more reliable conclusions may be drawn.

VARIABLES

The fundamental concepts of my research design are energy use, population growth, and climate change, measured over time. I have chosen several variables to represent these concepts. Population growth is represented by population density, climate change is represented by temperature, and energy is represented by electricity use. Additionally, I included income as a control variable because of the previously discussed relationship between energy and economic growth.

I chose these variables for several reasons. Population density and size helps assess the intensity of urbanization in a particular city. As the movement of people from rural to urban areas increases, the number of people per area in cities increases, as does the absolute quantity of people. In this context, population density is measured by the total population divided by the total area of a city. Population is defined as the number of people who permanently reside within the urban boundaries, which are specifically defined through census estimates.

I have chosen electricity to represent energy because of its relevance to both urbanization and climate change. Electricity is an essential factor in practically all aspects of life and will continue to be so far into the future. While society may develop substitutes for oil, there is no substitute for electricity. Moreover, electricity is a key instigator of climate change, as power generation accounts for the highest proportion of global greenhouse gas emissions out of all energy sectors (Montgomery, 2010).

I have chosen temperature because it is often referenced as a proxy for climate change and because of its relevance to the amount of electricity needed for heating and cooling

buildings. Additionally, I have hypothesized an important potential feedback loop, where the generation of electricity with fossil fuels increases global temperatures, leading to an increased or decreased electricity use needed for heating and cooling.

In one sense, population density is disproportionately related to residential electricity use because it pertains to the concentration of people living in some form of residential buildings. Conversely, commercial and industrial electricity consumption may be influenced by people who commute from adjacent cities and who do not live within the city in which I am comparing it's population density. Though this may be partly true, the concentration of population in a city will still influence other sectors of electricity consumption in various ways. For instance, the concentration of people, and their associated consumer activates, may influence the number of commercial businesses in a certain area, resulting in increased commercial electricity use. Moreover, industrial sectors may congregate near concentrations of people because they provide employment, resulting in relationships between industrial electricity consumption and population density. Although the relationship between residential electricity use and population density may be more direct, there clearly exists spatial relationships with other sectors of electricity use that justify using aggregate electricity consumption measures.

Y= per capita electricity consumption (sum of industrial, commercial, residential, & miscellaneous electricity use/total population)
X1= population density (pop/km2)
X2= total population
X3= average annual high and low maximum and minimum temperatures
X4= per capita income (total income/total population)

CHANDIGARH DATA

I collected data in India through personal requests from local administrative agencies, by using research libraries, and utilizing some existing online data sources. The

most extensive component of my data gathering process involved visiting various governmental departments in Chandigarh. Through roughly a dozen separate visits, I attempted to acquire data from the following agencies:

- Chandigarh Department of Town Planning, UT Secretariat, Sector 9, Chandigarh
- Chandigarh Electricity Department, UT Secretariat, Sector 9, Chandigarh
- Chandigarh Department of Environment, Paryavaran Bhawan (3rd Floor). ,Sector 19-B, Chandigarh
- Government of India, Regional Census Office, Janganana Bhawan,Plot No.2-B Sector-19-A, Madhya Marg, Chandigarh
- Chandigarh Renewable Energy and Science & Technology Promotion Society (CREST), 1st Floor, Paryavaran Bhawan Madhya Marg, Sector 19 B. Chandigarh
- Chandigarh Meteorological Centre, Sector-39, Chandigarh
- Directorate of Economics and Statistics, UT Chandigarh, UT Secretariat, Sector 9, Chandigarh

In addition to government agencies, I also utilized several research libraries to collect data. They included the following:

- Panjab University, Geography Department Library, Sector 14, Chandigarh
- Chandigarh College of Architecture Library, Vidya Path, Sector 12 D, Chandigarh
- The Energy & Resources Institute (TERI) Research Library, India Habitat Centre, Lodhi Road, New Delhi

Through these resources I was able to develop an original dataset, containing both quantitative and qualitative data, which is the aggregation of bits and pieces of data that I gathered from myriad different administrative bodies, research resources, as well as my field observations.

Quantitative Data:

- annual per capita electricity use, 1985-2011

- total electricity use, 2006-2011
- electricity use per consumption sector, 1967-2006
- annual per capita income, 1992-2012
- total decadal population 1900-2010
- total average decadal population density , 1961-2011
- annual monthly high and low maximum/minimum temperature 1982-2009
- GIS data; shapefile of city administrative boundary

Qualitative Data:

I developed field observations during my 3 months living in Chandigarh, in which I took notes and pictures of my surroundings as I traversed the city. For example, I kept a running list of observations regarding what may impact residential electricity use in Chandigarh. I also obtained anecdotal information from administration officials in various city departments as I collected data. I also referenced maps showing sectoral population density levels provided through census data and I identified sectors that represented a diverse range of high, mid, and low densities. I then visited each sector, taking pictures, notes, and observing the urban form.

SEATTLE DATA

Compared to my experience collecting data in Chandigarh, acquiring data in Seattle was straightforward and involved brief online searches and several visits to local governmental offices. I acquired electricity data from Seattle City Light, which is the public utility serving the Seattle area. Other data, such as population and economics, was acquired via existing online sources.

- Seattle City Light, 700 5th Avenue, Suite 3200, Seattle, WA
- Washington State Geospatial Data Archive (WAGDA)
- U.S. Census
- University of Washington Libraries

- Weather Underground

Quantitative Data:

- total annual electricity use (residential & non-residential), 1982-2012
- total decadal population 1900-2010
- total decadal average population density, 1900-2010
- annual monthly high and low maximum/minimum temperature 1982-2009
- GIS data; shapefile of city administrative boundary

Qualitative Data:

For Seattle, I leveraged my experience living and studying urban planning within the city for several years to develop a collection of observations and anecdotal evidence regarding population and electricity use.

ANALYTIC PLAN

My analytic plan employed descriptive statistical analysis of quantitative data and interpretation of qualitative observations for each case study city individually.
To analyze the quantitative dataset, I used the computing software R to carry out univariate and bivariate descriptive statistics to summarize basic patterns among variables over time. Scatter plots are used to discern associations between variables, such as whether the relationship between variables is generally positive or negative. These results helped shed light on my research questions and inform future statistical analysis that should unfold.

In addition, I organized my qualitative observations, in conjunction with additional research, to identify important characteristics that may influence variable outcomes in each city. For instance, I summarized my observations on residential electricity use, such as the type of common household appliances in Chandigarh. I also used

geographic information systems to present certain aspects of the dataset, such as sectoral population density, in a visual format that assists in assessing trends over time. Both my qualitative observations and GIS analysis help to bolster the quantitative statistical aspect of my analytic plan and create a comprehensive analysis of the dataset I developed.

I utilized the aforementioned techniques to analyze Seattle and Chandigarh separately and then compared the results of both analyses against each other. The comparative aspect of the analytic plan also used descriptive statistics to begin to investigate relationships between the variables of both cities. Furthermore, I created an evaluation matrix that juxtaposes the qualitative observations of each city, which leads into the subsequent discussion chapter.

SUMMARY

This chapter outlined the methodology approach I employed for assessing the interplay between energy and growth in Chandigarh and Seattle. In this chapter, I outlined the case study structure of my methodology, enumerated the chosen variables, explained the data I collected in both cities, and described my analytic plan.

CHAPTER 4: ANALYSIS

In this chapter I present an analysis of the data that I gathered for Chandigarh and Seattle, which includes quantitative and qualitative data, backed by additional research. I analyze both case study cities separately and then compare the results between the two. The analysis subsections include context, history, population, electricity use, land use, density, urban form, and climate.

CASE STUDY #1: CHANDIGARH

Chandigarh is a city in northwest India that is encompassed within the Chandigarh Union Territory and lies adjacent to the states of Punjab and Haryana (Fig. 7). It was the first large-scale planned city in India and today maintains a population of just around one million citizens.

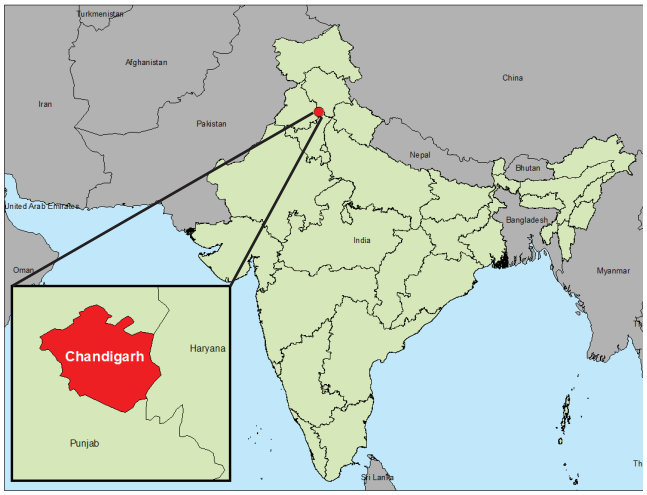


Fig. 7. Context Map of Chandigarh

HISTORY

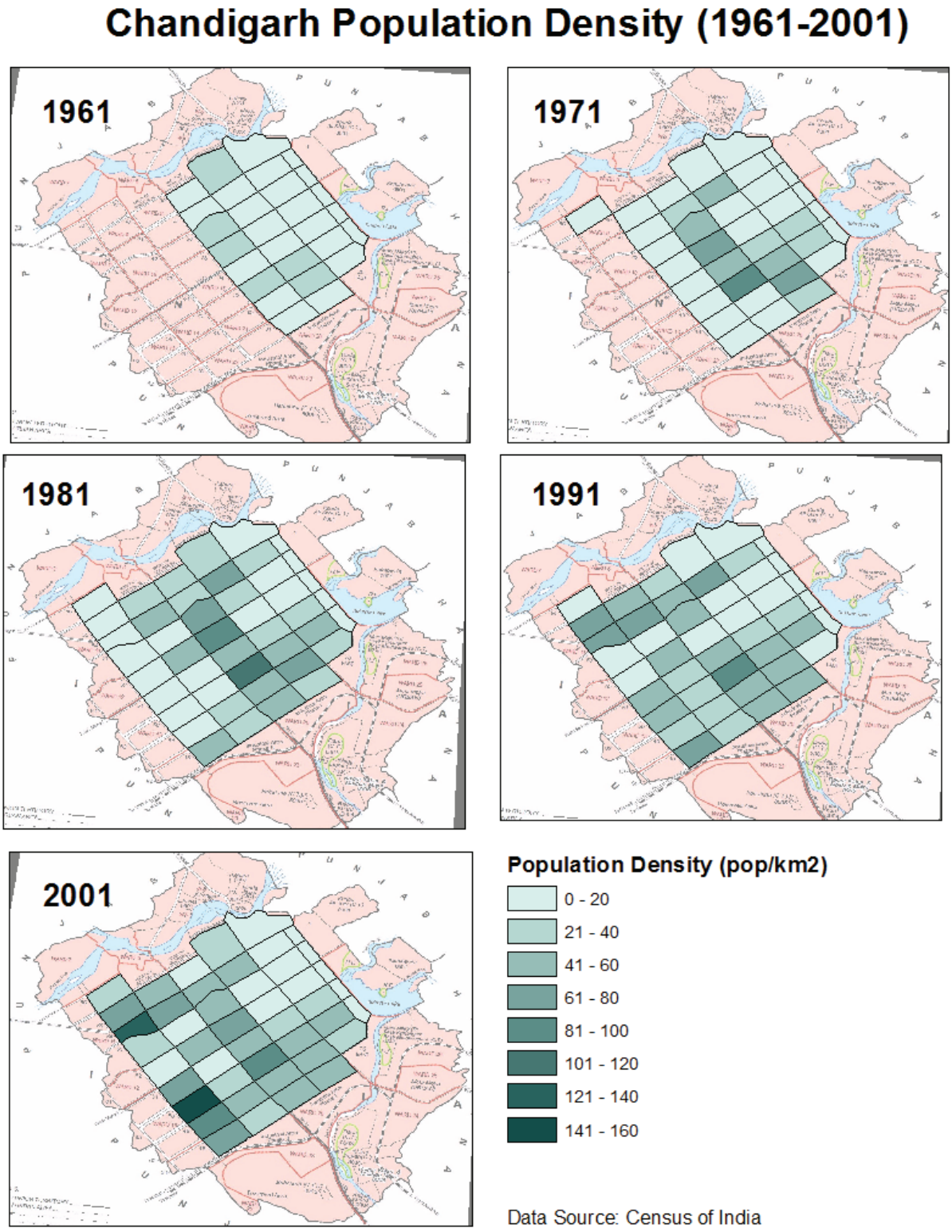
Chandigarh was conceived in the wake Indian independence in 1947 from Great Britain, where British India was divided into modern day India and Pakistan. As a result, the capital city of British Punjab – Lahore – was absorbed by Pakistan, leaving the modern Punjab Indian state without a capital city. India's first Primate Minister, Jawaharlal Nehru decided to create Chandigarh as a replacement for the previous capital city. The initial master plans of Chandigarh were developed by an American team of planners, but the ultimate planning and design process was carried out by French architect Le Corbusier. The design principles were complex and represented a variety of post-colonial influences, including the politics around the India-Pakistan partition, and "Nehruvian quasi-socialist nation-state ideologies, aspirations of modernity, and the convergence of western-eastern planning paradigms" (Chalana, 2013).

PLANNING, GROWTH, & DENSITY

Chandigarh was planned according to sectors, which are sub-city district or neighborhood units (Vimal, 1994). The original plan was for a population of 500,000 to be accommodated in two phases of development, where sectors 1-30 would first house 150,000 people, followed by 17 higher density sectors housing 350,000 people. Many viewed the planned population of 500,000 as an exaggerated sum because the city was brand new and its level of attractiveness to urban migrants was highly uncertain. At first, population growth was slow for several reasons including slow supply of building materials, poor transport links, and insufficient funds from the national government. But soon after its establishment it began growing at a faster rate than almost any city in India. This was the result the reorganization of Punjab in 1966, which established Chandigarh as the joint capital of the states of Punjab, Haryana, and of its own Union Territory. The upshot was an influx of governmental offices and their associated employees.

Although planned as predominantly high density, the city developed into one that is predominantly low density, based upon Indian standards (Fig. 8). The ratio of low density to high density sectors was planned as 2:3 but became manifested as 3:2. Population in each sector increased from 1961 to 1981 but then an array of sectors actual loss population during the 1980s (Ibid.). This evolution of growth could be explained by several factors. The first phase of development was occupied by groups of families but as the families aged, the younger members formed families and moved outside of phase one because there was not available housing. Additionally, some of the initial sectors consisted of rental housing. As land values increased over time, higher rents created pressures that pushed these renters out of these areas. By 1981 a variety of informal homes and settlements had become established. Eventually these populations were removed and reestablished in the peripheral villages. During the 1980s, the urban portion of Chandigarh UT grew at a rate of 36.2 percent while the rural portion increased by 130.1 percent (Ibid.). Immigrants to Chandigarh were unable to settle in the central sectors due to increasingly high land values and therefore settled in the

Fig. 8. Chandigarh Sectoral Population Density (1961-2001)



surrounding villages. Except for the city center, the major areas for employment are easily accessible from the periphery. For instance, the Capitol Complex is easily accessed by the northern villages of Khuda Ali Sher, Kansal, and Kaimbwala. In the far west portion of the city the universities provide significant employment and the industrial area provides employment in the southeast of the city. In sum, the city grew at a much faster initial rate than planned, but has recently slowed, as land values reached a high level, thus deterring increased growth.

Both population density and total population in Chandigarh show a similar trend of steady increase over time. In the first half of the twentieth century Chandigarh consisted of several small villages with a small, constant population. This changed when Chandigarh was designated an administrative city and officially planned, where the population immediately skyrocketed, and has experienced steady growth ever since. (Fig. 9). While population density was increasing at a very high rate in the first couple of decades after the city was founded, this decadal growth has slowed in recent decades and between 2000 and 2010, overall population density actually declined (Fig. 10). Similarly, decadal growth in total population spiked immediately after incorporation and has gradually decreased on a decadal basis ever since. Since the city was officially established, average decadal growth in total population has been 58 percent with a standard deviation of 38 percent. Average growth in population density during this time was 30 percent with a standard deviation of 22 percent.

