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The purpose of this dissertation was to devise a quantitative method to compare socioeconomic development and the associated urban growth, with the state of the natural environment. This research was developed on the premise that socioeconomic development is one of the major factors that drive urbanization and, urbanization impacts the environment. Especially when a geographic region experiences rapid urban growth, a preference for economic growth conflicts with the need to protect the quality of the natural environment in and around urban areas. This requires urban policy makers to design policies that balance the conflicting priorities. This research has developed quantitative metrics which have the potential to make it easier for policy makers and stakeholders to strike the balance between priorities for economic growth and environmental protection. And thus, help them make effective urban policies that are better suited for sustainable urban growth.

This work assessed the sustainability of urban growth in fifty three counties in central North Carolina with the help of sustainability indicators. The indicators were used as the tools to quantify economic growth and the state of the natural environment. And based on their characteristics, the indicators were aggregated either into a composite index for economic growth or, an index for environmental quality. The results are expressed with the help of these indices which conveyed multivariate information in a way that experts as well as the general public can comprehend. In so doing, this research

offered improvements in the procedure for selecting sustainability indicators, and in a method used to compute influence of individual indicator on the overall sustainability.

QUANTITATIVE ANALYSIS OF RESOURCE CONFLICT AND URBAN SUSTAINABILITY IN CENTRAL NORTH CAROLINA: A GISCIENCE BASED APPROACH

by

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Approved by

Dr. Rick L. Bunch
Committee Chair

Dedicated to my loving family whose support never wavered through this incredible journey

Dad, Vinayak

Mom, Madhuri

Brother, Soham

APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

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CHAPTER I

INTRODUCTION

This research has conceptualized urban sustainability as a phenomenon which emerges out of the interactions between socioeconomic and environmental systems. And, urban growth becomes a focal point of most of those interactions.

Socioeconomic development and urban growth share a symbiotic relationship (Masek et al. 2000, Deng et al. 2010). Urban agglomeration creates various economies of scale and promotes economic development. In turn, economic development acts as a magnet for educated and skilled population that becomes an integral part of a vibrant economy, for example, of a metropolitan area. These urban dwellers aspire for a wealthy and modern lifestyle characterized by certain lifestyle preferences such as, higher incomes, better housing, quality education, advanced health services, efficient transportation, or amenities like private automobiles, golf courses, and other recreational facilities. All efforts to satisfy these preferences result in consumption of resources and production of wastes (Johnson 2001). And, the intensity, pace, and spatial pattern of urbanization offsets the 'resources – waste products' balance and the urban growth becomes unsustainable in long run.

Although urban growth is essential and it has helped countries make economic progress (Tolley 1987), it incurs an environmental cost which is rarely accounted for in environmental impact assessments. Researchers have indicated that if the current

unsustainable urban growth continues, it will eventually retard socioeconomic development, lower the quality of life, and threaten the existence of urban areas.

Therefore, this research has defined urban sustainability as the state of harmony or balance between socioeconomic development, urban growth and the state of the natural environment and the quality of life. The research had two overarching objectives. The first objective focused on the investigation of whether growth in the study area is sustainable. The second objective was to develop quantitative metrics which will provide the stakeholders and policy makers an unambiguous basis to determine growth priorities and make informed decisions. Sustainability indicators are used to prepare a report card of urban growth which allowed a comparison of positive and negative aspects of growth and urbanization in the study area.

This research offered an improvement in a process to select sustainability indicators. The most common concern among the experts and users of sustainability indicators and indices has been the lack of robustness in the common indicator selection procedures which rely heavily on subjective and ad-hoc decisions made by experts or users. This research offered a way to make indicator selection robust and systematic by describing causal relationships among indicators with the help of an indicator framework (eDPSIR: enhanced Driving force - Pressure - State – Impact – Response) and then, making causal relationships the core of the indicator selection process.

Additionally, this research also described the use Principal Component Analysis as an objective and data driven technique to compute influence of individual indicators on the overall sustainability.

CHAPTER II

LITERATURE REVIEW

This literature review examines the scholarly work of geographers, urban planners, and other social scientists as it relates to a broader theme of sustainable urban development. The first section of this review discusses the different meanings of the terms ‘urban’ and ‘sustainable development’. It evaluates how researchers have defined the two terms, elaborates on the nuances between ‘urban’, ‘urbanized’, and ‘rural’. And, identifies the definitions of ‘urban’ and ‘sustainable development’ used in this research.

The second section briefly discusses the concept of sustainable development and identifies that, despite all the complexity surrounding it, sustainable development implies a delicate balance between all aspects of growth. The section also explores how scholars have researched various aspects of sustainable development and elaborates on the challenges of contemporary and sustainable urbanization. The second section examines issues such as human – environment interactions and human impacts on the environment. As it reviews popular and applied research that addresses these interactions and impacts, the second section of this review makes the case for indicator based assessment of sustainable development and composite indices. This literature review concludes with a description of utility, advantages of composite indices, and also, criticisms of those indices.

2.1 Defining Urban:

The word ‘urban’ is most commonly used to mean ‘city’ and it typically refers to a populated place with noticeable cultural diversity, vibrant economy, and other socioeconomic benefits and amenities that supposedly improve the quality of life of those ‘urban’ residents. In short, this means ‘metropolitanism’ (Kleppel 2002). Similarly, ‘urbanized’ implies an intensity of ‘urban ness’ a particular place exhibits. The term ‘rural’ is used to show the least or no urban character at all. These common perceptions about the meanings of ‘urban’, ‘urbanized’, and ‘rural’ are vague and subjective. Indeed ‘urban’ is a difficult concept to define because, it is complex and, has many aspects to it. More importantly, their descriptions change based on how the research question has been framed (Mcintyre et al. 2000).

Scholars lack consensus on an all-encompassing definition of ‘urban’. A geographer, lawyer, an ecologist, entrepreneur, economist all define ‘urban’ in a way that suits their needs and all definitions are logical in one sense or the other (Kleppel 2002, Mcintyre et al. 2000, Niemela 1999). Literature review shows that the term is defined either qualitatively, more like a description of what one can and cannot observe in a given place, or, quantitatively with the help of rigid metrics based on population count, density, or housing units. For example, Mcintyre et al. (2000) have studied sixty three peer reviewed articles which analyzed urban ecosystems, to understand how ecologists and social scientists have a different understanding of ‘urban’, even when urbanization is a social and ecological phenomenon. He notes that ecologists often use a categorical

approach to define ‘urban’. They define it loosely in terms of presence or absence of typical land uses such as housing units, built-up or paved surface, man-made parks, or planned open spaces. Some ecologists define ‘urban’ as a complex mosaic of human dominated and natural landscapes with a hierarchical organization of the components of an urban ecosystem (Rebele 1994). Others propose a more rigid definition by using the presence of humans to delineate an area as urban, or the absence to identify natural or rural regions. On the other hand, other researchers champion a linear gradient where urban ness of a place linearly decreases as one moves away from the urban core. This view appears to be based on the notion of concentric urban growth that radiates outwards from an urban center. For ecologists interested in the ecological footprint of a certain urban area, ‘urban’ means the built environment and they conceptualize it as a center of consumption of resources and production of wastes.

Mcintyre et al. (2000), note that ecologists’ definitions for ‘urban’ are typically qualitative and emphasize the ecological dimension rather than the socioeconomic dimension of an urban system. An ecologist naturally considers urban areas as the environment that has high human influence, and tends to highlight the influence in the definition. Social scientists conceptualize urban areas as agglomerations of population, centers of economic activities and complex social interactions (Glaeser 1998). Thus, a social scientist’s definition for ‘urban’ tends to stress human dominance in an area as expressed by population, density, housing or commuting characteristics, or other socioeconomic characteristics. These definitions result from extensive surveys and complex statistical analysis. Social scientists mainly rely on definitions prepared either by

the U.S. Census Bureau or, the Office of Management and Budget (OMB). It appears that these two federal systems have produced slightly different definitions of 'urban'. The differences resulted from the logic of how urban and rural was conceptualized by the two federal systems (Isserman 2005).

As Isserman (2005) states, the Census Bureau uses a simplistic logic in defining urban and rural areas. It associates built-up area with urban character and, what remains is automatically considered rural. Implied in this logic is the separation of urban from rural and, ignorance of interactions between the urban areas and its surroundings. It also means that the Census Bureau's definition is based on population and density and it does not explicitly consider the area occupied by a particular patch of built-up land, and thus, this definition appears to lose on the grounds of consistency across the U.S. On the other hand, the OMB's logic in defining urban and rural areas is based on the concept of a functional region. Their definition integrates urban and rural into a metropolitan area. A metropolitan area has a predominantly urban county at the core and, based on a relationship that each adjacent county shares with this core, those adjacent counties are added into a metropolitan area. This integration accounts for a variety of ties between the core and its surroundings for example, jobs and work force, competition about land and land use, education, infrastructure, agriculture, mining, or other issues on which urban and rural interests are tied up.

When we compare the Census Bureau's definition for 'urban' with that of the OMB, the OMB's definition seems more appropriate because, almost all counties have

both urban (built-up) and rural (no built-up, natural) areas. Isserman (2005) have shown that about fifty percent of rural population in the U.S. is located in places that have strong economic and social ties with nearby cities. Therefore, it makes sense to integrate an urban core and its surrounding into one functional region.And this is especially true considering the leapfrogging of urban growth which picked up momentum in the late 20th century (and it still maintains that momentum).

The literature also suggests that U.S. Census Bureau has made a conscious effort to improve its definition for 'urban' since 1950 (U.S. Census Bureau 1995, 2012 http://www.census.gov/history/www/programs/geography/urban_and_rural_areas.html - accessed on 1/20/2013). As the Census Bureau's definition for 'urban' evolved through time, it became more inclusive and more similar to the definition produced by the OMB.