Fig. 9. Chandigarh Total Population (1990-2010)

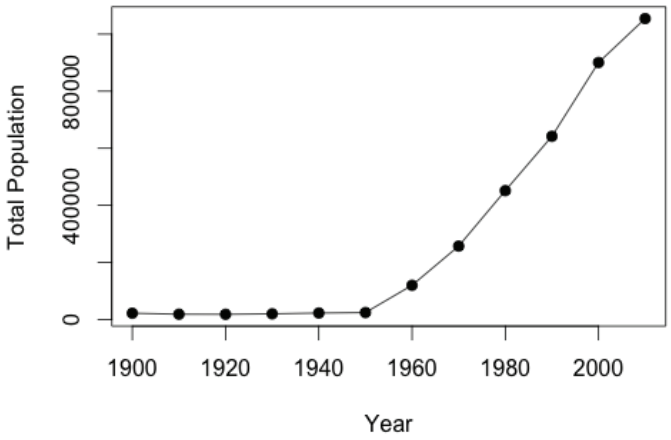
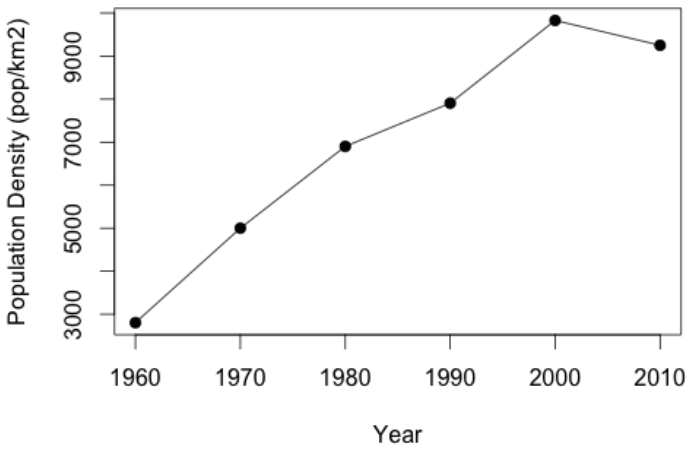


Fig. 10. Chandigarh Population Density (1960-



ELECTRICITY CONSUMPTION

The available data shows that annual electricity use in Chandigarh has been generally increasing over the past several decades. Both total electricity consumption and per capita electricity consumption demonstrates an increasing trend. Between 1967 and 2012, per capita electricity consumption in Chandigarh rose slowly for several decades with little fluctuation but then demonstrated some volatility from the mid 2000s to present (Fig. 11). Accordingly, year to year growth in per capita electricity consumption has been relatively static, although in the past decade there have been several large spikes. Average annual growth in per capita electricity use during the sample timeframe was 8.4 percent, with the lowest growth at -40.9% from 03-04 to 04-05 and the highest at 131.5% from 02-03 to 03-04. We can also see that total electricity consumption decreased from 2005 to 2006 but has been increasing since that time (Fig. 12).

Fig. 11. Chandigarh Per Capita Electricity Use

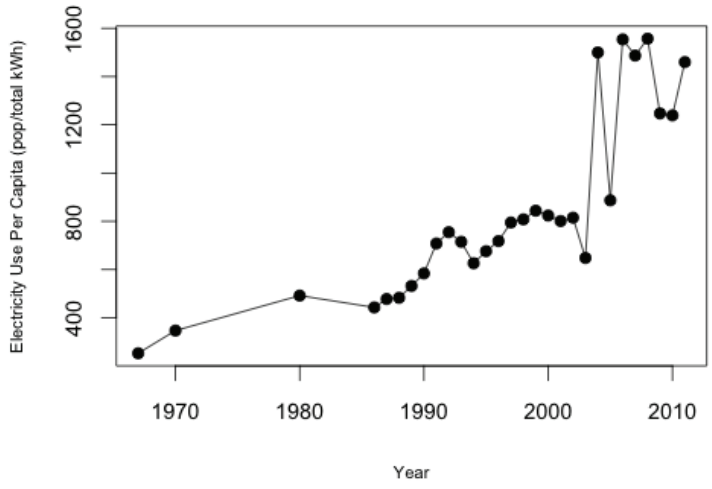
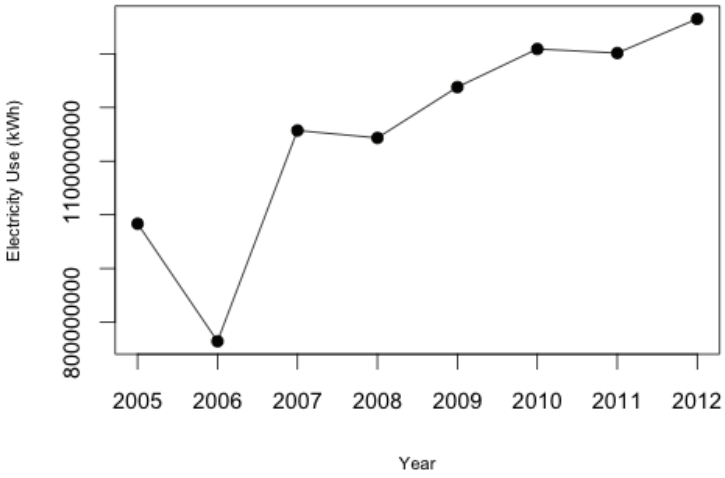


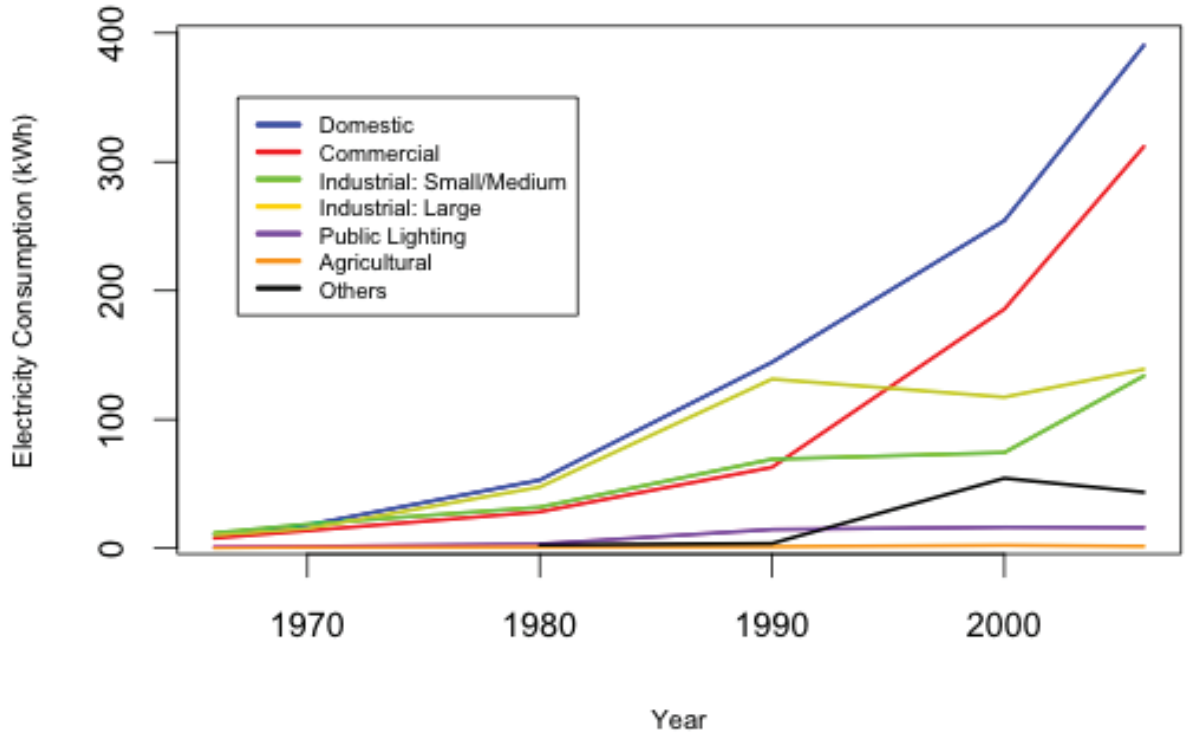
Fig. 12. Chandigarh Total Electricity Use



Breaking total electricity into sectoral categories over time enables additional observations. Between 1966 and 2006, the domestic and commercial sectors surpassed the industrial sector as the predominant users of electricity (Fig. 13). During this time the share of total consumption in the domestic and commercial sectors grew by 10 percent while the share of industrial sectors decreased by roughly 10 percent. In recent decades, the domestic and commercial sectors have been growing at the fastest rate and continue to dictate

total consumption levels.

Fig. 13. Chandigarh Total Electricity Use by Sector



INFRASTRUCTURE

In 1967, after the reorganization of the state of Punjab, the Chandigarh administration retained full responsibility of electricity distribution, which was previously the responsibility of the Punjab State Energy Board (PSEB) (CMP, 2013). Today, Chandigarh manages distribution but has no electricity generating sources of its own and relies upon neighboring states for power supplies. Unlike many cities in India, Chandigarh is characterized by ubiquitous access to electricity, with 90 percent of households having electricity. In the face of increasing energy demand over time, Chandigarh has been working to expand its power infrastructure. Total transformation capacity has increased from 15.6 MVA in 1967 to 646 MVA at present. The city currently maintains one 220 KV substation, thirteen 66 KV substations, five 33 KV substations, and eighteen hundred 11 KV indoor or pole mounted substations (Ibid.). The number of electricity consumers

has grown by 100,000, from under 30,0000 in 1967, while the peak power demand has grown from 14 MW to 350 MW in 2012.

Chandigarh is currently developing renewable energy infrastructure to help meet growing demand in a more sustainable manner. Chandigarh has established a goal to install rooftop solar photovoltaics at a capacity of 2.5 MW within 3 years and 10 MW within 10 years (TERI, 2009). The administration has begun installing over 2 MW of power on government land and buildings across the city, as well as investing in energy efficient building retrofits. Furthermore, there is a current proposal in the pipeline for a 25 MW solar power plant located on the edge of the city. Today Chandigarh has approximately 97 biogas plants, 275 residential solar PV systems, and 1529 domestic solar cookers (ibid.) While infrastructure has clearly been improving over time, I observed numerous inefficiencies that may influence levels of present day electricity

Fig. 15. Makeshift electricity connections

Fig. 14. Daytime streetlights

Fig. 16. Electricity Distribution

consumption and which likely influenced historic consumption. For instance, I observed entire rows of streetlights that were illuminated during the daytime (Fig. 14). In addition, makeshift electrical connections into residences and businesses are common (Fig. 15).

LAND USE

The original plan of Chandigarh consisting of a plethora of greenspaces, wide arterials, and large chunks of residential neighborhoods. Accordingly, the current existing land uses are residential (28%), circulation (23%), and open space (18%) (Fig. 17). Although the land use composition has changed over time, as

Fig. 17. Chandigarh Land Use Composition (2000)

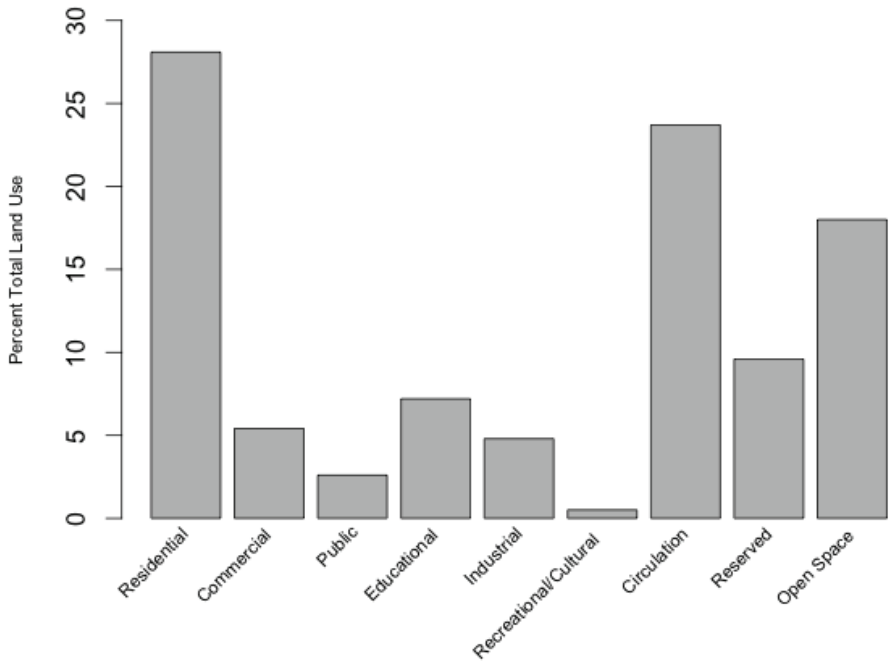


Fig. 18. Greenbelt in Chandigarh

Fig. 19. Chandigarh Open Space Map

Source: Chandigarh Master Plan 2013

commercial and industrial uses have developed, certain uses, such as open space and residential areas have remained relatively unchanged. Yet, based upon observations on the ground, the exact land use composition should not be trusted absolutely. For example, some of the open space is appropriated by the informal sector, as people use greenspaces to erect makeshift homes, as well as conduct commercial activities, such as selling fruit or ironing clothes.

HOUSEHOLD BEHAVIOR

As economic growth fuels increases in personal income for the residents of Chandigarh, electricity consumption of the residential sector will continue to grow, as people are

able to purchase energy intensive household appliances. Per capita income levels in Chandigarh have been steadily growing over the past 20 years, although the growth of income has been slowing in recent years. (Fig. 20). Still, residences in Chandigarh generally maintain relatively few energy-intensive electrical appliances and use many alternative methods for daily activities. For instance, household clothes drying machines are rare because sun drying clothes on laundry lines and balconies is the standard practice in homes (Fig. 22). The vast majority of households in Chandigarh, including the most wealthy, do not have household appliances that are common to Seattle. Rather, households hire multiple domestic workers to manually perform duties that are accomplished by electrical appliances in Seattle. Hired workers manually wash dishes and dry clothes, compared to Seattle, where dishwashers and laundry machines perform those same duties. If a standard dishwasher, washing machine, and clothes dryer demand 4500 watts of electricity combined and are running for one hour per day, they will use 1642.5 kWh annually. This is one reasons why residential electricity use is likely greater in Seattle than Chandigarh. It is uncertain whether hired help is more economical than purchasing electrical appaliances or that it is a cultural practice embedded into Indian society for a variety of other reasons.

Fig. 20. Chandigarh Per Capita Income (1994-2011)

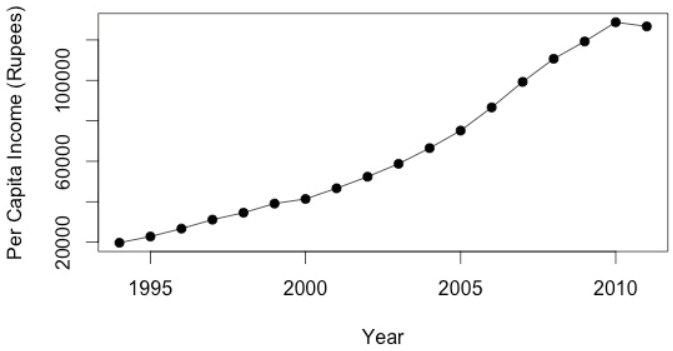


Fig. 21. Residential celebration

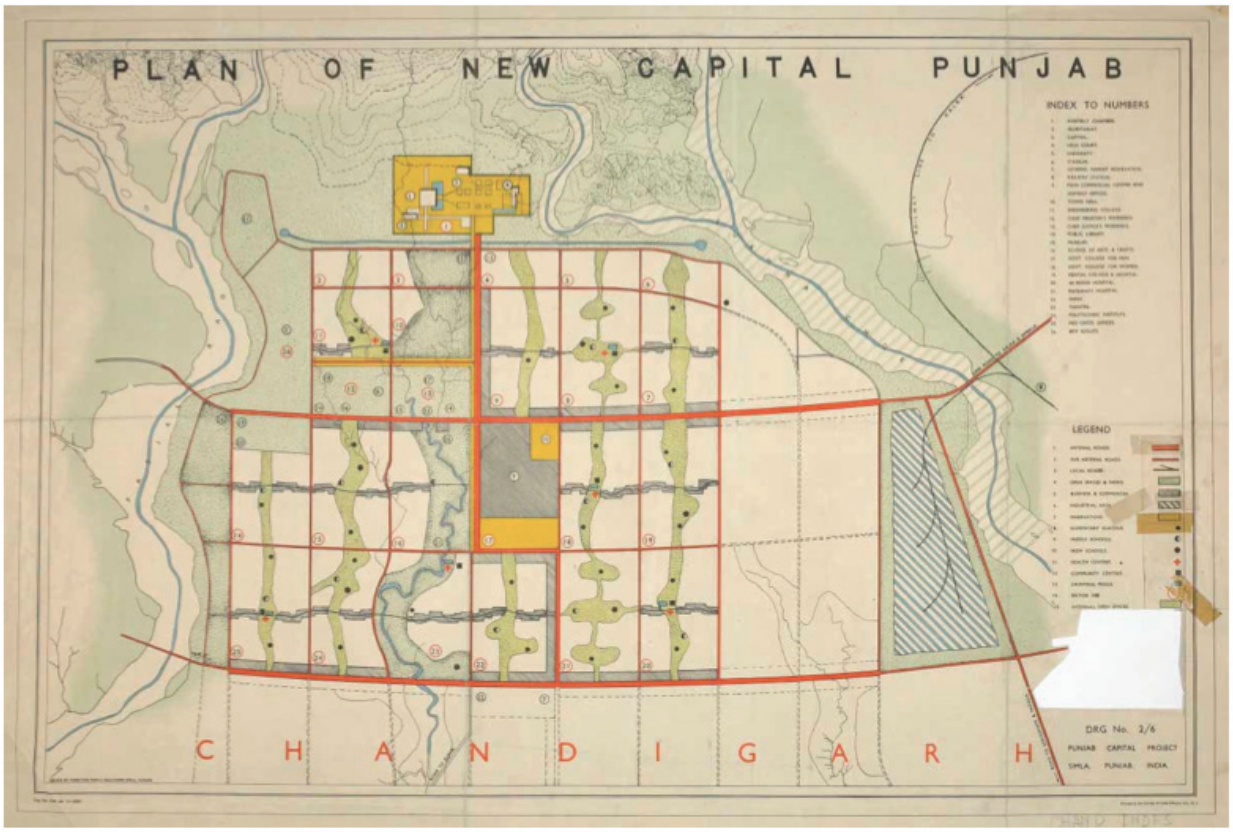
Fig. 22. Residential clothes drying

Dishwashing machines are also seemingly rare, with manual washing being the standard practice. While residential electricity use is predominantly modest, compared to Seattle, there are intermittent electricity binges for weddings and holidays, in which buildings are extravagantly furnished with hanging lights (Fig. 21). The continued use of traditional fuels for heating and cooking also assists in dampening electricity demand. These are mostly common in less wealthy households, who rely more on organic matter for fuel.

URBAN FORM

The original city design of Chandigarh was a collection of superblock, neighborhood units in a grid format, connected by wide arterial roads, and interspersed with ample greenbelts (CMP, 2013). The design also reflected the personality and modernist influence of Le Corbusier, with an emphasis on modular, geometric patterns (Fig. 23). Most sectors were planned at 800 m by 1200, which envisaged a 10 min maximum

Fig. 23. Initial Plan of Chandigarh



Source: Chalana, 2013

walking distance for residents to all basic amenities. The plan was based upon a hierarchical distribution of population, where population density would increase in the city from the north to south.

Today, Chandigarh is predominantly characterized by 2-4 story buildings, consisting of both detached and non-attached apartment style buildings, aligned in an irregular grid shaped pattern (Fig. 24). This seems to be the predominant urban form throughout the city. Yet, I also observed culdasac type urban design in sector 40, with low rise buildings arranged in a ring around parking and street space in the center (Fig. 26). There is also dense, traditional Indian development in several villages that are within Chandigarh, such Buterla, which is located near sector 41 (Fig. 27). These neighborhoods have taller buildings and very narrower streets. There are also several commercial centers, such as sector 17, where building heights are 5-6 stories and density of buildings and people is much higher. Although building height is often an

Fig. 24. Predominant urban form

Fig. 26. Culd-a-sac type urban form in

Fig. 25. Below ground markets

FIg. 27. More dense urban form in Buterla

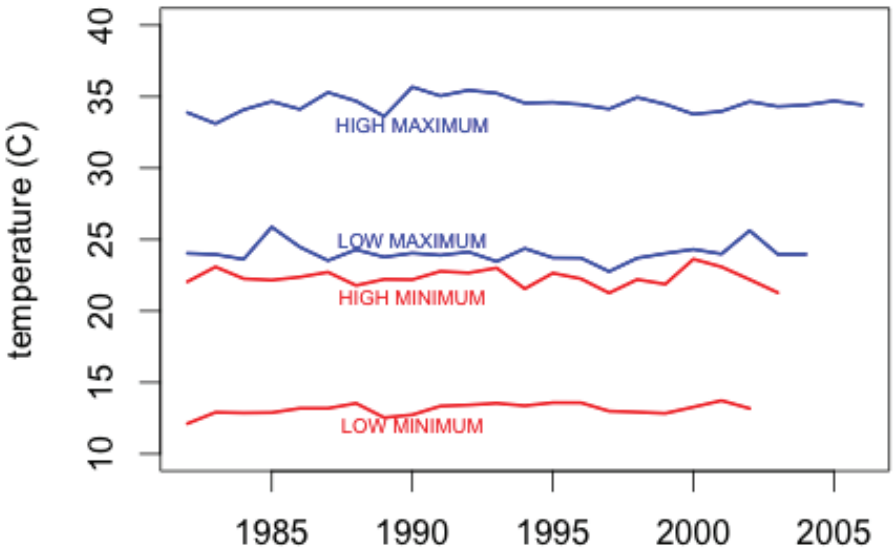
indication of density, this is not always the case. There are a numerous below-ground markets in Chandigarh (Fig. 25).

CLIMATE

Chandigarh resides at the edge of the Shivalik foothills at 304-365 meters above sea level between 30°40′ latitude north and 76°61′ longitude east (Paul, 2011). The climate of Chandigarh is characterized by cold dry winters, hot summers, and a subtropical monsoon season (CMP, 2013). Average annual temperatures range between 1-45 degrees Celsius and rainfall between 700-120 mm. There are four general seasons; winter from November through February, summer from March to June, monsoon from June to September, and post-monsoon from September to November.

Paul et al, assessed climate change in Chandigarh by analyzing long-term variability in temperatures and precipitation in the city from 1971-2011 (Paul, 2013). The authors' analysis demonstrates that during this time period Chandigarh was getting warmer in terms of minimum temperature, extreme weather events were generally decreasing, and annual rainfall show increasing trends. Additionally, the authors observed decreasing trends in mean maximum temperatures, increases in foggy days, and decreases in monthly rainfall in all months except June, September, and December. The graph below summarizes the minimum and maximum high and low temperature estimates from 1982-2009.

Fig. 28. Chandigarh Average Temperature (1982-2009)



Source: Paul, 2013

CASE STUDY #2: SEATTLE

Seattle is a city located in the Pacific Northwest of the United States in the state of Washington, which lies within King County and adjacent to Elliot Bay and Lake Washington (Fig. 29).

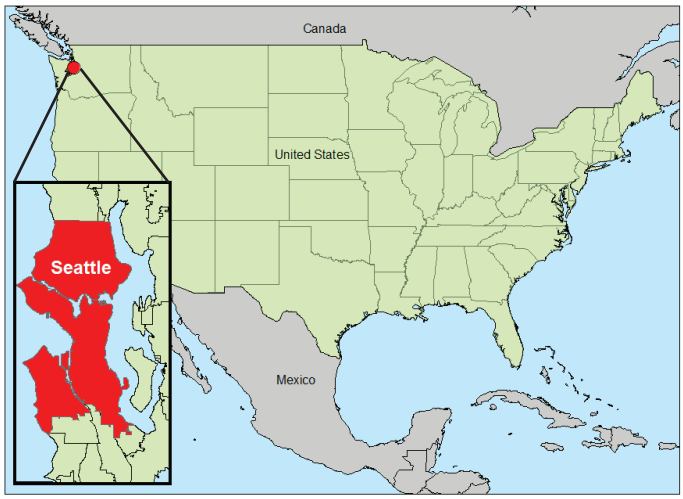


Fig. 29. Seattle Context Map

HISTORY

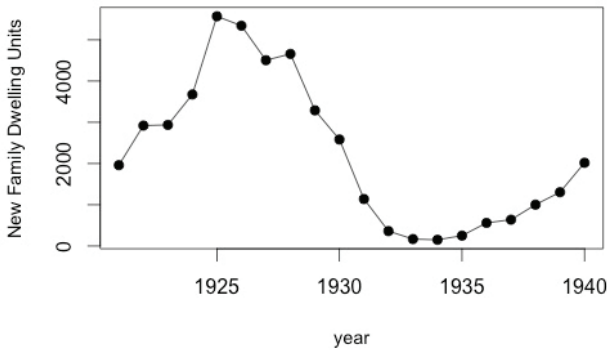
Seattle was originally settled in 1851 and was officially incorporated in 1869 as a strip of land located between Lake Washington to the East and the Puget Sound to the west (City of Seattle, 2014). As a result, development is topographically constrained from east to west by bodies of water. The nascent growth of Seattle was spurred by economic growth in lumber, coal, fishing, and shipping, which lead to burgeoning prosperity in the beginning of the twentieth century. In it's early days, Seattle hosted an international fair in 1909 and was home to the tallest building on the west coast of the United States for several decades in the early twentieth century (Sale, 1976).

In 1910, the people of Seattle voted to create a Municipal Plans Commission, which was established to create a plan for the city in order to meet future growth and demand (Ibid.). The first plan, spearheaded by civil engineer Virgil Bogue, drew inspiration from Haussmann's Paris, Wren's London, and L'Enfant' Washington D.C. Bogue "saw that the essential development of the city would be out rather than up, that urban development would be western, and so, by eastern standards, suburban in appearance." Yet, voters rejected Bogue's plans by almost two to one. Subsequent planning activities in the 20th century were limited to piecemeal neighborhood, open space, and transportation plans, until the passage of Seattle's first comprehensive plan in 1994.

POPULATION, GROWTH, & DENSITY

The initial development of the Seattle region can be characterized by three stages: Pioneer Development (1850-1880), Aggregation and Urbanization (1880-1910), and Centralization and Metropolitanism (1910-1940) (Schmid, 1944). The first period was characterized by a group of disparate congregations based upon mill production and trade. The second period was influenced by the introduction of railways and produced the first centralized concentration of markets and population. The third period was characterized by multiple concentrations of population and experience booms and busts in the growth of housing (Fig. 30). Between 1920 and 1930 the growth of population in Seattle comprised the majority of the growth in the Puget Sound Region as a whole (Berner, 1999). Yet, in the following decade, population in Seattle barely increased at all, while population outside of Seattle in King County experienced significantly growth. This reversal of growth trends from the city to the county reflected several trends including a lack of jobs in the city, increases in subsistence farming in the county, incentives for cheap housing, lower taxes, and the nascent use of the personal automobile (Berner, 1999). Since the

Fig. 30. Seattle Residential Construction (1921-1940)



Source: Berner, 1992

Fig. 31. Seattle Total Population (1990-2010)

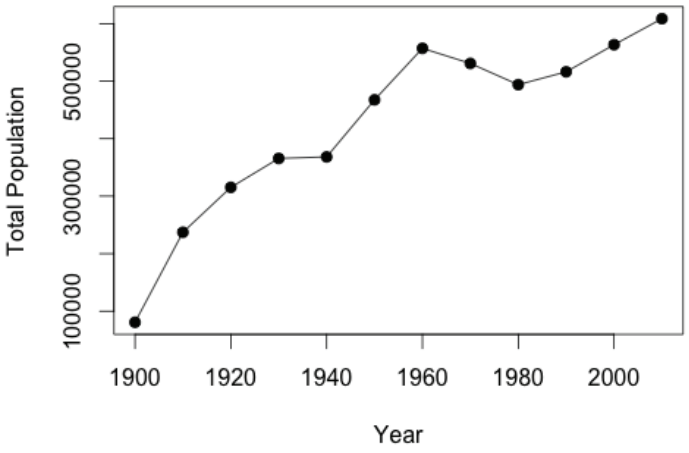
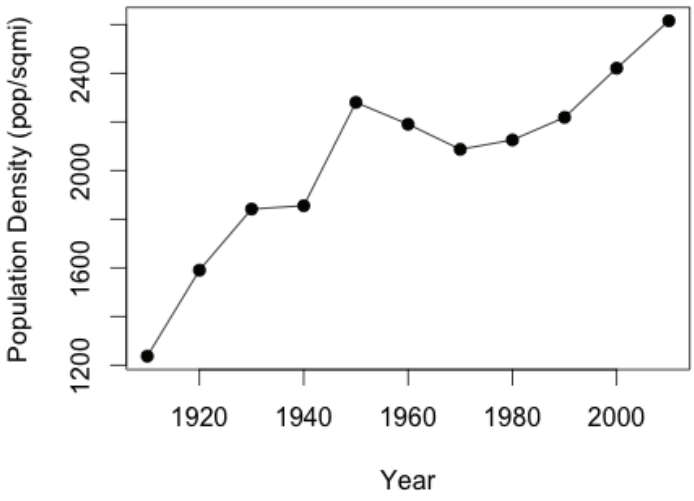


Fig. 32. Seattle Population Density (1990-2010)



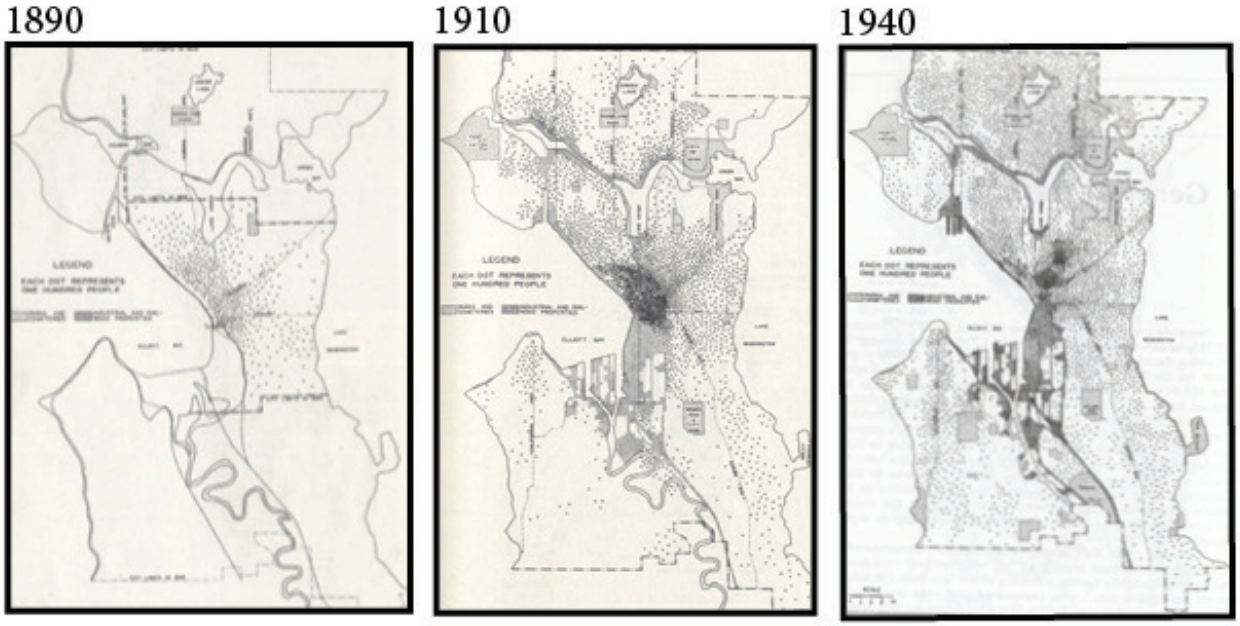
1960s, the population in Seattle remained relatively stable, as the surrounding suburbs have experienced the majority of population growth. In the 60s and 70s the shift of population from the city to the suburbs was partly the result of changes in household sizes (Sale, 1976). Younger people without children, as well as mature couples, were moving into the city while younger couples with children were moving out of the city. The upshot was that the number of households in Seattle increased but the total number of people actually decreased.