For example, for population censuses in the United States prior to 1950, the census bureau used a rigid and exclusive definition for 'urban'. Territories, persons, and housing units in incorporated places with a population of 2500 or above and, other areas which had population and population density above a certain threshold specified in special rules were considered urban. According to this definition all unincorporated places and territories were excluded from being classified as 'urban' even though they were likely to have exhibited urban attributes and a functional relationship with the nearby 'urban' place.

The census bureau acknowledged the limitations and defined the term 'extended city' in 1960, as an improvement over the earlier definition. This definition was more

inclusive in nature as ‘urban’ included populations, territories, and housing units which primarily had rural environments. And as a result of this, some cities started extending their boundaries to include surrounding regions that were essentially rural in character. And thus ‘extended city’ partially accounted for functional relationships between an urban core and its surroundings.

As part of its continued efforts to refine the definitions for urban and rural, the census bureau defined ‘urbanized areas’. These ‘urbanized areas’ were basically similar to ‘extended cities’ in the sense that they comprised of a central place represented by a significant urban core and, densely settled surroundings which represented the urban fringe around the central place. However, with ‘urbanized areas’ the census bureau introduced some rules that precisely determined what can be classified as an urban fringe in a given setting. It appears that these rules were prepared to account for the functional relationships between the urban core and its surroundings and, they tended to be inclusive rather than exclusive. For example, the Census Bureau states,

> The urban fringegenerally consists of contiguous territory having a density of atleast 1,000 persons per square mile. The urban fringe also includes outlying territory of such density if it was connectedto the core of the contiguous area by road and is within 1 ½ road miles of that core or within 5 miles of the core butseparated by water or other undevelopable territory. Otherterritory with a population density of fewer than 1,000 peopleper square mile is included in the urban fringe if it eliminatesan enclave or closes an indentation in the boundary of the urbanized area (U.S. Census Bureau 1995).

In line with these inclusive definitions for ‘urban’, this research accepts the broader meaning encompassed in ‘urban’ and the concept of ‘urban ness’. This study

denies the rigid association that only metropolitan can mean 'urban' and the rest has to mean 'rural' and thus, avoids the 'county trap' of Isserman (2005). Rather, it accounts for the functional relationships between the urban core and its surroundings (Lichter and Brown 2011, Irwin et.al 2009). In doing so, this research defines 'urban' as all those areas, in addition to urban cores, which fulfill the following criteria (Kleppel 2002)

a. Have sizeable population and population densities
b. Possess at least the basic level of infrastructure that is typically found in a city
c. Depend on urban services, either delivered locally or provided by a civil authority in a nearby city.
d. Share a functional relationship with a central place or a city

2.2 Sustainable Development:

The notion of what we today call 'sustainable development' was described even in medieval teachings as 'living in harmony with nature and in society", well before the modern science took notice (Mebratu 1998). It was only after the World Commission of Environment and Development (WCED) published a famous report "Our Common Future" in 1987, did the term become a jargon and found its way on the agendas of national and international institutions, governments and non-governmental organizations alike (Mebratu 1998, Lele 1991, Parris and Kates 2003).

The notion of sustainable development originated when keen observers and philosophers could witness how unprecedented economic growth that followed the industrial revolution of the 19th century, was destroying the natural environment. These

early scholars could also foresee the continued economic growth along and unprecedented extraction and consumption of resources that seemed significant enough to inflict permanent damage (or irreparable within one's lifespan) to the natural environment. This awareness had the seeds for the present day environmentalism and the debate about sustainable development. The importance of the environment for the overall well-being of humans was first recognized at the UN Conference on Human Environment held in Stockholm in 1972 (UNEP 21st plenary Meeting 1972, Mebratu 1998). The conference did not explicitly coin the term 'sustainable development' however; it identified man as the most influential agent that modifies the earth's environment. Furthermore, it recognized the human impact on the environment and acknowledged the urgent need for the global cooperation to manage the environmental consequences of our actions (UNEP 21st plenary Meeting 1972). With the progress of time the conflict between economic growth and the state of the natural environment grew stronger and, probably as a result of that, many international organizations like International union for the Conservation of Nature (IUCN), United Nations Environment Program (UNEP), World Wildlife Fund (WWF), World bank, the U.S. Agency for International Development (USAID), Canadian International Development Agency (CIDA), Swedish International Development Corporation Agency (SIDA), World Resources Institute (WRI), the International institute for Environment and Development (IIED), World Watch Institute, and the World Commission on Environment and Development (WCED) made efforts to define and conceptualize a pattern of growth or development that would allow us to maintain growth and sustain the environment - sustainable development.

Of all these efforts, WCED's definition of sustainable development enjoyed the most wide spread acceptance from experts all over the world (Tanguay et al. 2010).

In addition to these institutes, hundreds of individual researchers explored the meaning and the construct of the concept of sustainable development. They soon realized that sustainable development is a deceptive concept. It was considered important but, slippery. The inherent vagueness involved in the term sustainable development prevented consensus among scientists and experts on how to define it, and what does it exactly include? As a result of numerous uncoordinated studies, the scientific literature is now filled with varying and even contradictory definitions of sustainable development (NSF Workshop on Urban Sustainability 1998, Mebratu 1998, Lele 1991, Parris and Kates 2003). Since sustainable development is an integral concept in this research, the following sections will briefly review some major definitions of the concept, describe that they are actually variants of a common definition, and finally clarify how sustainable development is conceptualized in this research. This is important and necessary because scholars believe it is a difficult task to come up with just one all-encompassing definition and hence, it is the responsibility of the individual researcher to clearly define sustainable development for a particular study (Lele 1991, Parris and Kates 2003).

The definition of sustainable development, when conceptualized from a holistic perspective, appears vague. When it is defined with a reductionist point of view, it can be specific but then it loses the bigger picture. This means that the definition of sustainable development can seldom be comprehensive and precise at the same time. As a result,

individual researchers, institutions, politicians, and other experts have different opinions about what needs to be sustained and, what needs to be developed. Literature review suggests that the definitions and conceptualizations differ with respect to institutional objectives, focus and dimensionality of the desired solution, actors or instruments (like governments, NGOs) who would realize sustainable development, the geographic scale of concern, and the time span addressed (NSF Workshop on Urban Sustainability 1998, Mebratu 1998, Lele 1991, Parris and Kates 2003).

For example, Mebratu (1998) has summarized the 'institutional version' of the sustainable development (Table 1). National or international institutes typically have to deal with a larger and a diverse group of stakeholders who influence the choice of what the institute considers important to sustain and, what it decides to develop. And, it is generally difficult to build a complete consensus among such a diverse group of patrons. Therefore, these larger institutes typically produce broader definitions of sustainable development, with a few exceptions. As these definitions usually consider a multitude of things at one time, they tend to describe the objectives of sustainable development in a generalist sense. Moreover, a sustainable development initiative (agenda, design, actors, instruments, methods, and solutions) is managed from top-to-bottom. Public participation or consultation is minimal, if it is present at all.

Table 1. Institutional SD – Definitions & Conceptualizations (Modified from Parris & Kates 2003).

Institute	Sustain	Develop	Dimensions	Actors	Spatial scale	Temporal Scale
The World Conservation Union (IUCN)	Ecosystem diversity & quality such that it supports biosphere. Such that it provides opportunities for future	A condition that allows society to meet its needs and provides numerous chances to meet its potential	Multi dimensional	National governments	Country	Not specified
World Economic Forum	Vital environmental systems at their healthy levels.	Well-being of people and social systems	Two (Environment &Society)	National governments	Country	Not specified
Global Scenario Group	Essential health, services, & beauty of the earth	Abilities of a society to satisfy needs and opportunities for education, employment, & participation	Multi Dimensional	National governments	Country	Through 2050
Global Reporting Initiative	Resources (reduced consumption of raw materials, emissions of pollutants	Economic growth (profitability, employment, workforce diversity, health, safety, & dignity.	Two (Environment and Economic Growth)	Governments NGOs & Businesses	variable	Current year reporting

Mebratu (1998) compares his 'institutional version' of sustainable development with its 'academic version' (Table 2). This version summarizes how academicians respond to the debate over sustainable development.

He argues that academicians often take a reductionist approach and define sustainable development with much more precision.

Table 2. Academic Version of Sustainable Development (Mebratu 1998)

Academic discipline	**Drivers**	**Source of Environmental Crisis**	**Solutions Epicenter**	**Instruments**
Environmental economics	Economic reductionism	Undervaluing of ecological goods	Internalization of externalities	Market instrument
Deep ecology	Ecological reductionism	Human domination over nature	Reverence and respect for the nature	Biocentric egalitarianism
Social ecology	Reductionist-holistic	Domination of people & nature	Co-evolution of nature and humanity	Rethinking of social hierarchy

In addition to this, there are a number of sustainability initiatives with a regional or local focus. These efforts are usually led by NGOs, metropolitan planning organizations, community based organizations, or university researchers and, differ characteristically from the 'institutional version'. However at times, resemble the 'academic version' of sustainable development. A review of prominent and representative community based sustainability initiatives conducted in the United States highlights some of their unique characteristics such as;

a. Focus on a smaller geographic area or a region (e.g. county or metropolitan area)
b. Rely on public participation. A bottom-to-top feedback mechanism does exist
c. Clearly define objectives which include – enhance public discourse and informed decision making, improve the quality of life and overall well-being of a

community by balancing social, economic, and environmental dimensions of growth

d. Make use of objective tools - sustainability indicators - to track progress towards sustainable development. And, cover common themes (See table) that broadly cover social, economic, and environmental dimensions associated with growth.

Table 3. Structure of Community Based Sustainability Initiatives

Dimension	**Themes**
Social	Cultural life, recreation, & arts, Civic vitality, Public safety Education, Health
Economy	Economic vitality or growth, Housing, Technology
Environment	Development patterns, Sprawl, Commuting patterns, Efficient transportation, State of the environment & natural resources

Sources: Charlotte Regional Indicators Project (2007), Indicators of Smart Growth in Maryland (2011), Community Indicators Initiative of Spokane, Washington (2005), Boston Indicators Project (website accessed on 1/26/2013)

This review indicates that most, if not all, definitions and conceptualizations of sustainable development focus on three dimensions – social, economic, and environmental (Table 3). Sustainable development champions a healthy balance between the three dimensions so that the growth continues with minimal damage to the environment, resources, and other natural life support systems. The objective of any sustainable development initiative always is a better quality of life and overall well-being.