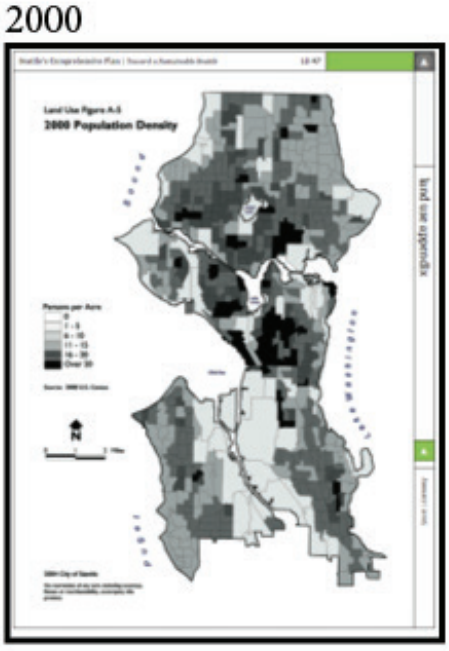
Both population density and total population in Seattle demonstrate roughly similar trends over time; a gradual increase with a several minor peaks and valleys. Decadal growth has remained constant over time, after decreasing once initial city growth occurred. Growth in population density has been less stable; spiking up and down in the early-mid twentieth century, then gradually increasing, before experience a slight decline in the last decade. The average decadal growth rate in density is 8 percent. Seattle's population has grown from roughly 80 thousand in 1900 to 600,000 in 2010, growing at an average decadal rate of 27 percent.

In its first several decades, Seattle's population was concentrated predominantly in the districts where the city was initially settled but by 1940, population density had spread throughout the city (Fig. 33). In recent decades, the highest population densities are still mostly found in close relation to the initial settlement area, although several dense pockets have sprung up in other areas of the city.

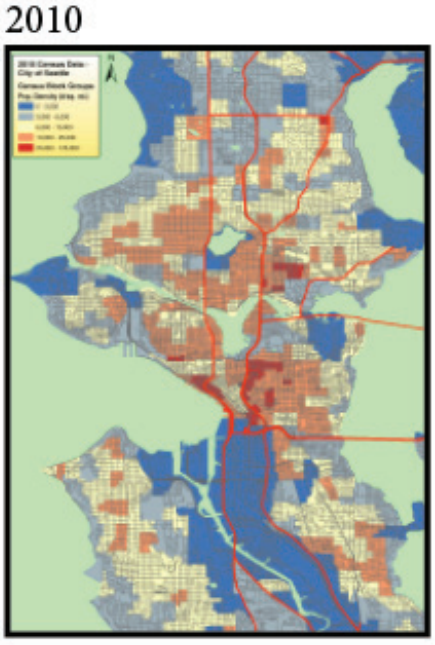
Fig. 33. Seattle Population Density Maps Over Time

Source: Berner, 1992





Source: Seattle Comprehensive Plan



Source: Newton, 2011

ELECTRICITY CONSUMPTION

During the beginning of the twentieth century, a growing population increased pressure for widespread and reliable electricity services (Berner, 1992). At this time, municipal electricity demand in Seattle, and the rest of the U.S., was substantively related to the use of electric powered streetcars. In addition to streetcars, the commercial and industrial sectors were the predominant consumers of electricity, with the domestic sector playing a minimal role. By 1920s the composition of city-wide electricity consumption in Seattle began to change as home electrification proliferated. The number of domestic electric ranges in Seattle increased from 2,500 in 1922 to 23,405 in 1930 (Fig. 34) (Berner, 1992). In the 1940s, central heating in buildings was limited to a small but growing proportion of the population (Fig. 36). During this time other electric appliances, such as toasters and radios, became affordable to all income classes and became increasingly found in more homes. In 1921, Seattle City Light had 63,000 customers and roughly 50 percent of their electricity consumption was generated from the Lake Union Steam Plant.

As electricity consumption was trending upward, City Light responding by expanding the electricity infrastructure by developing the Skagit River Hydroelectricity facilities. In the 1940s, expansion

Fig. 34. Installed Electric Ranges (1922-1930)

year	# of installed electric ranges
1922	2,500
1926	11,127
1927	14,679
1930	23,405

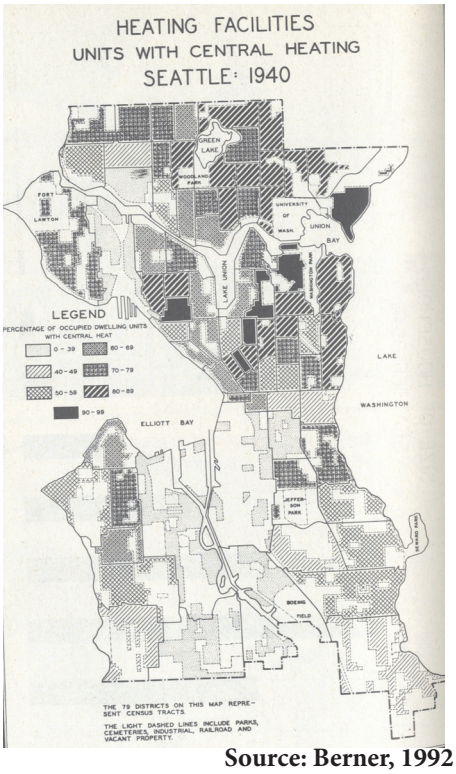
Source: Berner, 1992

Fig. 35 Electricity Sales (1939-1950)

year	Electricity sales (kwh)
1939	111.8
1942	183.1
1945	261.7
1947	276.1
1950	347.0

Source: Berner, 1992

Fig. 36. Seattle Units With Central Heating (1940)



Source: Berner, 1992

of electricity infrastructure was propelled by the World War II mobilization effort (Berner, 1999). Today, Seattle provides electricity through its municipally owned utility Seattle City Light, which generates between one half to three quarters of the electricity that is sold to consumers within the city (City of Seattle). The majority of the electricity is generating from hydroelectric facilities in Washington state. Seattle City Light's existing energy infrastructure is sufficient to serve the existing customer demand in Seattle. In recent decades, per capita electricity consumption in Seattle has been decreasing, while total electricity consumption has been stable, with a slight increase (Fig. 37 & 38). Annual growth in total electricity use has remained stable over the past thirty years, with growth rates ranging from -10% to 10%, with the average rate at 0.66%. Per capita growth in electricity has been generally constant as well but the average rate is much lower at -0.5 %.

Within the past thirty years, growth in total electricity consumption in Seattle has been primary influenced by the non-residential sectors, as total residential electricity consumption has remained constant (Fig. 39). During this time period

Fig. 37. Seattle Total Electricity Consumption

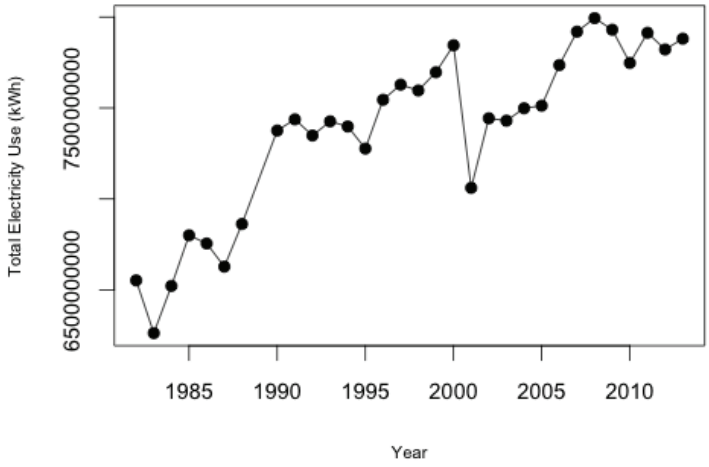


Fig. 38. Seattle Per Capita Electricity Consumption

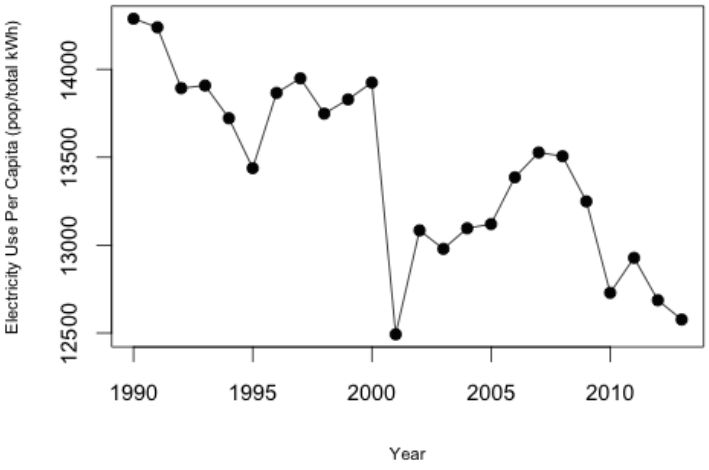
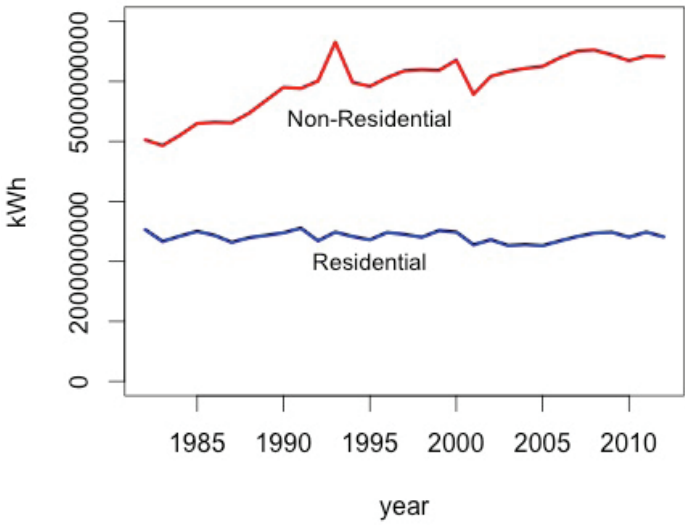


Fig. 39. Seattle Total Residential & Non-residential Electricity Use



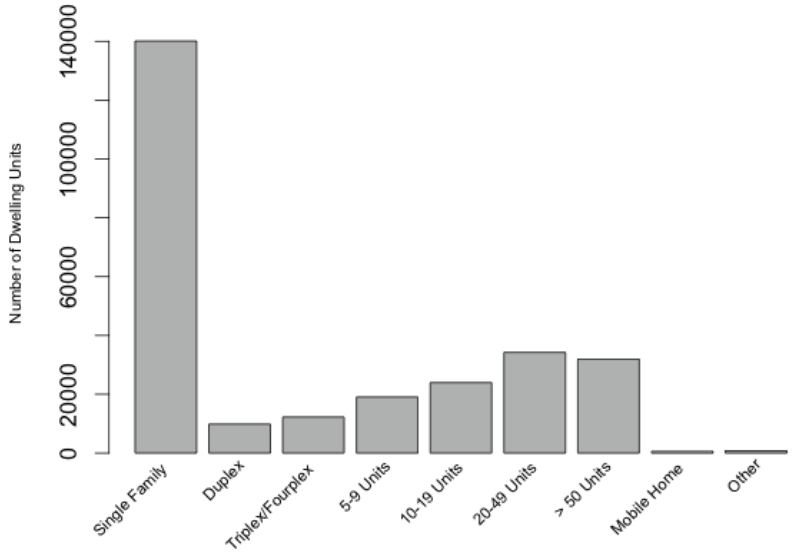
total residential consumption has fluctuated only slightly between 2263000000 and 2555000000 kwh, while non-residential consumption has increased by approximately 40 percent.

The literature review and analysis also demonstrated the importance of buildings in municipal electricity use. Seattle has recently engaged several policies to significantly reduce building energy demand. In 2010, Seattle enacted a building energy benchmarking policy that requires building owners to annually report the energy use of non residential and multifamily buildings of 20,000 square feet or larger. (City of Seattle, 2014). The city analyzes this data on an annual basis to assist in identifying strategies to reduce building energy use. A collection of downtown property owners has endorsed this program and formed the Seattle 2030 District, which aims to reduce energy use in its member buildings 50% below the national median by 2030. Since 2006, solar panels have been installed on 1000 buildings in Seattle and its solar capacity is 38 times what it was in 2006 (City of Seattle, 2014). There was a 179% increase in LEED rated buildings between 2009 and 2013. Residential energy use decreased by 3 percent and commercial energy use by 2 percent between 2008 and 2012.

URBAN FORM

In 1940, multi-family units were predominantly located in the downtown area, while single-family detached units were found outside of downtown. In 2000, the housing stock in Seattle was comprised of roughly 50 % single family and 25 % multifamily buildings of 20 or more units, and 16% smaller multifamily buildings of 5-19 units (Fig. 40). Today, Seattle is characterized by high rise buildings in the central downtown area and building height generally decreasing away from the center. The city administration has an urban village strategy that attempts to concentrate growth and density in numerous neighborhoods throughout the city (City of Seattle, 2014). These villages are commonly comprised of mixed use urban form, with 3-6 story apartment buildings in a core area. Surrounding the urban villages, are predominantly single-family residential areas comprised of 1-3 story, detached single-family dwellings.

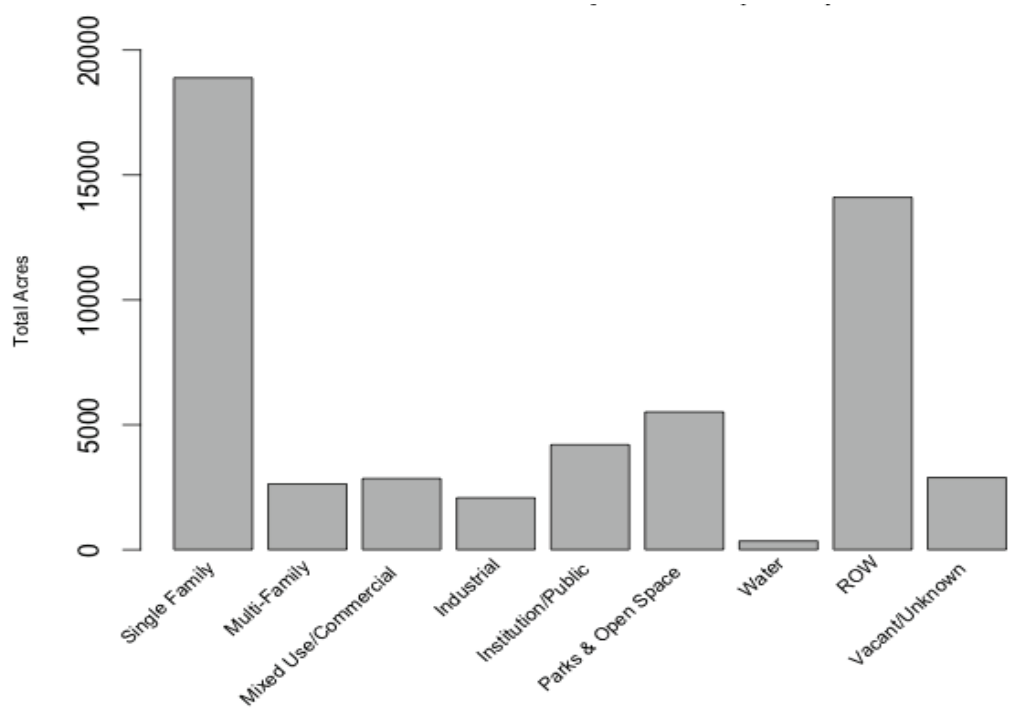
Fig. 40. Seattle Housing Types (2000)



LAND USE

At present today, land use in Seattle comprises 35% single family residential, 26% Right-of-Way, and 10% parks and open space (Fig. 41, City Seattle, 2014,). The area of open space in Seattle increased from 2960 acres in 1960 to 4545 acres in 2012 (City of Seattle, 2014).