And therefore, all the definitions of sustainable development can be considered variants of the WCED's definition - "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987).

2.3 Sustainable Urban Development:

This research conceptualizes sustainable development as the state of harmony or balance between socioeconomic development, urban growth and the quality of the natural environment. This conceptualization is based on the premise that socioeconomic development and protection of the environment often become conflicting priorities when it comes to sustaining urban growth in a long run (Campbell 1996, Dijk and Mingshun 2005)

Socioeconomic development and urban growth share a symbiotic relationship (Masek et al. 2000, Deng et al. 2010). Urban agglomeration creates various economies of scale and promotes economic development. In turn, economic development acts as a magnet for educated and skilled population that becomes an integral part of a vibrant economy, for example, of a metropolitan area. These urban dwellers aspire for a wealthy and modern lifestyle characterized by certain lifestyle preferences such as, higher incomes, better housing, quality education, advanced health services, efficient transportation, or amenities like private automobiles, golf courses, and other recreational facilities. All efforts to satisfy these preferences result in consumption of resources and production of wastes (Johnson 2001). And, the intensity, pace, and spatial pattern of

urbanization offsets the ‘resources – waste products’ balance and the urban growth becomes unsustainable in long run.

Urban growth is essential. Urbanization has helped countries make economic progress (Tolley 1987). However, socioeconomic development and urban growth comes at a cost. It damages the natural environment and, popular research (World Resources 1996-97) have indicated that if the current unsustainable urban growth continues, it will eventually retard socioeconomic development, lower the quality of life, and threaten the existence of urban areas. Therefore, it is important to explore the balance between socioeconomic development, urban growth, and the state of the natural environment, which this research does.

2.4 Environment – Development Nexus:

The relationship between natural environment and socioeconomic development is complex and indirect in the sense that it is often mediated through urban growth. Researchers conceptualize this relationship with a triangle. If urban growth is placed at the apex of the triangle, then, socioeconomic development and natural environment must be placed at the remaining two vertices. This section briefly explains how socioeconomic development is considered to promote urban growth, and how urban growth damages natural environment. The purpose is to clarify how economic development and environment become conflicting priorities when the former does not logically seem to have any adverse effect on the later. And, make the case for the analysis of the conflict

between the priorities for economic development and the priorities for the protection of the natural environment – resource conflict.

2.4.1 Economic Development and Urban Growth

Researchers consider economic development as a major driving force for urban growth (Satterthwaite et al. 2010, Christiansen and Loftsgarden 2011,). Liu et al. (2005) and Deng et al. (2010) studied the relationship between economic growth and expansion of urban land in China. Their study demonstrates that economic development and the structure of the economy, both are important determinants of expansion of urban lands. They measured economic development primarily as an increase in GDP and found that about 10% increase in GDP associates with about 3% rise in urban lands. Economic structure, on the other hand, is determined based on the share of GDP that comes from agriculture or manufacturing compared to the share that comes from knowledge and service industries. Deng et al., (2010), note that urban land expands as the share of knowledge and service industries in the GDP increases. Moreover factors like population growth, increase in agricultural investments and highway density also seem to correlate positively with the expansion of urban land.

Masek et al. (2000) did a similar study to explore the relationship between the dynamics in urbanized area and the variations in economic and demographic conditions. This study looked at the urbanized portion of the Washington DC Metropolitan Statistical Area and the surrounding region (for details, see Masek et al. 2000). Their results, also, yielded a positive correlation between increase in urbanized land and economic

development and population growth. Even though they refrain from defining a clear cut cause – effect relationship between economic development and urban growth, they do point out that, the relationship is systematic and urban growth is a response to the dynamics of economic and social factors. Furthermore, Maseket et al. (2000) state that these factors influence the choices individuals make regarding their lifestyles and these choices are often manifested as suburbs or urban sprawl.

Christiansen and Loftsgarden (2011) elaborate on a general mechanism of how socioeconomic factors actually influence the choices individuals make about their lifestyle. They studied urban sprawl from this perspective and identified various drivers of urban sprawl. Economic development is one of the major drivers.Their research builds on the statistical results of other studies and explains how the local and even international economic conditions (growth & structure) encourage population to agglomerate in a city and thus promote urban growth. They elaborate that, the population that migrates to a city in search of a better and wealthier lifestyle possesses the necessary skills and a drive to contribute to the mostly non-agricultural urban economy. As a result, the migrant population quickly integrates itself with the city's economy. This vibrant economy and an urban agglomeration offer advantages for access to and the use of public services, resources, and amenities. When the urban dwellers consume these urban services, it generates a demand for their supply which feeds back to economic development. This 'consumption – demand – supply' dynamic establishes a symbiotic relationship between urban growth and economic development. However, with continued urban agglomeration, competition for better services and amenities sets in. Also, scarcity of

resources such as water, clean air, or affordable housing makes itself noticeable, and this, often forces some urban dwellers to move out from the urban core and settle in a suburban setting. This form and pattern of urban growth takes a toll on the natural environment and therefore the relationship between urban growth and the state of the environment merits more attention.

2.4.2 Urban Growth and Natural Environment

'Urban resident' might correctly describe most of us living in the 21st century. Popular research has shown that humanity has never been so urban ever before in its entire history, and their projections of urban growth hint at continued increase in the growth in the foreseeable future. The intensity and pace of contemporary urban growth is a concern for all because,it poses social, economic and environmental challenges. Among those, environmental degradation is perhaps the most important (Sen et al. 2000). Moreover, the spatial pattern of modern urban growth, often described as sprawl, seems to worsen the issue of sustainability.

Johnson (2000) summarized prominent definitions of urban sprawl and characterized it as an urban landscape that has segregated land uses, automobile dependent transit, a push for Urban growth at suburban or exurban locations, lower residential and employment densities and an uncoordinated pattern of development with wasteful use of resources. A majority of scholars consider urban sprawl as a serious threat to the environment. Environmental impacts of sprawl can be grouped into two broad categories. First are those associated with excessive consumption of natural open

space or farmland and the resultant ecosystem damage with the loss of biodiversity. And second are the impacts associated with increased pollution, heat island, increased runoff of water, and health conditions.

As sprawling urban growth consumes natural open space, it hampers the ability of the ecosystem to provide resources and absorb wastes. A disturbed supply of ecosystem resources has adverse impacts on economic activities and it lowers the quality of life of urban dwellers. This threatens the sustainability of urban growth. Furthermore, urban sprawl promotes automobile dependent transit, extensive use of fossil fuels and other resources. This typically results in increased air pollution. Also, with the expansion of impervious surface, runoff increases which leads to increased risk of flooding and increased water pollution. When population is exposed to higher levels of atmospheric pollution and stresses related to long commutes, they run higher risk of developing respiratory and cardiovascular health conditions.

2.4.3 Conflict between Economy and the Environment

When we simultaneously consider the two relationships described above, it becomes clear that economic development is a major driver of urban growth. Urban growth is also a major factor that threatens the natural environment, especially when it is rapid and sprawling. This makes economic development and protection of the natural environment conflicting priorities of urban planning.

Urban growth in a region is considered sustainable when the region achieves its targets of economic development while still maintaining the quality of the environment at

a desired level so that, urban dwellers have the opportunities to lead a prosperous and healthy life. Thus, in order to ensure sustainable urban growth or development, urban planners and decision makers have to strike a delicate balance between the priorities for economic development and the priorities for the protection of the natural environment.

Researchers have studied urban growth and sprawl from different viewpoints. The next section reviews prominent of those viewpoints and makes a case for indicator based assessment of sustainable urban development.

2.5 Urban Growth Research – Viewpoints, Approaches and Methods:

Popular research studies urban growth from two viewpoints. The first deals with the spatial form and pattern of urban growth. The second viewpoint compares advantages and disadvantages of modern urban growth with the intent to determine whether contemporary urban growth is desirable or not. The approaches that scholars take and the methods they apply to study urban growth change with their perspective of urban growth. Each of those approaches and methods have a unique purpose, and they shed light on different aspects of urban growth.

2.5.1 Urban Form and Spatial Pattern

Urban form refers to the overall appearance or morphology of an urban growth. For example, when a layman sees a satellite image of an urban area, he sees if the growth is spread over a large geographic area. He also identifies any patches of dense growth against any sparse growth. Unknowingly, he captures urban form. Scientists, however,

express urban form with the help of quantitative measures of growth that primarily capture the degree of centrality and the spatial relationships which connect geographic units of analysis. Scholars have extensively studied urban form because it characterizes urban growth, and directly determines any positive or negative impacts the growth might have on the economy, society, or the environment (Seto et al. 2010).

The research on urban form evolved over time. Earlier studies compared the population growth of core areas with that of suburbs, and in most cases, found that suburbs grew in size relative to the core areas or central cities (Seto et al. 2010). Scholars also quantified urban growth as a function of density (population, housing units, or employment density) and related this density to the distance from the urban core. Since low density growth is the most prominent feature of sprawl, researchers studied the density gradient and determined threshold values. If the density of urban growth in a region was found to be below the threshold, the region was considered to have urban sprawl. Measures like these were aggregate and static in the sense that they could only quantify overlying geometric form at a given time however, could not relate the form with the dynamic socioeconomic and demographic factors which interacted to create the form. Also, without the knowledge of underlying processes, measures could not be modeled to predict changes in urban form.

Approach to analyze urban form changed when researchers explicitly attributed urban form to underlying spatial processes. Researchers borrowed metrics from landscape ecology and fractal geometry to explain the spatial interactions between social,

economic, and demographic actors that shaped urban growth (Frenkel and Ashkenazi 2008). With this change, the focus of popular research shifted from urban form to the change in urban form in space and time. A change in urban form is best captured by changes in land use, and thus, landscape metrics like continuity, concentration, centrality, nuclearity, density, mixed uses, proximity, accessibility, heterogeneity index, contiguity index, and patchiness became the tools to quantify urban form and model the changes in it (Song and Knapp 2004, Galster et al. 2001, Sudhira et al. 2004, Ewing et al. 2002, Torrens and Alberti CASA Working Paper 27).

Abilities to model urban form and the knowledge of underlying spatial processes allowed researchers to predict the spatial locations of future urban growth. This triggered an extensive development of urban simulation research, and scholars developed mathematical models to simulate urban form and the location of future growth. Prominent of these are automata class and agent based models. These conceptualize geographic space made up of pixels – discrete units of analysis. And then, each of these pixels is made to evolve in time and space based on mathematical rules.

While a number of efforts were being made to simulate growth and model urban sprawl, proponents of new urbanism were advocating for compact development and rigid growth boundaries. The popular belief was that a compact, mixed use, and transit oriented urban growth would be self-sufficient and sustainable however, research has shown weak or even negative correlation between city's compactness and sustainability (Newman 2005).

Research on urban form and the spatial pattern of growth sheds light on the geometry and spatial location of current and future urban growth. The metrics allow researchers to better characterize urban sprawl and distinguish it from the normal urban growth. However, this research does not explicitly state whether urban growth or sprawl is a state to be desired or not. Without any meaningful comparison between the advantages and disadvantages of urban growth in a particular area, decision makers cannot decide whether to promote further growth or curb it.

2.5.2 Cost –Benefit Analysis of Urban Growth

One way to compare advantages of urban growth with its disadvantages is to perform a cost-benefit analysis. As explained earlier, urban growth is preferred for the social and economic benefits it offers however, it is criticized for the negative impacts it has on the environment and human health. The first step in the cost-benefit analysis of urban growth is to identify specific costs and benefits as they relate to both, economy and the environment. Urban growth incurs costs as a huge amount of money has to be spent to provide and maintain the necessary infrastructure and public services to support growth. Economic benefits, on the other hand, are expressed as increases in revenues, businesses, or employment. Both, economic costs and benefits of urban growth are naturally expressed in monetary terms and are therefore easy to quantify. On the contrary, urban growth incurs environmental costs because of pollution, deforestation, or waste production. Any environmental benefits of urban growth are difficult to notice, however, urban agglomeration and economies of scale can sometime function efficiently to

produce some environmental benefits of urban growth. Nonetheless, environmental costs and benefits are rarely expressed in monetary terms, and are therefore difficult to quantify. Researchers have long identified the need to monetize the environmental costs if urban growth to represent the true cost of growth. Ecological economists have applied survey based methods (revealed and stated preferences) to monetize environmental costs. However, this exercise is highly subjective and scholars have heavily criticized it. Moreover, they also question the reliability of methods used to monetize environmental costs because, the methods rooted in conventional economics seem incompatible to assess the true cost of a resource that is not a commodity in the regular market.

2.5.3 Indicator Based Assessment of Sustainable Urban Growth

Another way to prepare a report card of urban growth and compare it's positive and negative sides, is indicator based assessment of sustainable development. Researchers develop sustainability indicators to study complex systems. These indicators are used as tools to evaluate the system's current state and performance, possible future trajectories of the system, and any signals that might warn of impending changes in the system's behavior (McCool and Stankey 2004). Scholars conceptualize urban regions as complex systems that have three major components – society, economy, and the natural environment. Given this, an indicator of urban sustainability is a quantitative variable that specifically quantifies at least one characteristic or a component of a complex urban system. For example, number of private automobiles per family can just be a variable, without a particular context. However, when the variable is associated with the ability of

the population to purchase and maintain those automobiles, it serves as an indicator of economic performance or growth. Similarly, ambient concentrations of pollutants can be a mere number. When placed in a broader context of vehicular exhausts, emissions from industrial facilities, and its effects on species diversity, and human health, those numbers become the indicators of environmental quality. This means that an indicator has a specific role in the evaluation of the performance of the complex system, and has a broader significance than a mere variable (Tanguay et al. 2010, McCool and Stankey 2004). Furthermore, Maclaren (1996) differentiates indicators from variables because; indicators suggest (if not highlight) linkages and relationships between different components of a complex system. Knowledge of these interactions furthers our ability to evaluate and model the system performance. She also notes that when sustainability indicators have spatial attributes, they allow us to portray the dynamics of growth or sustainable development over geographic space. And such a portrayal helps scholars and decision makers take informed decisions.

These indicators quantify sustainability (rather than urban form and spatial pattern of urban growth) and allow researchers to track progress of a certain region towards the goals of sustainable development. In this sense, indicator based assessment of sustainable development is comprehensive, as the analysis compares different dimensions of growth and helps scientists determine whether the growth is equitable, livable, and viable, and hence sustainable (Tanguay et al. 2010).

Interest in the development and use of sustainability indicators was seemingly triggered by the publication of Brundtland commission's report, 'Our Common Future', in 1987 (Tanguay et al. 2010, McCool and Stankey 2004, Maclaren 1996). As extensive debate on sustainable development followed the publication, researchers realized the need to develop 'new signals of urban growth' (Alberti 1996, Livermann et al. 1988) that were easy to measure, able to capture the dynamics of growth, and could help make better informed policy decisions. Then, international organizations took the lead to develop and use sustainability indicators. For example, the UN Commission on Sustainable Development (UNCSD), United Nations Center for Human Settlements (UNCHS), The World Bank, World Health Organization (WHO), Organization for Economic Cooperation and Development (OECD), World Resources Institute (WRI), and European Environmental Agency (EEA) channeled huge amount of efforts and resources to develop sustainability indicators (Alberti 1996). Since then, sustainability indicators have been a popular choice of researchers, planners, and politicians alike. This is primarily because of ease of indicator use and their ability to convey complex information in a meaningful way such that, it is understood by experts as well as common public (Neimeijer and DeGroot 2008). As a result, the work on indicators has crossed the disciplinary boundaries, and is being conducted on a wide range of geographic scales (McCool and Stankey 2004, Livermann et al. 1988, Shen et al. 2011). Such a widespread use of indicators is asserted by a large number of sustainable community initiatives and other such efforts that develop and use indicators to address sustainability issues at various scales like city, metropolitan statistical areas, or functional regions that constitute

a group of adjacent counties. Sustainability initiatives at local and regional scale have proliferated in the developed countries (See 'sustainablemeasures.com' for a detailed list of local indicator based projects in the United States).

Maclaren (1996) describes how a typical sustainability indicators based project is structured, and how the indicators are actually used to report on urban sustainability. In this section, four prominent indicator based projects are reviewed. Each project was (or still is being) conducted in the United States at the community or regional scale, and how they fit into the structure described by Maclaren (1996).

The first project that is reviewed is Sustainable Seattle (1998). This project can be considered as the father of most other sustainability indicator based projects because,

> Sustainable Seattle is acknowledged world wide as a leader in the development of regional sustainability indicators based on citizen's values and goals for their communities. Redefining Progress, an independent organization, surveyed over 170 sustainability projects around the country and found that at least 90 of them used Sustainable Seattle as a model for their own initiative (sustainableseattle.org accessed on March 7th 2013).

The second is Boston Indicators Project (2004). The project notes North Carolina's Piedmont district as one of the Boston's competitor regions that replicates 'Boston's formula'. The third project is, Indicators of Smart Growth in Maryland (2011). Their report mentions that the Maryland project "is viewed as an innovative approach to combat ills of sprawl and protect the natural resources, while still retaining the control on land use". The last project is Charlotte Regional indicators Project (2007). This is arguably a major and widely accepted sustainability indicator project in North Carolina.

Step 1. Define Sustainability and Identify purpose for the development of Indicators

Researchers must first identify their own meaning of urban sustainability, and then, specify what they need to achieve to consider the development in their city or a region as sustainable. This means that researchers must have a clear idea about the purpose or a desired state for which they are developing sustainability indicators. Researchers and other institutions which work towards sustainable development have unique goals for sustainability.

Sustainable Seattle aims to develop actionable indicators in the sense that, they guide actions of individuals to complement policy decisions taken at a higher level in the hierarchy. Boston Indicators Project expects their sustainability indicators foster public debate and awareness about the sustainability issues, and the project also wishes to make the data accessible to public. The goal of the Maryland project is to analyze time-series data and present the results in a form that is easy to read, use, and evaluate. This project answers a question; 'where the growth is effective, and where can we improve it?' Thus, it attempts to direct urban growth to most suitable places rather than curbing the growth altogether. The Charlotte project also has similar goals. It analyzes how sustainability indicators change over time and provides benchmarks. The project also compares these sustainability trends with the trends observed at the state and national level.

Moreover, Alfsen and Sebo (1992) reviewed how national and international organizations define their goals for sustainability (Table 4).

Table 4. Sustainability Goals for Indicators.

Organization	Sustainability Goals
Office of Economic Cooperation and Development (OECD)	Sustainability indicators track progress in both, economy and environment. The purpose is to analyze the relationship between the two and integrate that with policy decision making. Target audiences are decision makers.
The Economic Commission for Europe (ECE)	Indicators are developed to study the current state and future trends in the environmental conditions. Focus is on the environmental dimension of sustainability
The Statistical Office of the United Nations (UNSO)	These indicators track the changes in natural resources. Target audiences are policy makers. UNSO expects their indicators to be useful for national policy decisions, and international comparisons.
Environment Canada	Indicators focus only on environmental issues, and are designed to facilitate effective communication with experts and common public alike. The goal is to report the state on the environment as an index.
The Swedish Commission for Environmental Accounting	The goal is to synthesize individual indicators into indices that are expected to track sustainability of different components of the natural environment.
Danish Environmental indicators	Apparently, the goal of these environmental indicators is to promote public debate on environmental issues and facilitate public participation.

Step 2. Define the Scope

Once the researchers have defined their goals for urban sustainability, they must specify the scope of the indicator project. Maclaren (1996) notes that the scope of the project includes a number of things like definition of the target audience, spatial and temporal scales, and the number of required indicators.