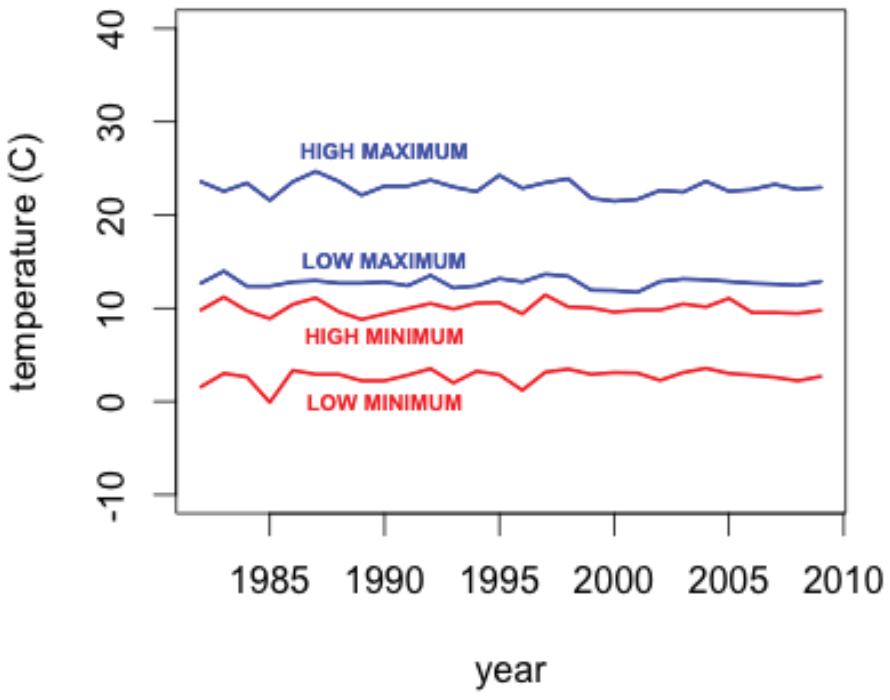
Fig. 41. Seattle Land Use Composition (2003)



CLIMATE

Seattle is located at sea level in the Puget Sound-Lowlands climate zone on the western side of Washington State, directly abutted by Elliot Bay to the west and Lake Washington to the east (WRCC, 2014). Seattle is characterized by a relatively mild climate with average winter temperatures between 28-41 degrees F and average summer temperatures in the mid 70s. Annual precipitation ranges from 32 to 35 inches. There are indications that climate change is impacting climate in the Pacific Northwest. For instance, snowpack in the cascade mountain range, which is the foundation for hydroelectricity for Seattle, declined by about 20 percent since 1950 (Mote et al., 2014). The result is decreased streamflow and potential decreased capacity to deliver electricity to Seattle. Average high and low maximum and minimum temperatures from 1982-2009 are shown below.

Fig. 42. Seattle Average Temperatures (1982-2009)



Source: Weather Underground

CASE STUDY COMPARISON

In this section I juxtapose the data of both cities to lay a foundation for a subsequent discussion of similarities and differences. In particular, I compare the population and electricity because data was available for continuous periods for both of these variables. The other qualitative data is summarized in an evaluation matrix. As displayed below, Chandigarh and Seattle reside in unique geographical locations, on nearly opposite sides of Earth (Fig. 43) and have generally distinct present day quantitative characteristics (Fig. 44)

Fig. 43. Global Context Map

Fig. 44. Present Day Quantitative Characteristics

	Seattle	Chandigarh
Total Population	626600	1054686
Population Density (pop/km2)	3000	9000
Land Area (km2)	217.2	114
Total kWh	7880804432	1365050000
kWh Per Capita	12577	1460
Per Capita Income (USD)	42,369	3,417
Coordinates	47.6 N 122.3 W	30.4 N 76.6 E

POPULATION & DENSITY

Both cities have seen generally increasing populations over time but their trajectories are idiosyncratic. Chandigarh's population stayed relatively static for the first half of the twentieth century and then started to rapidly climb from 1950 until present day. In the decades after its inception, population density in Chandigarh increased at a dramatic rate, until the last census when the population density decreased. There are no periods in which Chandigarh experienced negative growth. Its growth rate between 2001 and 2011 was 17.10%, which was its slowest decadal growth since its inception (CMP, 2013). Seattle has had several periods of fast growth during the twentieth century, including in the early twentieth century and in the 1950s. Yet, it also experienced negative growth after 1960. Seattle is characterized by stable and gradually increasing population density over time. As the graph demonstrates, population density in Chandigarh from 1960 to present is much greater than in Seattle. The density of Chandigarh only years after it was founded was roughly similar to Seattle after being in existence for over 60 years.

Fig. 45. Total Population Comparison

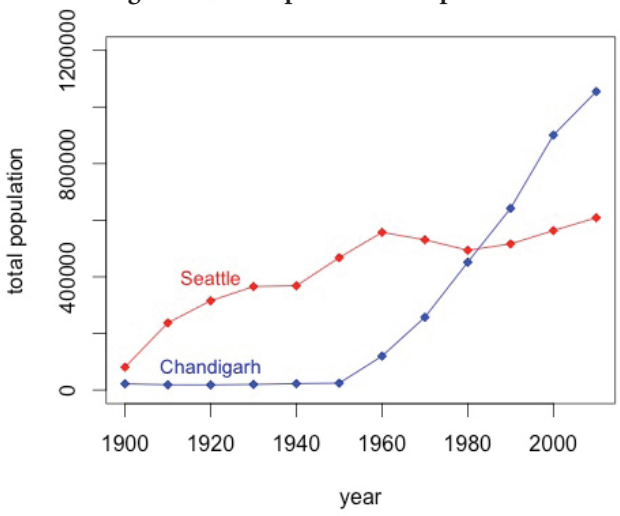
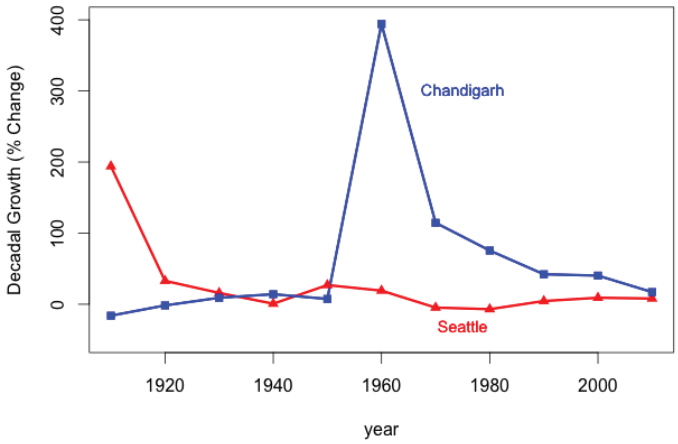


Fig. 46. Decadal Population Growth Comparison



When compared to the full range of densities present in all cities on earth, Chandigarh is in a medium density group while Seattle is on the lower end of the spectrum (Fig. 48). Chandigarh is denser than all other US cities except for New York but less dense than many cities in India. Seattle is slightly less dense than most large US cities and noticeably less dense than

most Indian cities. Even compared to other similar sized cities in the US west, Seattle is still not that dense (Demographia, 2014).

Fig. 47. Population Density Comparison

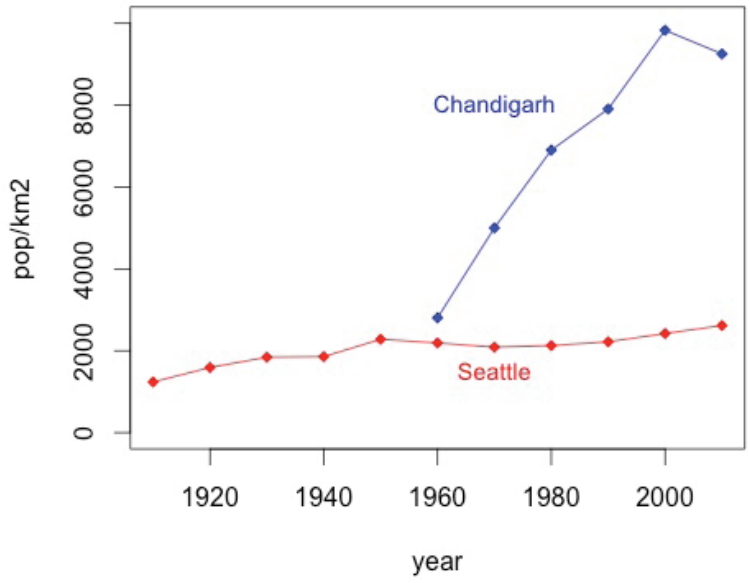
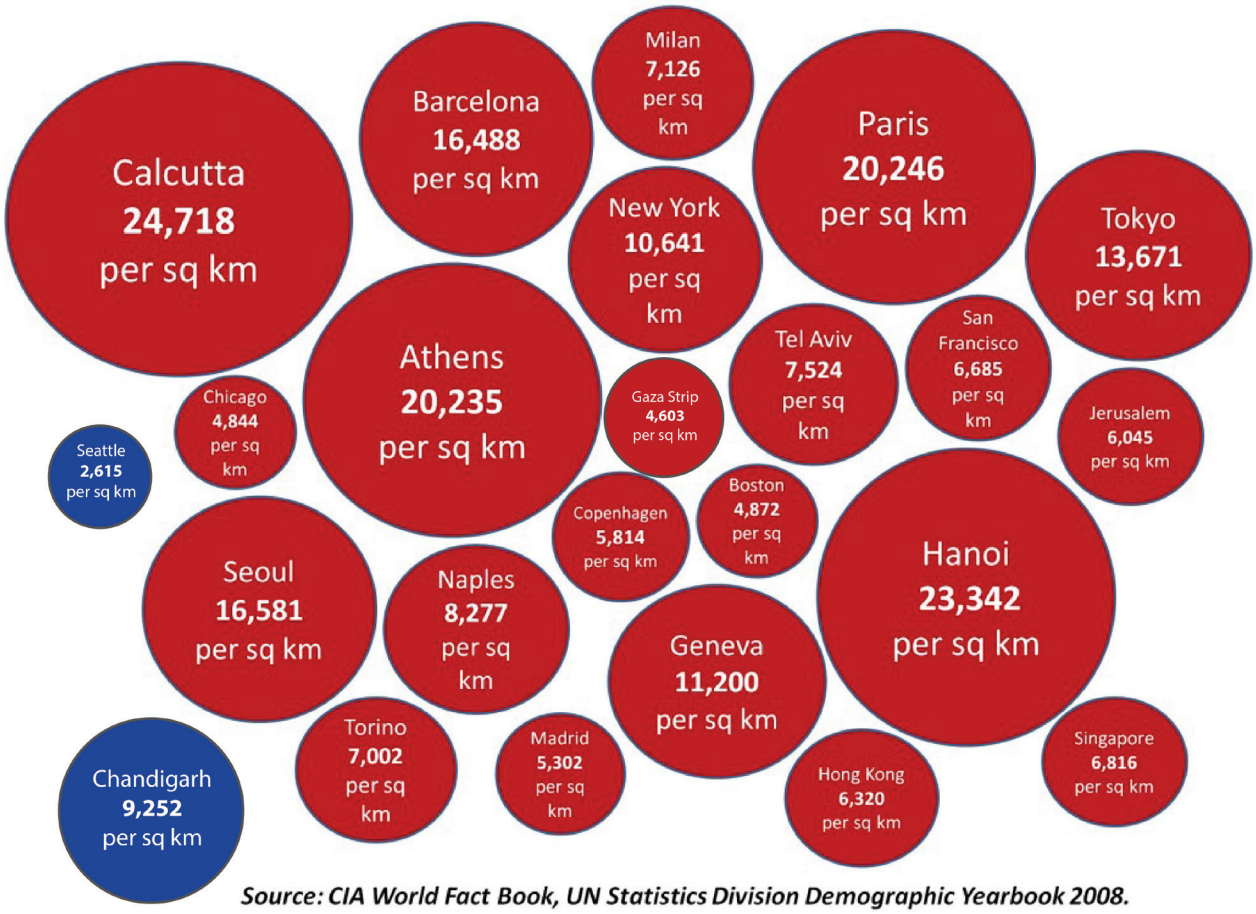


Fig. 48. Population densities of cities around the world



Graphic adapated from cija.ca

ELECTRICITY

Chandigarh and Seattle have noticeably different levels of electricity consumption. Between 1990 and 2010 average per capita electricity consumption in Seattle was 13420 kWh and in Chandigarh it was 942.3. This disparity is especially notable because these figures control for differences in total population. While Chandigarh has experienced increased levels of per capita electricity consumption over the past 20 years, Seattle has experienced a decline. Although per capita electricity consumption in Seattle has been declining, total consumption continues to rise slightly. Similarly, between 2005 and 2012 average total electricity consumption was 7,382,000,000 kWh for Seattle and 1,157,707,500 for Chandigarh. Both cities have years in which their electricity consumption declines and both demonstrate some volatility in electricity consumption from year to year.

Fig. 49. Per Capita Electricity Consumption Comparison

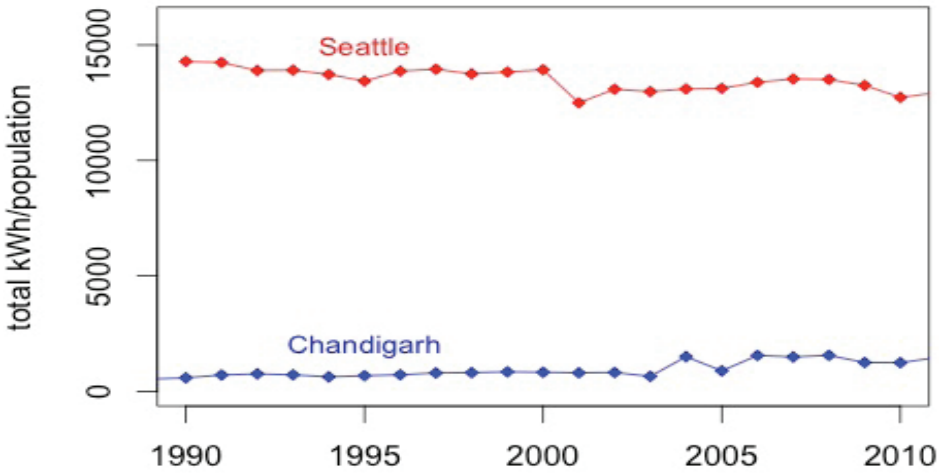


Fig. 50. Total Electricity Consumption Comparison

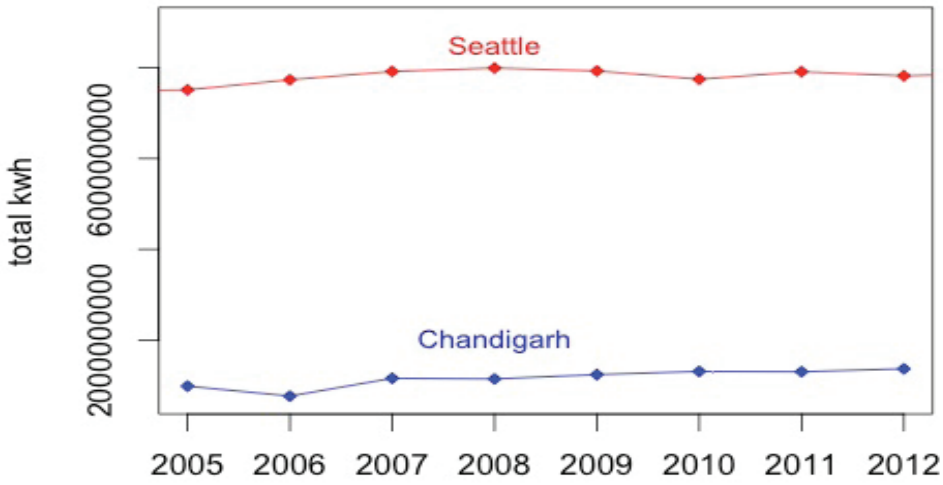
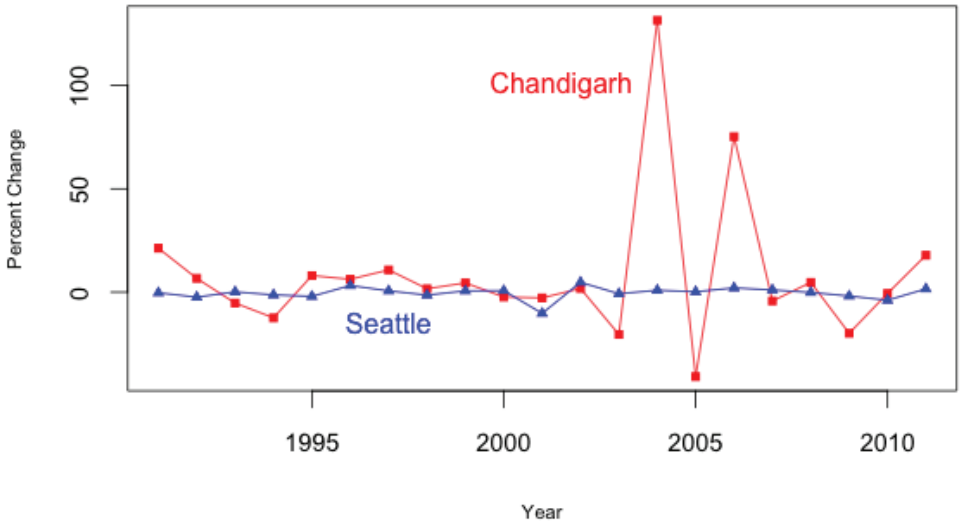