Sustainable Seattle considers all aspects of sustainable development. When the project developed their fourth set of indicators in 1998, the objective was to develop up to 70 indicators to look over a 5 year period. The Boston project, on the other hand, delineates 10 specific sectors (see 2004 report for details) which, it considers important to monitor in order to track Boston's progress towards the sustainability goals. The temporal aspect the Boston project considers depends on the availability of the data. If the data are available, indicators are analyzed over time. If not, they are analyzed as a snap shot in time. The Maryland project distinguishes between 6 categories of indicators to monitor performance of 10 sustainability principles it defines (see 2011 report for details). Whereas, the Charlotte project considers that sustainable development is a combination of economic, environmental, and social factors. It identifies 10 themes and monitors those with a total of 54 indicators.

Step 3. Select Indicator Framework

The third step is to choose an appropriate indicator framework. These frameworks help simplify the complexity of urban systems, and in so doing, frameworks provide an opportunity to study the interactions between various indicators. Knowledge of these interactions allows researchers to take informed policy decisions.

The four sustainability indicators projects that are reviewed here do not explicitly refer to any indicator framework. However, Alberti (1996) reviewed the various frameworks that are commonly referred to in indicator based studies. The first is the Pressure – State – Response (PSR) framework, developed by OECD. The PSR

framework categorizes indicators as pressure, state and response.Each of these categories refer respectively to the causes of the stress (e.g., increased use of automobiles), the current state of the system (e.g., increased air pollution), and the efficacy of responses that are designed to reduce the stress on the system (e.g., public transit oriented development policies). Other frameworks such as, Driving force – State – Response (DSR), and Driving force – Pressure – State – Impact – Response (DPSIR) represent arguable improvements in the original PSR framework.

Step 4. Define Indicator Selection Criteria

The fourth step is to define indicator selection criteria. These criteria are the general rules used to screen the variables before they are included in the analysis, as indicators. Scholars have come up with a variety of selection criteria. These, in general, make sure that the indicators are "scientifically valid, represent a broad range of conditions, able to respond to change, relevant to the needs of potential users, based on accurate and accessible data, attractive to the media, and are unambiguous" (Maclaren 1996).

It is a common practice to initially select a large number of indicators that are subsequently evaluated to define a final set of indicators. The purpose of their evaluation is to reduce clumsiness, redundancy, and any unreliable indicators. The evaluation process ensures that the retained indicators best represent at least one of the goals of urban sustainability. Maclaren (1996) describes how researchers use a variety of methods to evaluate these indicators. To one end, is a one-step evaluation method that screens

each indicator to check, if it fulfills most of the selection criteria. This is a binary evaluation in the sense that, if an indicator satisfies the criteria, it is accepted. Otherwise, it is rejected. A slightly more complex evaluation method assigns different weights to selection criteria, and then, indicators which satisfy most number of highly weighted selection criteria are considered desired and are included in the analysis.

The four projects reviewed here use a hybrid approach to select sustainability indicators. A hybrid approach combines a subjective component (emotions, feelings, preferences, community values advocated by residents, and expert opinions) with an objective one (technical expertise or statistical characteristics of the variables). Indicator projects expect this approach to create scientifically valid sustainability indicators to which, community residents can relate easily. Usually, this is an iterative procedure and a variable is included in the analysis as an indicator if it has the ability to support actions that improve the trend towards sustainability.

Step 5. Analysis of Indicators

Indicators are either analyzed individually or they are grouped together in an index. Individual analysis of each of the selected indicators allows researchers to determine the current state of a particular indicator, track its changes over time, or even model how it is likely to change in the foreseeable future. This is usually a detailed analysis with minimum aggregation of information. Tanguay et al. (2010) state that scientists usually prefer this kind of an individualistic analysis of sustainability indicators. However, literature review shows that when a large number of sustainability indicators

are individually analyzed (and for a larger geographic area), the details can quickly overwhelm the target audience. An overly detailed analysis may make it difficult for the target audience to look at a bigger picture and understand if the region as a whole is making progress towards the sustainability goals or not.

If similar or like indicators are logically grouped together and are synthesized into a composite index of sustainable development, it becomes easier to evaluate if a particular geographic region is on the path to desired sustainability. Composite indices of that quantify the degree of sustainable development have been popular among researchers, planners, and more importantly common public for a long time. Tanguay et al. (2010) since indices are easily understood by laymen, decision makers and politicians prefer to express the results of indicator based project with the help of fewer meaningful indices. The four indicator projects reviewed here analyze indicators individually. The results are expressed in the form of tables, graphs, maps, or a combination of all of three.

2.5.4 Composite Indices of Sustainable Development

Composite indices of sustainable development have earned significant popularity. These indices aggregate disparate indicators that may or may not have common unit of measurement. Thus, indices are mathematical combination of aggregation of those indicators. Since the two most important points of discussion about composite indices are their construction and interpretation, the following section briefly reviews composite indices to explain how these indices are created and what they mean.

2.5.4.1 Construction of Composite Indices:

Saisana and Tarantola (2002) note that researchers use either statistical or, participatory approaches to construct their composite indices of development. And, the construction generally involves following steps; selection of indicators which will be aggregated into the index, scaling of indicators to bring disparate indicators to one common scale of measurement, determine indicator weights that quantify the importance or contribution each indicator makes towards the index, and the choice of the method to aggregate indicators into an index.

Standardization of Raw Data

The second step involves the standardization of raw data. The main reason to standardize raw data is to make disparate indicators, which often have different and incompatible units of measurements, comparable by transforming them to fit one common scale of reference. Booysen (2002) identified four approaches that researchers commonly use to standardize their raw data. First, to use the data as it is without any explicit transformation. This applies when the raw data is already expressed in terms of percentages or ordinal responses. Second approach is, to compute standard z scores and t values such that the standardized data have a mean of zero and standard deviation of one. This appears to be the most commonly used standardization approach for the computation of composite indices, and it is also considered most suitable for composite indexing (Saisana and Tarantola 2002, World Economic Forum 1996: as cited by Booysen 2002). The third approach is well suited for raw qualitative data. This suits well when the raw

data is qualitative in nature. In that case, semantic responses are graded or categorized into different levels and each grade or level is then identified with a unique number. For example, if residents of a particular city are surveyed to study how much they like their city, and, if they are provided with answer choices such as; not at all, somewhat, like it, or like it very much; then, these semantic responses can be transformed to fit a numerical scale where, 1 would correspond to 'not at all' and 4 to 'like it very much'. Johnston and Sheey (1995) and Gwartney (1996) use similar standardization procedures to compute their Index of Economic Freedom and Economic Freedom Indices, respectively (Booysen 2002).And the fourth approach is linear scaling transformation. The data or indicators are scaled from 0 to 100, relative to a subjectively determined reference point. This means that the researcher needs to come up with a unique reference point for each individual indicator. This approach to standardize data appears tedious and more subjective than other techniques mentioned above.

Weighting of Indicators

The third step in the construction of composite indices is weighting of indicators. Indicators have different level of importance and, the contribution of each individual indicator towards the aggregate index may also be significantly different. To account for this differential influence of indicators, researchers sometimes apply additional weights to those indicators. Booysen (2002) broadly categorizes methods used to determine indicator weights into two groups, subjective and objective. The most common subjective method is to determine indicator weights based on expert knowledge. In expert

knowledge based methods, a number of experts are individually and independently consulted to weight indicators according to their knowledge. A slight variation of this method is that, experts and policy makers are asked to weight indicators based on how they perceive, for example, a particular issue or a policy action that is being questioned. Weights based on experts' perceptions were applied to weight indicators that were combined in the Human Resource Development Index. Researchers, doubt indicator weights determined this way because; weights are completely based on subjective expert opinion, number of experts to consult varies a lot, and it is error prone if experts are asked to evaluate and weight a large number of indicators.

Multivariate statistical techniques allow researchers to objectively determine indicator weights. Some of these statistical techniques are based on the correlation amongst the indicators and the dimensionality of the data. For example, National Innovation Capacity Index (Porter and Stern 2001) uses multiple regression analysis to determine indicator weights. This works best when a researcher is able to categorize indicators as inputs and outputs or targets. Then, the outputs become the dependent variable and all input indicators become the independent variables. The regression equation assumes a linear relationship between the dependent and independent variables, and then, regression coefficients are used as indicator weights (Porter and Stern 2001, Booysen 2002).

Furthermore, methods such as Principal Component Analysis (PCA) and Factor Analysis (FA) use the correlation amongst the indicators to group indicators into

components or factors, and thereby reduce the dimensionality of the data. Researchers have used PCA in different ways for composite indexing. When principal components are combined into an index, they are sometimes weighted based on the proportion of variance in the original variables each component explains. The one that explains the most variance gets the highest weight. Another method to quantify the differential influence a particular component has on the composite index is to weight the component score based on a linear relationship between the component and some of the variables that are excluded from the composite index. A few researchers have also argued about the possibility to use the correlation coefficients between the components and the individual indicators as indicator weights. They argue that, when the indicators are not correlated and if the PCA is based on a correlation matrix, the correlation coefficients between the indicators and the components can be used as indicator weights. Saisana and Tarantola (2002) have reviewed a number of composite indices. They note that, Internal Market Index, Science and Technology Indicator, Business Climate Indicator, and Success of Software Process Implementation use PCA in some way to determine indicator weights and to derive the composite index.

Other statistical techniques used to determine indicator weights, are based on statistical distance to target. This requires a researcher to clearly distinguish between the indicators that are used to track the progress towards the target, and the indicators that represent the target itself. Then, a simple arithmetic can be used to determine how far or close the current value of an indicator is, to the target. If a current performance, as measured by one or more indicators, denotes a longer distance from the target, a higher

weight is assigned to those indicators implying a sense of urgency for the action. Environmental Policy Performance Indicator and Human Development Index use the 'distance to target' method to determine indicator weights (Saisana and Torantola 2002).

Researchers criticize majority of these methods used to weight indicators. Subjective methods are criticized for the lack of strong scientific and statistical foundations whereas; the so called objective methods are criticized for being completely data driven, rigid, and for not accounting for human knowledge, values, perception, or preferences. Thus, no indicator weighting method enjoys universal acceptance and consensus of researchers. Given this, a few researchers have argued for equal weighting of all indicators. The idea is to not assign any explicit weights to indicators and assume that each indicator has the same influence on the composite index. Even though this method is simplistic, it fails to consider the complex interrelationships between the indicators. Without these interrelationships, the indicators are meaningless. And, the method that does not consider the linkages between the indicators oversimplifies the reality.

This discussion might naturally lead one to think about a method that is flexible enough to incorporate human knowledge and the statistical foundations, at the same time. The Analytic Hierarchy Process (AHP), proposed by Thomas Saaty, is one such method. Expert knowledge or stakeholder preferences are incorporated as qualitative input which is then objectively analyzed with a procedure called as pairwise comparison. The result is the indicator weights that are based on qualitative as well as quantitative inputs. AHP

does not completely eliminate the subjective component in weighting of indicators but, it offers a systematic way to reduce and incorporate it into decision making. Any researcher, who wishes to use AHP, still needs inputs from a number of experts. And, an individual (and an early career) researcher may not have the necessary resources to use AHP in his own research. This sometimes puts some practical limitations on its use.

Aggregation of Indicators

Disparate indicators are aggregated into a composite index. Booysen (2002) notes that this aggregation can be a simple addition of indicators or, it can also be based on the estimated functional relationships between the indicators. Functional aggregation is more complex and supposedly better represents the reality; however, researchers sometime criticize this approach as 'empirically biased' (Booysen 2002). Nonetheless, scholars have a general consensus that, the composite indices of development should remain as simple as possible, while avoiding over simplification that might obscure the reality (Morris 1979: cited by Booysen 2002). Furthermore, the purpose for which a particular composite index is developed and the target audience influences the choice of method used to aggregate the indicators. Consider this example. When the purpose of a composite index is to assess the progress towards the sustainability goals, and the target audience is common public, an easy to understand index with a simple aggregation technique works best. On the contrary, when the purpose behind the development of a composite index is to research the methodological aspects, and the target audience is

expert policy analysts and researchers, then, a complex index with a complex aggregation might make a point (Grinsberg et al. 1986: cited by Booysen 2002).

2.5.4.2 Composite Indices – Advantages, Disadvantages & Criticism:

Advantages and disadvantages of composite indices for development are commonly discussed with respect to their 'methodological simplicity and conceptual clarity' (Booysen 2002).

Composite indices are most commonly praised for their ability to summarize complex and disparate indicators into a fewer number of metrics. This makes composite indices a better tool to convey the dynamics of multidimensional issues in a way non-experts can easily understand. Thus, composite indices have an advantage for their ability to paint a bigger picture and act as an eye catcher. However, the argument extended to counter the points made above relates to the soundness of the methodology used to create composite indices. Some researchers are concerned that the poorly constructed indices may over-simplify the complexity and send out erroneous signals about the dynamics of the issue being considered. Moreover the bigger picture, which is certainly easier to make sense of, may lead decision makers to false conclusions or decisions that are convenient, rather than correct. Scholars have also mentioned the possibility of composite indices being misused by politicians if the simplistic conclusions are drawn. And, these scholars suggest developers of indices to check the sensitivity of the indices to slight changes in inputs and decision makers or users of the indices to keep an eye on the individual indicators while they are interpreting the composite index (Saisana and Torantola 2002).

In addition to this, Booysen (2002) have reviewed the criticisms extended towards the composite indices. At first, he notes that the indices are criticized for not including all possible aspects of sustainable development, for example, Human Development Index (HDI). The index, as the name suggests, is supposed to quantify a multifarious concept like human development. However, HDI only considers two social indicators (life expectancy and schooling) and one economic indicator (gross national income per capita) to produce a metric of human development (UNDP 2013: http://hdr.undp.org/en/statistics/hdi/ accessed on 3/19/13 and Lind 1992: cited by Booysen 2002). Mori and Christodoulou (2012), on the other hand, consider indices that focus only on certain aspects of development as 'single-unit indices'. They further mention that these indices are more specific in nature and provide a clearer understanding of the aspects of development that these indices consider. Moreover, how researchers scope their composite indices may also depend on how they define sustainable development. Different definitions may lead researchers to scope their indices differently. And finally, availability of data may decide which aspects of the development researchers can include in their composite index.

Second, Booysen (2002) refers to the question of how applicable and comparable certain indicators are, nationally and internationally. His review suggests that researchers call for different indicators, which most truly represent the economic, environmental, and physiographic conditions of that certain region, to be incorporated into the composite index for that region.

For example, the same socioeconomic indicator – number of jobs outsourced to India in a given fiscal year – might mean exactly opposite things to India and the United States.

The third point that comes up in Booysen's review is that, researchers doubt if composite indices make any real contribution to the knowledge or, do they really convey any information that an individual indicator cannot convey. Booysen (2002) cites a few researchers who point to the high correlation between the social and economic indicators, and deride composite indices as practically meaningless. This appears to be a valid point, especially when the indices aggregate data at a national or an international level. However, as one moves towards larger geographic scales the relationship between social and economic indicators is most likely to be dynamic and complex. Therefore, at these scales disparate indicators capture how these dynamics are played out over geographic space and time. It is also important to understand how changes in economic indicators relate with different racial and ethnic groups that make up the entire demographic of an area.

Fourth, Booysen (2002) notes how researchers criticize the methodology used to select indicators. Since the practitioners and users of composite indices lack consensus about selection methodology, number of indicators, indicator weighting scheme, and aggregation method, some researchers consider composite indices too subjective. This is a valid point.

However, the explanation given in defense if why some indices leave out certain aspects of development, also applies here. And therefore, the best way around is that each researcher explains his choices and why those were considered logical and appropriate.

And the fifth criticism that surfaces in Booysen's review relates to the nature and quality of the data that is used to create composite indices. Generally, a huge volume of data of different kind that is collected by a number of organizations is combined into a composite index. Issues related to the nature and quality of the data arise; because of a number of reasons. First, the data can be quantitative or qualitative. And second, different data is often measured in incompatible units of measurements. Third, the data may be a representative sample or, estimates derived from the sample. Fourth, the data may be collected in different ways like, regular surveys, telephonic surveys, voluntary surveys etc. Fifth, some data may be collected automatically with the help of instruments (e.g. air pollution, or temperature data). Composite indices of sustainable development, in most cases, need all these different data, and no single organization (or researcher) can practically collect all of these data first hand. Therefore, the best way around is to use the available data from credible sources and account for its accuracy whenever possible.

2.5.4.3 Presentation, Evaluation, & Usefulness of Indices:

In addition to conceptual and methodological soundness of composite indices, their popularity vastly depends on how they are presented, how they are evaluated or interpreted, and how useful they are (and appear) to common public.

Researchers prefer to present results of their composite indices in different ways. Some use charts, tables, and graphs to explain the dynamics of each individual indicator (Lee and Huang 2007). Others use maps to show how the dynamics of each indicator plays out over geographic space. And few others map their composite indices (instead of individual indicators) over geographic space (Charlotte Regional indicators Project 2007). This research maps composite scores over space because; sustainable development has a spatial component that must be considered in the analysis. A map of composite indices would allow planners, stakeholders and common public to see how the degree of sustainability in the study area varies over the space and to identify any meaningful spatial patterns. Spatial processes which produce these patterns must also be studied to make better informed decisions.

The second important issue is of how researchers, decision makers, and other users evaluate and interpret actual index values. Mori and Chritodoulou (2012) note that, scholars most commonly evaluate and interpret indices in relative terms, when it would be more promising to provide an absolute meaning to a particular index value. They argue in favor of interpretation of index in absolute terms because; the components of a complex urban system (social, economic and environmental) have absolute thresholds or limits (Fischer et al 2007). As long as each of these components is within these limits, it is in harmony with the rest of the system. However, as any of those components crosses the threshold, it disturbs the balance of the whole system making it unsustainable.

And thus, Mori and Chritodoulou (2012) argue that a composite index should allow researchers to monitor the progress towards sustainable development, with respect to these absolute thresholds.

Even though this is a technically correct point, it is difficult to precisely define these thresholds or limits. For example, "the difficulty lies in determining the limits to human economic activities in cities indirectly through their negative impacts on the environment. it is necessary to convert ecological and environmental thresholds into the amount of human activities, but this is complex and requires many assumptions". Mori and Chritodoulou (2012) suggest a systematic way to get around this issue of evaluation of indices. They suggest three types of standards. First is, scientifically defined absolute thresholds (whenever possible). Second is, internationally accepted values as thresholds. And the third is locally applicable thresholds (relative evaluation in an individual country). And then, they suggest that researchers evaluate or interpret their index values with either one of these standards as a reference.

Booysen (2002) and many others have identified another issue that relates with the evaluation of composite indices. The ambiguity sets in when one attempts to explain the numerical difference between index values. For example, an index value of 10 may not necessarily be the double of index value 5. The higher number only indicates a higher magnitude or intensity. To avoid this confusion and make results more meaningful researchers often express their index values as percentiles. This eliminates the confusion and also makes the two different indices comparable.

And finally, the third important issue that influences the popularity of composite indices is their usefulness. Despite all the criticism extended against composite indices, Booysen (2002) considers the indices extremely useful tools that simplify complex information, systematically combine disparate data, and express the complex information in a way that catches the public's eye.

CHAPTER III

STUDY AREA, RESEARCH QUESTIONS, AND DATA

3.1 Study Area:

This study assesses urban sustainability in 53 counties that cover most of the physiographic piedmont of North Carolina (figure1). The study area encompasses the Raleigh-Durham-Cary combined statistical area (Combined Statistical Area: CSA), the Greensboro-Winston Salem-High Point CSA, and a portion of Charlotte-Gastonia-Salisbury CSA (figure 2).