Fig. 51 Annual Growth in Per Capita Electricity Use Comparison



COMPARISON SUMMARY

	Seattle	Chandigarh
Greenspace	10% of total land use	18% of total land use
Energy infrastructure	Hydroelectricity, city owned generation facilities	Imported, no generating facilities, inefficiencies
Electricity Use	Slowly increasing total consumption, efficiency increasing quickly,	Facing rapidly increasing demand,
Density	Low density, slowly increasing	High density, reaching density threshold?
Climate	Mild, Cool	Hot summers, Cool Winters
Planning	Medium historic government planning, high present government planning	High historic government planning, low present government planning

Although the two cities do have some qualitative similarities, at present day Seattle consumes roughly seven times more electricity than Chandigarh, on twice as much land, with several hundred thousand less people, who earn on average 4 times more money. They have similar proportions of greenspace to total land, though Chandigarh's is slightly higher. Seattle seems to possess more advanced, and better maintained infrastructure. They both have increasing total electricity use, and while Chandigarh imports all electricity from neighboring states, Seattle manages the majority of its generating facilities. Both cities have seen increasing density in recent years, though that density is manifested differently in each city. They have very distinct climates and recent evidence shows changes based upon historical patterns.

These present day characteristics of both cities have been influenced by different degrees of past and present government planning interventions, as well free-market processes. Chandigarh was devised relatively instantaneously from top-down policies and was planned from its inception until present day. Funded by the National Government of India, the original plans were based upon the Garden City movement, which was an attempt at centralized urban growth, with low residential density levels (Churchman, 1999). Similarly, density in Chandigarh has been impacted by the Peripheral Control Act, which was originally intended to constrain outward growth but has become arguably obsolete over time (Vimal, 1994).

Although Chandigarh was physically planned and designed from its inception, only recently has the city begun more extensive urban planning strategies. The forthcoming Comprehensive Master Plan 2031 is the city's first true comprehensive plan, which formally establishes present day policies regarding a range of topics such as housing, sustainability, transportation, and infrastructure (CMP, 2013). Though the administration has laid out a detailed vision of the city looking into the future, Chandigarh still feels as if it lacks active, dynamic modern day planning activities. For instance, many of the numerous park spaces simply consist of dirt fields with one or two playground structures, rather than the lush spaces for moral and physical edification in which they were intended. Moreover, in each sector, there are large subset

maps of the city's sectors, which are intended to assist pedestrians traversing between sectors. Yet, based upon the conditions of these signs, it literally appears as if they have not been maintained since they were installed. They are rusted, bent, and at times completely illegible due to apparent attrition. Although these signs are substantively trivial compared to other planning outcomes, they seem to encapsulate the state of modern day city planning in Chandigarh, at least compared to how planning is manifested in Seattle.

Conversely, Seattle slowly burgeoned into autonomous city through myriad free market processes, while government planning was relegated to designing parks and roads. Seattle began as a small collection of sellers and manufacturers along the central Puget Sound waterfront and over time burgeoned into large urban agglomeration. Seattle's first comprehensive plan was adopted in 1994, four years after the passage of the Washington State Growth Management Act (Fox, 2010). Growth in Seattle is influenced by multiple different plans, such as its own comprehensive plan, countywide planning principles, regional growth plans, and state plans. Regional planning policies impact municipal electricity use by influencing the flow of people into and out of cities. Current density in Seattle is influenced by the Washington State Growth Management Act (GMA), which was enacted in 1990 and required Seattle to establish an urban growth boundary (UGA) to focus new growth in areas that have existing infrastructure, preserve regional open spaces, and prevent worsening suburban sprawl. In sum, Chandigarh was planned heavily at its inception but has less current planning, while Seattle had less planning during its formative years but is characterized by extensive planning at present day.

CHAPTER 5: DISCUSSION

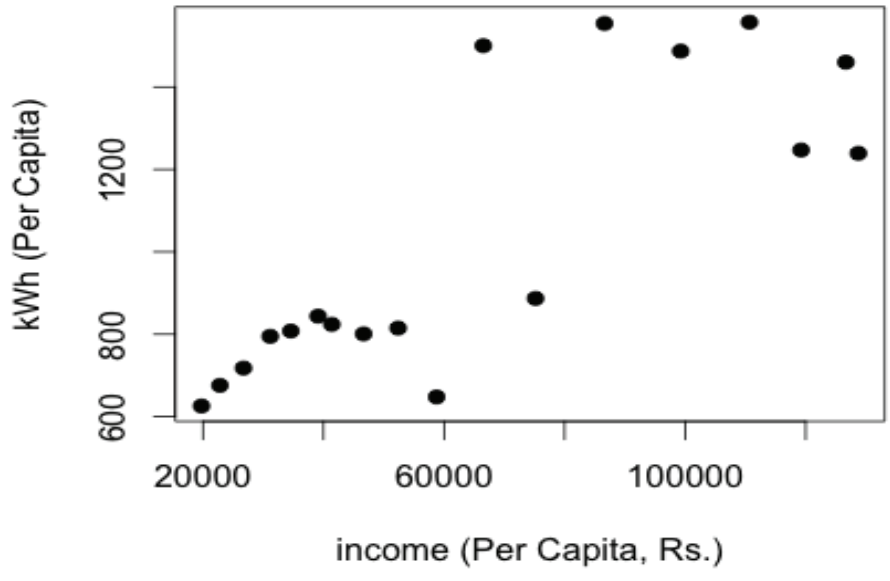
INTRODUCTION

In the previous section I presented the analysis of the dataset I gathered and the observations I collected regarding energy-growth patterns for Chandigarh and Seattle. In this chapter, I discuss the inferences and potential conclusions that may be drawn from the analysis.

ENERGY GROWTH PATTERNS

One of the primary questions of my research is whether we can identify similar trends between the growth of city size and electricity use in Seattle and Chandigarh. The first and most obvious observation is the stark disparities in levels of electricity use between Chandigarh and Seattle over time, even those that account for differences in total population. This could be interpreted as either Chandigarh is deprived of electricity or that Seattle is profligate in its' use of energy. Though there are likely truths in both, the energy disparity can be explained by myriad factors, including profound economic differences. Taking into account purchasing power parity, per capita income in 2012 was 12,710 USD in Seattle, compared to 3,417 USD in Chandigarh. Moreover, there appears to be a roughly linear relationship between annual per capita income and per capita electricity use in Chandigarh (Fig. 52). This infers a positive

Fig. 52. Chandigarh Income and Electricity Consumption



relationship, indicating that electricity consumption may be directly tied to levels of per capita income, which helps to explain the observed chasm in electricity use in the two cities.

The analysis also showed that during the past several decades growth in total electricity consumption has changed in both cities, but for different apparent reasons. In Chandigarh, recent growth in total electricity consumption has been led by the residential sector, while the majority of growth in Seattle is accounted for by non-residential sectors. Yet, regardless of recent trends, the domestic sector is still the highest contributor to total electricity consumption in both cities. This indicates that both the form of residential buildings and the behavior of the occupants of those buildings are the principle determinants of electricity use in both cities. The corollary is that energy efficiency in residential building design should be a priority in pursuing municipal energy conservation programs in both cities.

Furthermore, economic growth is usually viewed as a positive trend, but it may increase household electricity consumption as people acquire more disposable income to purchase household appliances. As Seattle has become more affluent, it has recognized the pertinence of residential sector energy use. Today, the city has a Conservation Resource Division of their public utility that partly works to reduce energy use in the residential sector. As Chandigarh experiences further economic growth, it would be wise to heed Seattle and pursue energy efficiency in their domestic sector. Yet, Chandigarh can also provide insight for Seattle in regards to household electricity consumption. For instance, residents in Chandigarh commonly use sunlight to dry clothes and wash dishes by hand rather than use electricity appliances, which helps to dampen residential electricity consumption. Both behavior within the residential sector and the design of the residential sector are ostensibly the two most significant variables in assessing municipal electricity use.

During the sample time period, density in both cities has been increasing. In Chandigarh, both population density and total population have been increasing but

during the past census, Chandigarh experienced a decrease in population density for the first time. From a strictly quantitative perspective, this could be interpreted as a threshold, where the city was not able to accommodate more density. But as the numerous vacant lots and open space in Chandigarh indicate, there is clearly enough space for increased density simply through infill development. It is possible that density decreased for reasons similar to what happened to Seattle in the mid twentieth century, when there was an exodus of urban residents to the suburbs. As Chandigarh becomes more affluent, it is possible that residents will seek more spacious, affordable lots and homes, which are more available in peripheral areas. Car ownership in Chandigarh has become extremely high over the last several decades and transporting from 'suburban' area to the city has become less of an impediment.

When compared to levels of density in Chandigarh, Seattle is a sparsely populated city. Although population density in Chandigarh is much higher than Seattle, it does not feel that much more dense. Part of the challenge with achieving higher densities in Seattle is that it has such a high proportion of detached, single-family residential land use. At the same time, there currently is a contentious debate in Seattle regarding policies that increase density in and around single-family neighborhoods. This opposition to increased density may hinder Seattle from reaching higher levels of aggregate population density. As a result density becomes congregated in certain neighborhoods manifested in the form of high-rise apartments. The upshot is that these high rise neighborhoods create ample shading that prevents solar gains and mitigates energy efficiencies from passive solar design. If density was integrated into detached single-family neighborhoods, then there may be more opportunities for gains in energy efficiency through passive solar design. The lesson is that density does not have to take the form of high rise buildings but there must be ample land available dedicated to medium density.

Today, both Chandigarh and Seattle currently face pressures to accommodate additional populations within their fixed area of city land. Seattle is expected to accommodate an additional 150,000 people by 2040 (Seattle Post Intelligencer, 2008

). Growth in the surrounding areas of Chandigarh is booming, but it is uncertain to what extend Chandigarh will accept additional growth. Chandigarh's status as a historic city presents challenges for accommodating additional population growth. In fact, Chandigarh has been under consideration for World Heritage City status. For instance, just north of the Capital Complex lies an area of land that has been designed agricultural land, though its productivity is dubious. Le Corbusier envisioned the capitol complex with an unimpeded sightline towards the shivalik foothills, with this land existing as a rural landscape. Therefore, any plans for high density development in this area are often scrutinized because they would interrupt this aesthetic element of the original plan. Given projections for immense urban growth in India as a whole, what is Chandigarh's responsibility to accommodate a share of this growth in a sustainable fashion? If it does not open its doors to new urban residents, then they will simply go to a different city that may or may not abide by sustainable principles. What will Chandigarh's role be in the evolution of Indian urban growth and thus the future of global energy use and climate change? Will it reject growth and remain a modernist urban museum or will it accept its responsibility to accommodate growth in a sustainable way?

SIZE AND EFFICIENCY

Another pertinent discussion point is what the analysis reveals about whether larger cities are more efficient than smaller cities. It is generally understood that the concentrating of people in cities enables economies of scale that engenders the efficient use of infrastructure and energy (Fragias, 2013). Using a biological analogy to assess city size and efficiency, the concept of urban metabolism is a well-established concept that helps explain how cities depend upon a variety of energy inputs in order to maintain their core functions. This is based upon "Kleiber's Law", which states that organisms with a larger mass consume more total energy than smaller ones but as organism size increases, the rate of energy consumption is proportionately less than the rate of growth in mass (Ibid.). This seems to imply that between two cities with the same population density, the city with the greater total population will have less per capita electricity

use. The biological analogy is especially intriguing when considering the physiological origins of Chandigarh's original master plan. Le Corbusier envisioned the original master plan of Chandigarh as analogous to the human body, with the head as the Capitol Complex, the heart as the central commercial district, the lungs as the green spaces, the mind as the educational institutions, and the circulatory system as the roads (CMP, 2013).

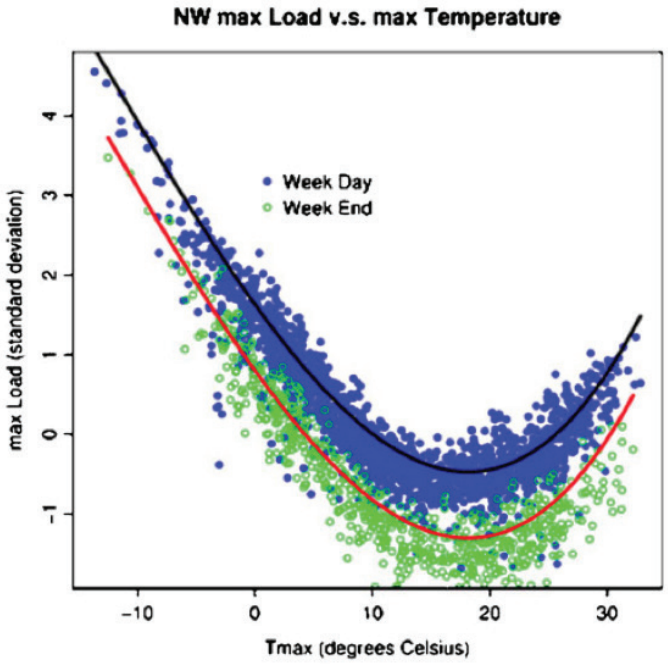
Based upon the data analysis, annual per capita electricity consumption in Seattle shows a decreasing trend since 1990, while total consumption has been increasing marginally each year. Given that population continues to increase, this indicates that Seattle is becoming more energy efficient. Conversely, both per capita consumption and total consumption in Chandigarh has been rising, indicating that efficiencies are not being achieved. We can also see that Chandigarh is larger than Seattle in total population and has lower levels of per capita electricity consumptions. This is an indication that Chandigarh, as a larger city, is more energy efficient. The data analysis shows that Chandigarh surpassed Seattle in total population between 1980 and 1990 and since that time has demonstrated lower levels of per capita electricity use. In order to begin assessing the congruence of the aforementioned urban metabolism analogy to this analysis, we would need to analyze whether there were notable changes in the disparity in energy efficiency before Chandigarh surpassed Seattle in total population size. Unfortunately, continuous electricity data for both Seattle and Chandigarh was only available for the period after Chandigarh became larger than Seattle.