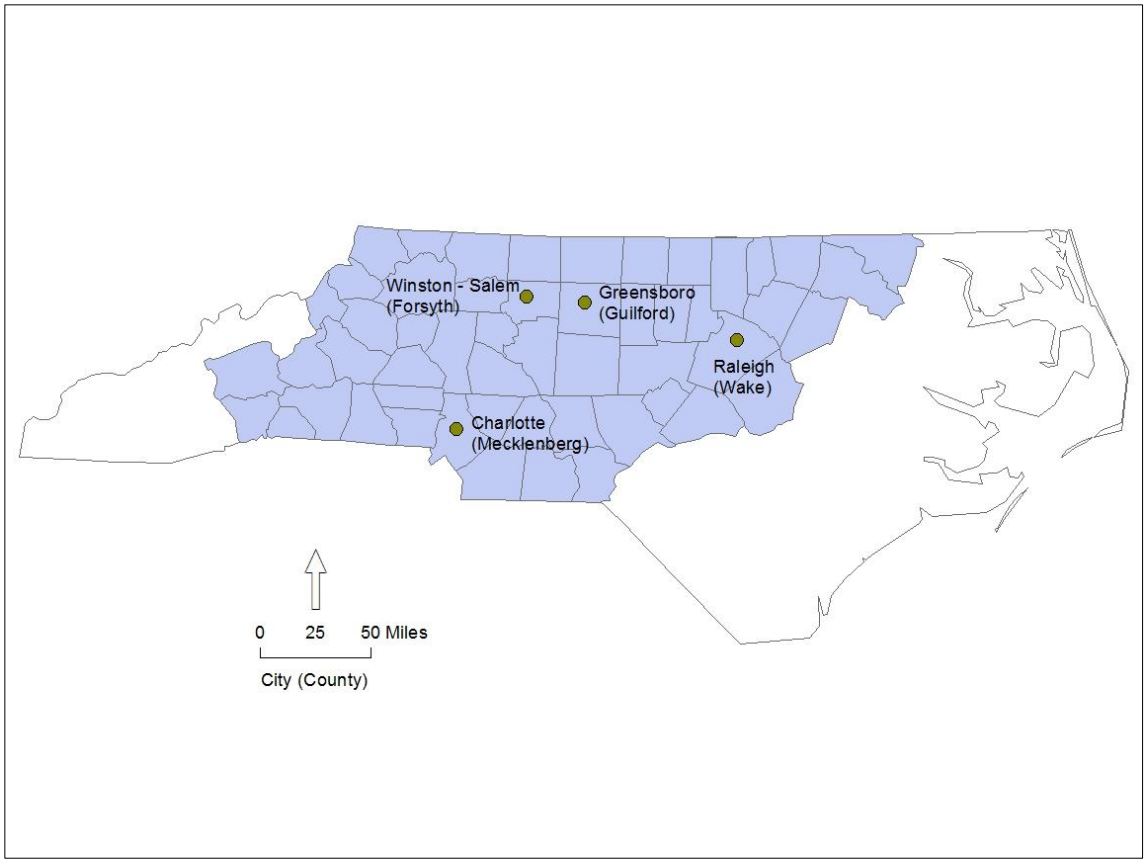

Figure 1. Study Area. Major cities are highlighted with their respective counties in parenthesis.

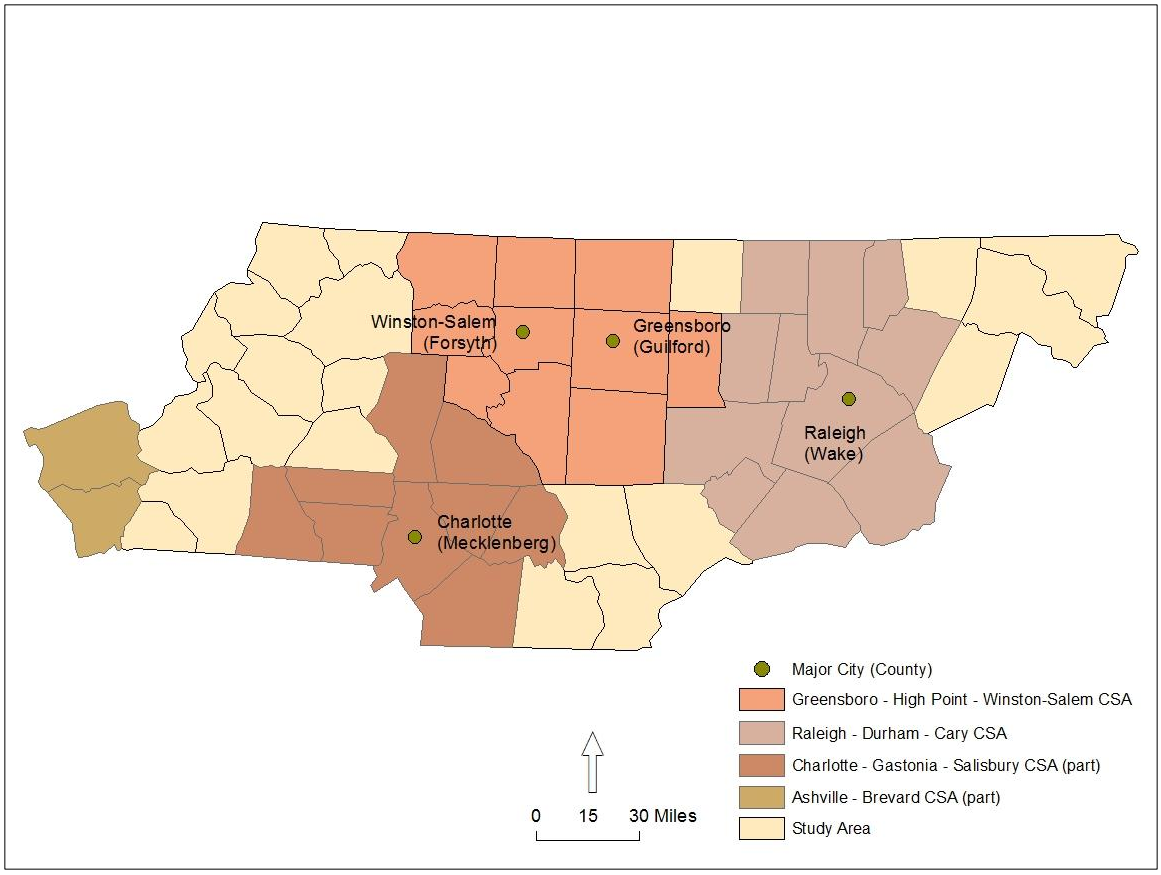

Figure 2. Combined Statistical Areas (CSA) within the Study Area. Note that, a portion of some CSAs lies outside the study area.

This region has an interesting blend of urban and rural character. It includes most of the urban counties in the state, and these are surrounded by rural counties in North Carolina (North Carolina Rural Economic Development Center 2013). Thus, each of the CSAs is essentially a functional region with an urban core. Urban core comprises of a major city or a county which encompasses that city.

Such urban cores function as the hubs of economic activity and, the counties and cities that surround these urban cores, then, serve as functional regions characterized by significant interactions of goods, people, and resources.

These CSAs share some common characteristics such as, significant population growth, better and more opportunities for businesses and jobs, better facilities of higher education, relatively higher incomes that allows the population to lead an urban lifestyle which is considered to have a better quality of life. Like these urbanized regions, rural counties in the state have also shown some signs of overall growth. Population in these counties has increased by 15% in the past decade. While manufacturing remains the prominent economic sector in rural N.C., healthcare, farming, and other smaller businesses are the new sectors which emerged and have contributed to the growth of rural economy in the past decade.

Scientists expect that, the whole region will grow in population and economy in near future. And, the growth will continue to occur in and around urban cores. The rural counties are also expected to grow steadily at a fair pace. However, there is a flip side to this story of growth. The CSAs within the study area are experiencing the negative impacts of urbanization on the natural environment. Regional plans prepared by the governments of some of the highly urbanized counties note that, all the three CSAs share common environmental concerns like severe urban sprawl, loss of farmland and other natural resources, and high dependence on automobiles.

In addition to this, a recent study published by the N.C. Department of Commerce (Bunn and Ramirez 2011) reiterates these facts and sheds light on the changing social and economic dynamics in the state (figure 3).The study notes that the state, as a whole, is experiencing a demographic shift and a transitioning economy (the study also notes that the recent economic recession has accelerated this transition). Demographers find that North Carolina continues to witness significant population growth. So much so that, it has the sixth highest growth rate in the nation and, most of its growth has occurred in and around urban cores within the study area. While North Carolina is continually adding more and more citizens, the state's economy is evolving to become a knowledge based and service industry related economy (hence forth referred to as knowledge and service economy)