CLIMATE CHANGE

Another prominent research question is how climate change may impact energy use in each city. Generally, differences in climate likely play a significant role in influencing electricity use patterns in Seattle and Chandigarh. While Seattle has a relatively mild climate, Chandigarh is characterized by extreme contrasts between hot summers, where temperatures can reach 45C and cold winters that reach the freezing level. These climatic differences are relevant for several reasons. Seattle's mild climate means that

there is a lesser need for either heating or air conditioning, though heating energy is still relevant due to Seattle's location at a high latitude. The electricity demand in the summer in Seattle is generally low compared to Chandigarh. In the Pacific Northwest, where Seattle is located, the relationship between peak hourly electricity demand and daily maximum temperature is non-linear; electricity demand decreases as temperatures increases but once temperatures warm to a certain point - roughly 20 degrees C - electricity demand begins to increase again (Fig. 53, Hamlet, 2010). In contrast, Chandigarh is located at a lower latitude and domestic electricity is predominantly allocated for air conditioning. Central heating in Chandigarh is in fact quite rare but individual space heaters are a more common source of indoor heat during the winter.

Fig. 53 Seattle Temperature Patterns



Although the climate appears to be changing in both Chandigarha and Seattle, I am unable to truly assess the relationship between temperatures and electricity use because additional research is required. Temperature patterns from 1982-2009 provide some insight into climatic changes but a longer time frame and additional data is needed to reach more reliable findings. Furthermore, climate change may impact electricity use in both cities, yet the specific outcomes are uncertain because of geographical differences between the two cities. Recent climate impacts in Chandigarh and Seattle are complex and the hypothesis that warmer temperatures generally lead to higher electricity consumption should be viewed with scepticism upon further research.

The quantity of open space in both cities is also relevant to the analysis of electricity use and climate partly because of the urban heat island effect. The urban heat island

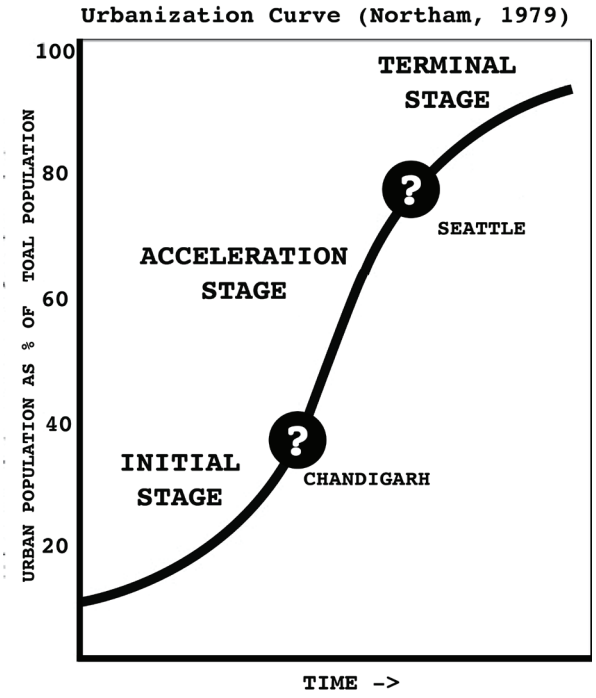
effect is a phenomenon in which areas with significant impervious surface land-cover absorb radiation from the sun, which increases the ambient temperature of those areas compared to adjacent areas (Young, 2012). The result is warmer urban temperatures, which influences energy consumption patterns. Chandigarh was historically designed with a significant quantity of greenspaces. Today these spaces can be observed extensively throughout the city and comprising approximately eighteen percent of the total existing city land use. Similarly, Seattle has ample parks, open spaces, and vegetative cover. This significant composition of pervious surface cover may help to mitigate urban heat island effect in both cities. Yet due to the differing climate in Seattle and Chandigarh, the resulting energy outcomes will differ. For instance, less urban heat island effect in Chandigarh will reduce electricity for cooling but in Seattle it may increase electricity for heating.

Chandigarh is experiencing rapidly growing electricity consumption, much of it that is enabled through the burning of coal for power generation, which contributes to global climate change. Hydroelectric power supplies in Seattle are currently being impacted by climate change and changes will likely continue far into the future. Therefore, there seems to be an intuitive interest for Seattle in how growth in Chandigarh and other India cities proceed. But another key finding is that Chandigarh's future contribution to climate-induced changes in Seattle's electricity supply will likely be minor, compared to other cities in India because of its history and heritage. Chandigarh was nominally designed by arguably the most renowned architect of the 20th century and has been considered as a UNESCO World Heritage City. As a result, growth and development seem to proceed in a more cautious manner, compared to other Indian cities. For instance, a high density, purportedly sustainable housing proposal just north of Chandigarh has repeated challenged in the courts, partly because it disrupts the sightline to the mountains, which was an essential element of Corbusier's original city plan. Such considerations clearly constrain growth and design policies in Chandigarh, which directly impacts energy, and will likely continue to do so into the future.

URBANIZATION THEORY

From the analysis, we can see how population and energy use in Chandigarh and Seattle fluctuate from decade to decade but form observable patterns when viewed over a century. We can compare the long-term growth trends in both cities to investigate whether they may align with the theory of urbanization as a generic, chronological process. As previously mentioned, Northam was one of the first to posit a formal theory of urbanization evolution with his urbanization curve, where a city will begin growing slowly at its inception, then begin growing rapidly, and then eventually slow down as more time elapses (Mulligan, 2013). The analysis shows that population growth in the area where Chandigarh currently exists was practically zero prior to 1950 but when the city was formally established by the national government population proliferated. Subsequently, population increased rapidly during the late 1900s and then slowed during beginning of the early twenty first century. Chandigarh could be in the midst of an acceleration period, which hypothetically may be followed by a leveling out of urbanization and growth (Fig. 54). Yet, it is difficult to assess a urbanization evolution theory to Chandigarh because of the minimal time that has passed since its inception. Although the site in which present day Chandigarh presides has been inhabitated by small populations for over a century, the city only formally came into existence during the 1950s. Therefore, it is challenging to discern meta-trends in its population growth because of the short timeframe.

Fig. 54. Seattle and Chandigarh on the Urbanization Curve



Conversely, Seattle was incorporated as a city in 1869 and has a longer timeframe in

which to assess its growth as an urban entity in time. From the analysis, you can see that Seattle grew rapidly in the early 1900s before slowing down from 1920-1940, which may have been related to the great depression. But growth picked up speed again from 1940-1960 before slowing down from 1960-1980 and from 1980 to present the population has been growing steadily. Seattle's growth since 1900 is characterized by periods of slower growth and acceleration, yet it is difficult to generalize a specific shape, such as an S, to describe its evolution of growth. Although we have a longer time frame to assess growth patterns, it is possible that this is still not enough time.

One explanation of the difficultly of placing both Seattle and Chandigarh on a single curve is that they began growing during distinct periods in history. The S curve was hypothesized in reference to the initial group of urbanizing regions in the west during the twentieth century. But for regions in India that are only now experiencing urbanization, growth is particularly rapid, potentially resulting in a steep J shaped urbanization curve (Mulligan, 2013). Therefore, rather than attempting to place Seattle and Chandigarh on one urbanization curve, there should be multiple curves. For instance, it is possible that there are urbanization cohorts, based upon levels of country urbanization during the 20th and 21th centuries (Ibid.). Based upon this theory, the U.S. is lumped into the first club of highly urbanized countries; today the percentage of the population in the United States who reside in urban areas is over 80 percent. Conversely, India is part of the 4th club of least urbanized countries; its urbanization level is just over 30 percent. There may be typologies of urbanization processes, in which cities can be classified into different groups. Each group follows the same general pattern but has different absolute levels of density and electricity use.

Viewing urbanization as a temporal process helps explain the differences between the two cities. Seattle grew during the first spate of urbanization that occurred during the West during the 19th and 20th century, while Chandigarh is growing amongst a second phase of urbanization that is currently occurring in many developing countries in Asia. A common perspective is that urban growth in Indian cities is occurring under conditions that are incomparable to urbanization in the western world during the

twentieth century (Mulligan, 2013). For instance, the urbanization that occurred in the West during the 20th century was practically synonymous with economic development. Conversely, the current urbanization processes in much of the developing world are often not equally accompanied with equitable distributions of wealth (Madlener, 2011). My research seems to confirms the belief that Chandigarh is amid a new phase of urbanization that is unlike what occurred in Seattle in the 20th century. Given structural socioeconomic differences between the context in which Seattle and Chandigarh are urbanizing, it seems likely that their trajectories will differ, with the later urbanizing at a faster rate.

An ancillary purpose of this paper is to assess whether this form of research methodology can contribute to the further development of an urbanization science, by attempting to compare urbanization among distinct cities using a mixed-methods approach. At this point in the development of urbanization science as a distinct paradigm, quantitative analysis of large data sets seems to be the predominant methodology. For example, recent research has explored urbanization from the standpoint of complexity theory, using immense datasets to explore scaling and emergent properties of cities (Bettencourt, 2013). In these studies, cities are usually distilled into a few general variables and then aggregated into datasets with hundreds or thousands of other city's variables. Researchers aggregate a plethora of cities and demonstrate universal relationships amongst them. Although this type of analysis is immensely interesting, I wonder to what extent this type of methodology can actually helps us understand what is happening on the ground and therefore devise necessary responses.

There are several methodology approaches to investigating whether there are universal characteristics of cities. Using population density as an example, one approach would be to identify the population density of myriad international cities and observe the statistical patterns that exist through quantitative analysis. Once patterns were observed, one could then research each city individually to assess the idiosyncratic causes of the empirical trends from a qualitative perspective.The methodology

employed in this paper is a mixed methods approach, employing both quantitative analysis and qualitative observations. Therefore, the challenge is to assess the contributions to urbanization science of a mixed methods approach.

One characteristic of urbanization science is a rigorously interdisciplinary analytic perspective (Solecki, 2013), whereas past urbanization studies are often approached from myriad different disciplines, resulting in specialized but isolated analysis of complex, connected processes. My research intentionally attempts an interdisciplinary perspective by gathering data from multiple different perspectives. For example, I look at temperature (climatology), urban form (urban planning), population (demography), income (economics), and electricity (engineering). Coalescing numerous different disciplines into a quantitative analysis is problematic because the distinct assumptions in which each is founded upon fade into the background, though they are likely extremely pertinent. A mixed-methods approach is better able to identify and account for the idiosyncracies and asusmptions of each discipline when attempting interdiscplinary analysis.

Moreoever, the contribution of a mixed methods approach to urbanization science, compared to a strictly quantitative approach, is a deeper understanding of trends that are observed among multiple cities. Since the ultimate goal of urbanization science is to respond to contemporary issues in society, it is useful to know the context behind the graphs and data points. Without conducting field research, it would be nearly impossible to truly understand the reasons behind the disparities in electricity use between Chandigarh and Seattle. A mixed methods approach contributes to urbanization science by vetting and testing theories by acquiring thorough contextual information in the field. For instance, a qualitative perspective is needed to help explain the stark contextual differences in which Chandigarh and Seattle developed and which influenced present data characteristics. While Seattle burgeoned from a traditional bottom-up perspective, Chandigarh was seemingly created from strictly top-down state intervention. This disparity between their historical development challenges urbanization theory from a quantitative perspective and indicates the benefits of

more thorough descriptions of past and present city structures. Although quantitative analysis lends itself well to developing theory, urbanization science needs descriptive analysis to test emerging theories.

My research also helps expose some dubious assumptions of a strictly quantitative approach to comparing cities. By delving deeper into the contextual and historical aspects of city growth, it becomes clear that the definition of a single city changes over time and this definition is created rather arbitarily. For instance, one dilemma with attempting to assess the evolution of urbanization is deciding how to define a city from a temporal perspective. Chronologically, when does a city as a distinct entity begin and end? Chandigarh was essentially a collection of small villages until Nehru and the national government of India decided to intervene to create a new city on top of what already existed. Seattle expanded its administrative urban area numerous times after it was incorporated as a city, yet it has maintained every expansionary area as part of the original city. But what if each expansion was not included as part of Seattle but established as separate, unique city? These ambiguous definitions clearly impact how we evaluate the evolution of urbanization in both cities and should be explicitly stated. It seems that a qualitative perspective can better account for such assumptions.

Although urbanization evolution and scaling analysis both contribute to urbanization science, there seems to be a tension between the two. For instance, the claim that there is a scaling relationship between population size and electricity use is based upon observations from one calendar year. Therefore, the specific conclusion is that at this specific point in time, there appeared to be generic characteristics. But this claim does not necessarily apply to past or future periods of time. Although there are likely universal tendencies of cities at points in time, these characteristics will change over time. Additionally, scaling only applies to cities of the same urban system (Bettencourt). So how do we define urban system? India and Seattle are ostensibly components of different urban systems; one in the northwest United States and the other in northwest India.

Lastly, urbanization science is an incipient discipline that has yet to be formally embraced by the scientific community. The establishment of a new field of science requires a distinct change, or revolution, within the general scientific community, where researchers cease to work within 'normal science', but instead use a distinct set of methods, process, and theory (Kuhn, 1962). The result of successfully working outside of 'normal science' is the creation of a new paradigm. The establishment of a new paradigm may occur when scientific progress in a specific area is sufficiently unprecedented to attract a scientific cohort away from the status quo. Additionally, that progress should still be open ended enough to enable ample scientific activity to follow (ibid.) To become a paradigm, a theory must be better than the existing theory, yet it need not be omniscient (ibid). Moreover, in order to establish a urbanization science as a distinct paradigm, its foundational theory must be falsifiable (Popper, 2002). Popper argues that science progresses by invalidating possible causes for observed phenomena rather than confirming the existence of relationships (Peters, 1998). Attempting to establish a distinct scientific field is a daunting task and will require repeated attempts and failures, in order to reveal potential characteristics. In order to engender a scientific revolution in the science of cities, researchers should not become siloed within certain methodologies, but rather should consider a wide range of approaches that help test their theories.

CHAPTER 6: REFLECTIONS

In this section, I discuss my experience conducting cross-national case study research for several reasons. An ancillary purpose of my thesis research is to increase the share of methodological knowledge across borders by physically conducting research in a foreign environment. I hope that by describing my experience doing so, other researchers attempting similar comparative studies will gain insight from my successes and failures. There are many obstacles to conducting research in a foreign place and it is important that these are acknowledged, in order to enhance future research.

DATA ACQUISITION

The process to request data from the Chandigarh administration was often lengthy and laborious. The administration maintains minimal online information regarding what type of data is available and who one should contact to inquire about a data request. Therefore, I had to simply show up at administrative offices and ask to speak to various people. Most often, I simply located the office in which I suspected the data would be housed and then asked around in order to connect with the appropriate manager or employee. On several occasions, I was required to provide a signed letter from my professor, which outlined the data that I was requesting and providing approval of my research intentions. Administrative officials sometimes appeared leery and suspicious of my intentions, as if my research had ulterior motives. My experience pursuing data within Chandigarh administrative agencies was generally characterized by ample wait times, conversations with multiple different employees, numerous cups of Chai, and ultimately being provided with a small, limited sample of data. Pursuing data from governmental agencies was time intensive and, although it was not completely fruitless, resulted in a quite modest collection of data.

DATA PROCESSING

In Chandigarh I was practically always provided data in hard copy form, in which I

then needed to scan and convert to a format suitable for data analysis. This process introduced potential error into the data because I would occasionally have to manually vet and adjust the data if it did not convert accurately. For instance, I usually scanned the hard copy data tables into PDFs and then converted them to .csv, using one of several free programs available online. When using research libraries I used my digital camera to physically take pictures of data tables that were embedded within various student dissertations, reference books, and other documents. I did so because digital scanning was usually prohibited. Again, I then converted the resulting pictures of data tables from JPEG to .csv format. For the temperature data, I was forced to convert jpeg graphs of data tables into raw data using another free, online program. Again, this introduced a great amount of additional error into the data.

ANECDOTES

I visited the Chandigarh Electricity Department several times, as electricity data is a core element of my thesis. After several, long conversations with multiple employees regarding the existence and availability of data regarding annual electricity consumption, I was provided several pieces of paper containing a few data points. Yet, I knew that this department maintained much more data because I had read a written report that summarized a large dataset, which cited the Electricity Department as the source. This was one of several instances in which I suspected that much more data was available but that the department was unwilling to share it with me. From my conversation with several people, I got the feeling that access to a larger dataset may have been available at a different time or by simply talking to a different person. Time constraints did not permit me to expand the effort needed pursue the additional data.

My experience collecting temperature data provides a fitting example of my general experience collecting data in India. I attempted to acquire temperature data from the Chandigarh Meteorological Centre (CMC), who indicated the existence of a dataset on forty years of climatic data for Chandigarh. The dataset consists of temperature data gathered by the India Air Force (IAF) from their Chandigarh Airport observatory from

1971-2010 and Chandigarh's meteorological observatory from 1961-1977. Unfortunately, I was not provided access to the full temperature dataset because of proprietary concerns of IAF. Therefore, the data used in this paper was estimated based upon Paul's paper, which provides a summary analysis of the original dataset (Paul, 2011) Paul's paper contained dozens of graphs that summarized the desired dataset. I extracted this data by digitizing the graphs, which were in jpeg format, using another free program available online. This required calibrating the axes and then manually clicking on each data point, whether the point is on a line or the top of a bar graph. As a result of this somewhat crude process, the temperature data are rough estimates, rather than precise figures.

My experience collecting data at Panjab University was another notable and enlightening experience. I visited the Panjab University Geography Department because their website advertises courses in geographic information systems and I hoped to acquire spatial data for Chandigarh. I met with the chair of the department and after requesting basic spatial data (ie city administrative boundaries), I was told that the data does not readily exist, though I could speak with a student to help find or develop such data. We were subsequently introduced to a PhD student who agreed to assist with our request, requiring a small payment of Rs. 600 (10$). The student created the spatial data himself by referencing four different maps to identify the 'likely accurate' administrative boundaries. Using the edit features in ArcGIS he then traced the boundaries manually and created the line features. In general, I was noticeably surprised that a large university department that has academic programs in GIS and remote sensing would not have an easily accessible file of the city boundaries. From this experience and others, I learned to jettison any basic assumptions I previously had regarding the existence and accessibility of data in India.

Language and culture created additional barriers to research. In Chandigarh, I often had difficultly communicating with the administrative employees who were assisting with my data requests. Determined meeting times were often frustratingly flexible and resulted in ample wait times. There were also technological discrepancies between

the research process in Chandigarh and Seattle. In India I was only provided data as hard copies, while in Seattle it was already in digital form. The data in hard copy form slowed down the research process because I needed to convert the data to digital form using several different techniques. It may have also introduced some error in the data from this manual conversion process. In general, I think the lack of digital storage of data inhibited Chandigarh from being able to provide ample data. The slow internet in India also hindered online research.

In the end, I was able to develop a modest but viable dataset that was the result of piecing together a variety of small pieces of data that I gathered from government agencies and research libraries. Conversely, in Seattle, I acquired some data as hard copies but the majority of the data was already in digital format. The data acquisition processes in Chandigarh and Seattle were quite distinct and provided lessons for future research.

LIMITATIONS

There are several notable limitations to this paper, which have influenced the scope of the research and the interpretation of the findings. Whenever conducting comparative research there are tradeoffs between accounting for the complexity of individual places and making generalizations between multiple places (Peters, 1999). Such tradeoffs are manifested when taking a case study, or configurative approach, versus employing a strictly statistical method. The former focuses on a thorough description of a particular place, accounting for as many and all variables as possible. The statistical method identifies certain variables and compares those across systems. Thus the case study approach is more capable of assessing the complexities of a certain place but less able to produce generalizations about multiple places. Due to constraints in time and resources, this paper favors the configurative over the statistical. Therefore, the findings are limited to descriptions of the data and observations, without the ability to make firm generalizations with statistical backing. The purpose of this paper was to provide a configurative analysis of two cities and create a framework for a subsequent

statistical analysis. In comparative studies, there is also a tradeoff between internal and external validity (Ibid.). In my research, internal validity is the degree to which population density or climate change has influenced electricity consumption over time and external validity is the extent to which the findings for Seattle and Chandigarh can be generalized to other cities in the US or India respectively. Because of the limits of my research design and use of data, internal validity is ostensibly greater than the external validity.

There also may be inherent limitations to comparing across political systems, geographical boundaries, and cultures (Ibid.). It can be argued that cities such as Chandigarh and Seattle are unique places whose patterns of growth and decline are the result of idiosyncratic processes and events that are endemic to their respective geopolitical environments. Conversely, structural-functionalism argues that all political systems can be compared, albeit according to generously broad concepts, because they must maintain similar core functions (Ibid.). As my discussion of urbanization science and scaling indicates, I believe that it is possible and useful to compare Chandigarh and Seattle, regardless of their apparent differences. Although these two cities may seem entirely disparate, they have several important similarities that may help mitigate extraneous variance and help justify comparison. For example, they have similar population sizes (500,000-1,000,000), relative levels of economic prosperity, and both rely upon glacial runoff for electricity generation and water supply. Nonetheless, as I approached these case studies from a comparative perspective, I understood and acknowledged the fundamental differences between the disparate contexts in which both cities exist. Given the stark differences between the two, any observed similarities may be especially notable.

Access to reliable data also limited the scope of research and depth of analysis. During the data gathering process I encountered a paucity of data in Chandigarh and a few data limitations in Seattle. Therefore, I was not able to include as many variables into the analysis. As a result, my ability to comprehensively discuss the determinants of electricity consumption in both cities is limited. Although population density, per

capita income, and electricity use may demonstrate similar trends over the observed period, there may be other variables, such as price of electricity, that have influenced these trends but were not included in the analysis because the data was not available. Furthermore, my analysis is limited by the quality of the data; in particular the precision and accuracy of the data that I acquired in India. The problem of data quality in India is not unique to my research. Other authors have previously cited the existence of dubious data in India; "many authors have underlined the problem of comparing over time and space the urban census data in India. They point out mainly the fuzziness of criteria that designate statutory town and census town as well as the lack of homogeneity in their application by different Indian states and from one census to the next since 1951" (Swerts, 2014). Although I cannot definitely comment on the quality of the data I gathered, I surmise from my experience gathering data and from other researchers, that more accurate and precise data could be gathered for these variables.

Comparing Chandigarh and Seattle is also complicated by the way that variables may be measured differently in India and the US. For instance, establishing reliable estimates for population density and energy use in Chandigarh is difficult because of informal residences scattered throughout the city. In addition to disparate shacks and tents, there are approximately 18 larger-scale slum settlements in the city, with total population reaching tens of thousands. This increases population density that is not accounted for in official statistics and these areas draw electricity illegally. Illegal electricity hookups are also not well documented. As a result there may be significant electricity use that is not necessarily associated with any particular use sector.

My sampling methodology also presents an additional limitation. For instance, my sample contains selection bias because I chose Seattle and Chandigarh out of convenience and expediency, rather than selecting cities randomly. Furthermore, any conclusions I make are limited by the ability of my samples to representation their populations; to what extent do Seattle and Chandigarh represent a typical city in the United States and India respectively? If my samples are not representative of their populations, then it is difficult to extrapolate the results of my analysis outside of

the case studies that I examined. With that in mind, Chandigarh is a unique city in the Indian context. Chandigarh was essentially designed from scratch, though there previously existed several small villages on the site in which the city was established, and was master planned based upon garden city principles by multiple planners, including the French architect Le Corbusier. In that sense, Chandigarh is rather unique and not representative of the majority of rapidly growing Indian cities. Nonetheless, regardless of its origins, Chandigarh still faces the same present day urbanization pressures that are being observed throughout India.

SUMMARY

This chapter presented a discussion of the results of my data analysis, based upon the concepts examined in Chapter 2 (Literature Review). The analysis demonstrates a variety of similarities and differences between energy-growth trends between Seattle and Chandigarh over time. Based upon these patterns, I discussed energy efficiency, the evolution of urbanization, the applicability of contributing to an urbanization science, climate change, and lessons gained from international research.

CHAPTER 6: CONCLUSION

This chapter concludes the paper by summarizing key findings, future research, and providing closing remarks. As outlined in the introductory chapter, my research questions ask: 1) How can comparing cities contribute to a shared understanding of the relationship between city size and energy use amid a changing climate?, 2) Are there generic patterns that can be observed in seemingly dissimilar cities?, and 3) What methodological approaches are useful for developing a theory of urbanization science? In order to investigate the original research questions, I hypothesized that as cities become bigger and warmer, their electricity use will rise as well. Moreover, I hypothesized that this relationship between city size, temperature, and electricity consumption over time in Seattle, Washington and Chandigarh, India is fundamentally different. Additionally, I hypothesized the existence of thresholds, where the impact of urban density and size eventually ceases to contribute to increased energy savings or efficiencies. To a various degree, my research was able to shed light on these inquiries. The outcome is several key findings that are both practical and theoretical.

FINDINGS

My research has highlighted several findings that are useful for practical planning purposes. Based upon the initial analysis, there appear few similarities between energy-growth patterns in each city and these are outnumbered by the ostensible differences. For instance, the residential sector is a primary consumer of electricity in both cities, although the growth of this sector in Seattle has plateaued while residential consumption in Chandigarh is rising. As Chandigarh experiences increased economic prosperity it would be wise to invest in energy efficient building design and residential energy conservation incentives. Although Seattle is becoming more energy efficient than Chandigarh over the observed period, I have not found any levels of density that engender an ideally energy efficient city. Although urban planners generally espouse compact cities as paragons of sustainability, it is still highly uncertain how effective that planning model will be in addressing global climate change (Marcotullio, 2013).

We should be leery of implementing any planning policies that assume a one-size-fits-all relationship between density and energy efficiency. Additionally, climate change will likely impact electricity use in both cities, though the specific outcomes will differ because of their disparate geographical locations. Moreover, Chandigarh's literal impact on climate and energy in Seattle will likely be minor, partly due to Chandigarh's unique heritage. Although energy use in Chandigarh is rising quickly, which contributes to global climate change, additional city growth will likely be constrained by the city's unique place in urban history. As a result, energy use in Chandigarh will be stifled and growth will be accomodated by adjacent cities.

My research also unearths several findings which are relevant to theory and contribute to the growing field of urbanization science. The process of urbanization that is currently occurring in and around Chandigarh currently appears unlike that which propelled initial growth in Seattle. Therefore, it is difficult, if not impossible, to generalize an urbanization curve in which both cities follow. More time is needed to observe growth patterns, especially in Chandigarh, to develop reliable theories of urbanization trajectories. It is possible to compare cities characterized by distinct socioeconomic and cultural contexts but such comparison presents a variety of methodological challenges. For example, this type of research faces ample impediments in acquiring comprehensive and accurate data. Attempting cross-country case study comparison on electricity use in cities is a challenging but tractable endeavor. These obstacles are indicative of the general challenge of attempting to contribute to an urbanization science. Recent research on complexity studies of cities has contributed much to the growing field of urbanization science, but it has eschewed a thorough contextual understanding in favor of generalizability. There are tradeoffs to taking a strictly statistical approach versus a descriptive approach. By exposing the importance of field observations, my research shows that mixed-methods research is a necessary component of urbanization science because quantitative theory needs to be tested in real world situations.

FUTURE RESEARCH

My research improves upon the existing literature in several ways and points towards the need for ample future research. First, my research explicitly addressing energy in terms of electricity use, whereas previous studies employed energy quite broadly. Considering that power generation accounts for the highest proportion of global GHG emissions out of all energy sectors, this is an important distinction to make (Montgomery, 2010). Also, most studies have analyzed energy use by incorporating transportation into their model. Therefore, most results indicate a positive relationship between energy and urban density because higher densities limit the distances that must be traveled using traditional transportation fuels. Future research should continue to disaggregate fuel types when studying urban growth in order to produce more nuanced analysis of urbanization-energy use patterns.

Secondly, I use the city as the unit of analysis, rather than taking a national or state perspective. Other studies that exclude transportation fuels and look solely at electricity have not used the city as the unit of analysis. Using the city as the unit of analysis is important because it empowers urban planners to directly use research results in practice. By taking this perspective, I intend my research outcomes to be directly applicable to city planners as they make decisions regarding future urban form and infrastructure in their jurisdiction. Moreoever, my research attempts to increase the amount of knowledge flow between cities amongst different stages of urbanization by comparing the dynamics of energy and urbanization between an American and Indian city. There are minimal studies that attempt to compare electricity-urbanization patterns of cities between different countries, especially those considered more developed and less developed. Other comparative research of this type generally compares cities within a country, or it compares entire nations on a global scale. Although research has analyzed this topic on the national scales, there is a need to study subnational scales, such as metropolitan areas (Liddle, 2013). The majority of comparative research is conducted at the country level, where there is ample data available from national governments and international institutions but city level data is less available. Future

work should expand the scope of the case studies research presented here and include additional cities from India and the US. I recommend additional collection of similar data on cities adjacent to both Seattle and Chandigarh to assist in further understanding the spatial factors that may be in play. Adding additional cities would increase the likelihood that the statistical findings would be representative of more cities in India and the US, rather than only representative of each city individually.

This paper serves as starting point for comparing the energy-growth patterns in two distinct places that may both benefit from comparative analysis. Due to a variety of constraints and limitations, the conclusions of this paper point to ample future research. This project was intended as a first attempt at investigating energy-growth patterns in two seemingly unique cities, using a mixed methods approach. Due to discrepancies in data availability, I was not able to perform much statistical analysis. A next step would be to gather additional data, which would enable more reliable statistical analysis. Non-stationary time series analysis is one advanced statistical technique that would likely be appropriate for this type of dataset. I recommend gathering additional quantitative data to fill holes in the existing dataset, as well as adding additional variables to the dataset. For example, there is general need to connect growth patterns within individual electricity sectors, such as residential, commercial, or industry, with other metropolitan growth variables (Solarin, 2013). Assessing the determinants of municipal electricity consumption at one point in time is a challenging endeavor because of the myriad variables that must be considered. Thus, attempting to explain the origin of municipal electricity consumption over time is even more daunting. Cities are complex entities that we are just beginning to understand. Examining this relationship is a messy and challenging endeavor due to the myriad variables that may play both direct and indirect roles in influencing electricity consumption. Once the dataset becomes more complete, I suggest advanced statistical analysis to bolster more reliable conclusions.

Existing, research on the relationship between a changing climate and electricity use is nascent and deserves further exploration, using case studies from cities in unique geographical areas. At this point in time, there is a near consensus that climate change

is impacting energy use patterns in cities but the exact relationship between geography and energy outcomes is unclear. This was demonstrated by comparing Seattle and Chandigarh. Changes in annual and seasonal temperatures impact electricity use for heating and cooling buildings, but the net energy impact is dependent on local geography. Some cities may actually use less energy under different climate conditions while others will use more. More research is needed on electricity use in geographically diverse cities that control for numerous climatic variables over an extended period of time.

Lastly, more research is needed, using multiple methodological approaches, to assist in establishing a coherent urbanization science and to resolve any existing tensions between theory and reality. For instance, there is a tension between claiming that there are universal characteristics of cities and examining urbanization as an evolutionary process. Such tensions arise from the complexity of the urbanization process and can be better understood through a combination of field research and quantitative analysis. Though advanced analysis of large datasets contribute much to theory, future research should needs to integrate qualitative observations for a science of cities to become established as a paradigm.

SUMMARY

In conclusion, this type of research is useful and is needed in the face of growing global challenges pertaining to climate change, energy use, and urbanization. Looking into the past is the first step in beginning to comprehend what may occur in a highly uncertain future. This paper showed that comparing cities from particularly unique international settings is challenging, but can yield useful insights. Both Chandigarh and Seattle face impending challenges that can benefit from insights gained through comparative research. Lastly, because of western society's primary contribution to present day changes in climate, we should lead the way in research and knowledge creation that will help engender more benign forms of future urban growth.

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