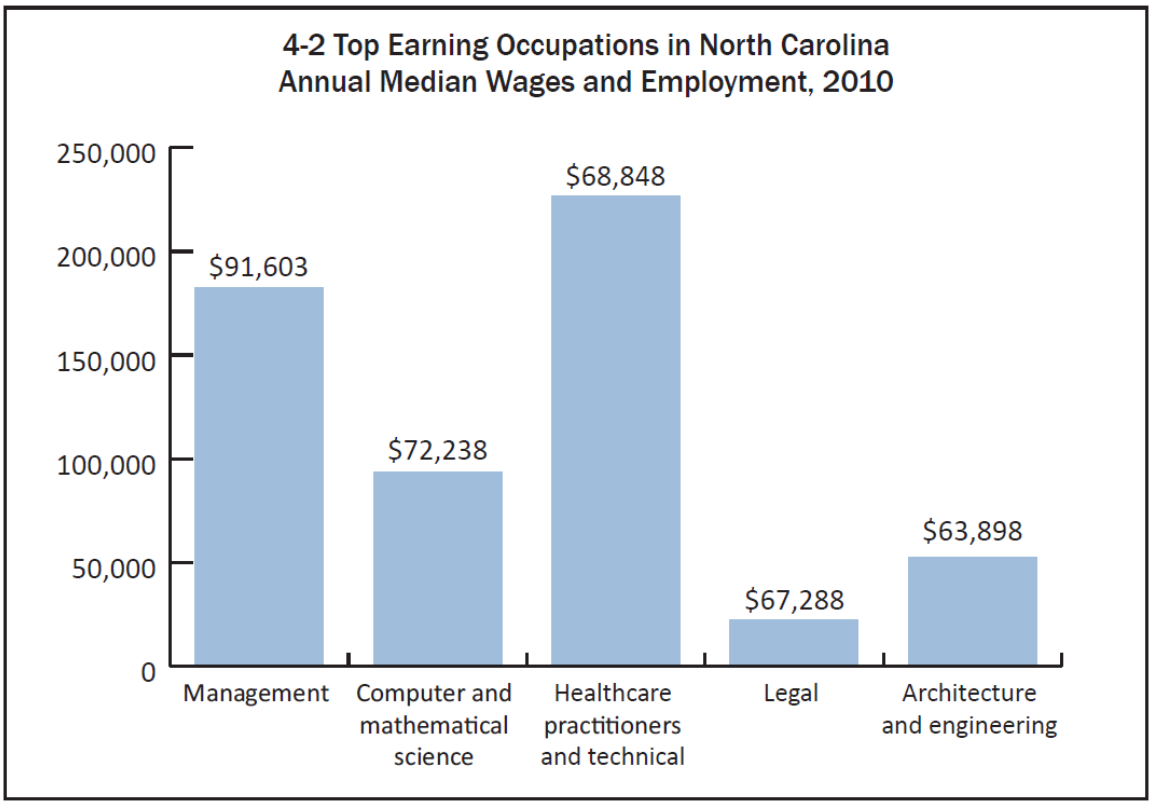

Figure 3. Top earning Occupations in North Carolina. These are knowledge based technical occupations that provide specialized services to customers. (Source: N.C. Dept. of Commerce 2011).

Also, the study notes this new knowledge and service economy as vibrant, entrepreneurial, and the one that revolves around innovation. An economy like this, influences lifestyle preferences of the majority of the population. Economic prosperity provides opportunities and means to lead a modern urban lifestyle that is based on higher rates of consumption of a variety of resources, including natural resources like land, air, water, and biodiversity. Given the pattern and pace of contemporary growth, it is likely that this consumption of resources may damage the natural environment. This damage may even be irreversible.

To explore how the contemporary urban lifestyle has affected the quality of the state's natural environment, North Carolina Department of Environment and Natural Resources (NCDENR) conducted a study (Conservation Planning Tool 2012).The study notes that anthropogenic influence on the environment is visible in every part of the state. In addition to the excessive consumption of land, the study specifically mentions that air quality, clean drinking water, traffic congestion, and loss of biodiversity are the concerns which should be addressed with priority.

However, the reality is much more complex and dynamic than it seems. The state is under pressure from stakeholders and the federal government to cash-on the evolving economy and the potential it has for more economic gains. And, at the same time, the state has to deal with similar pressures and urgencies from the federal government directives, environmentalists, and common public to preserve the natural environment. As a result, the state of North Carolina has launched a number of ambitious efforts, some to foster economic growth and others, to protect the natural environment.

Most of North Carolina's efforts for economic development fall under an initiative called 'NC Tomorrow' and the motto is 'Building communities for tomorrow's jobs'. This initiative was created with the assistance and guidelines of the U.S. Economic Development Administration as collaboration between various state level organizations. The most important task of NC Tomorrow is to chalk out Comprehensive Economic Development Strategy (CEDS) for the state. The CEDS will incorporate six investment principles that represent a focus on economic developmentand, six livability principles

that represent a focus on sustainable communities. However, after the review of literature it seems that, the idea of CEDS is organized around economic development and its focus on sustainable communities is relatively weaker.

Most notable of the state's efforts to protect its natural environment is called 'One North Carolina Naturally' and the motto is 'Working together through conservation to map a healthy and prosperous future'. The initiative has created the North Carolina Conservation Planning Tool. The main purpose of this tool is to coordinate statewide conservation efforts and, protection of the natural environment is the organizing concept of this initiative. The Conservation Planning Tool is designed to direct the growth in North Carolina to areas where the growth will have minimal impacts on the environment. The focus of the tool is to internalize the priorities for environmental concerns and conservation into decision making process.

Now, how well these initiatives complement each other is an interesting question to consider. Since the initiatives like these have significant influence on the quality of life of common people, it is essential to study how economic growth, and urbanization that is associated with it, relates with the quality of the natural environment within the study area.

3.2 Research Objectives:

This research has two overarching objectives. The first objective focuses on the investigation of whether growth is sustainable. The second objective examines ways to communicate the results so that decision makers and common public can understand them and have an unambiguous basis to determine growth priorities and make informed policy decisions.

The first objective requires that the study offers a detailed conceptual representation of interactions among economic and environmental factors that influence urban growth. The research objectives also call for a methodology that makes use of relevant variables to provide a metric to reflect on the interactions and urban sustainability. Therefore, this research uses sustainability indicators (also called as indicators of sustainable development) as the variables to assess the sustainability of urban growth in the study area. And, communicate the results with the help of aggregate indices that effectively convey complex information. The idea of using sustainability indicators and aggregate indices provokes certain questions, and that, defines the scope of particular research questions this study addresses.

3.2.1 Research Question 1

The first research question deals with the issue of selection of sustainability indicators and, an appropriate conceptual representation of a complex urban system with the help of the selected indicators. This study explores how individualistic indicator

selection criteria can be combined with advanced selection criteria that specifically focus on the interrelationship between the sustainability indicators.

Individual indicators, as researchers suggest, may not have much of a value when considered in isolation. However, when their interrelationships are taken into account, an analytical problem solving logic (Neimeijer and de Groot 2008) evolves out of that set of indicators. This logic provides added value to an indicators based assessment of sustainability. In order to develop this analytical logic, a clear procedure based on reasons is required to connect the two ends which involve the selection of sustainability indicators (based on individualistic selection criteria) and the overall goals of the indicator based assessment and problem solving (which requires a focus on interrelationships between the indicators).

To establish this connection, it is essential to have a simplified yet, detailed conceptual representation of an urban system. Given this, the research investigates the efficiency or suitability of enhanced Driving Force-Pressure-State-Impact-Response (in short, eDPSIR) indicator framework to develop the required analytical problem solving logic.

eDPSIR is perhaps the most comprehensive indicator framework because, it distinguishes the most number of steps along the way from driving forces to responses. Neimeijer and de Groot (2008) argue that, eDPSIR handles more complexity as it considers multi-dimensional causal relationships (causal network) between the indicators rather than just linear and parallel causal chains. Thus, it is expected that the structuring

mechanism of eDPSIR will better represent the complexity of an urban system. For example, it is reasonable to expect that eDPSIR provides a better understanding about the purpose, analytical function, and hierarchy of any particular indicator with respect to the entire system. Italso opens up the possibility to examine the advantages and disadvantages between eDPSIR and DPSIR.

3.2.2 Research Question 2

The second research question investigates whether growth in the study area is sustainable. The purpose is to interrogate the relationship between economic development and the impacts on the natural environment, if any, and whether the region is moving towards sustainable development that is environmentally sensitive.

This research uses sustainability indicators and examines the influence or contribution of each individual indicator towards the overall sustainability of growth. The influence of an indicator is characterized as a weight. Researchers have different opinions about how to derive these indicator weights. Most of the methods used to compute these weights have a high degree of subjectivity. Therefore, this research explores Principal Component Analysis (PCA) as an objective method to derive indicator weights.

It is expected thateconomic growth would be mostly concentrated in the counties that host major cities in the study area. Therefore, these counties and adjacent counties are likely to exhibit some negative impacts on the natural environment or human health. All rural counties are likely to have a better environmental quality but a lesser economic development.

It would be interesting to see if this hypothesis holds true. And if it does, is it reasonable to generalize it at least for the entire study area that consists of fifty three counties?

This kind of dynamic growth needs to be constantly monitored. Popular research has shown that economic development and urban growth are closely associated with each other and, the combination of the two often has negative impacts on the natural environment and human health. These impacts may even offset economic gains. However, with recent demographic and social research, it has become clear that majority of the population prefers to be urban (or would prefer, given the opportunity to do so). This preference for a certain kind of lifestyle establishes a loop wherein migration of people into urban or metropolitan areas fuels economies of scale, which in turn, allures even larger population to be a part of luxurious, modern urban lifestyle. In such a scenario of rapid urbanization (with ever greater potential for future growth); planners, policy makers, and governments have to take on the challenge of maintaining the economic development at the optimum level while keeping the environmental degradation at the lowest level possible. Thus, there is a clear conflict between economy and the natural environment and, to address it successfully is a tricky maneuver. One way to help decision makers take informed decisions in such cases is to provide them with an objective metric that will help experts and non-experts understand the growth dynamics and determine appropriate priorities. The second research question assesses the degree of sustainability of urban growth in the study area. Also, it communicates the results in the form of an objective and easy-to-understand indices.

3.2.3 Research Question 3

The third question compares weighted sustainability indices with un-weighted indices. Although researchers have used a variety of objective and subjective methods to derive indicator weights however, no method enjoys wide spread acceptance.All objective and subjective methods are believed to have their own drawbacks and, the confusion about a suitable method to derive indicator weights persists. A few researchers have argued in favor of not weighting the indicators at all (or, assigning equal weights) since the method may oversimplify the reality by ignoring the varied influence the indicators are expected to have on the sustainability. Therefore, this research compares a statistical and objective indicator weighting scheme with the no or equal weighting.

3.3 Data:

Given the nature and objectives, this research is data-intensive in the sense that it required data from a large number of diverse sources. An extensive search was undertaken to explore all possible data sources to collect the data pertaining to a number of economic and environmental variables. These variables are the sustainability indicators used in this research and, are required to quantify economic growth, urbanization, and the quality of the natural environment before urban sustainability could be finally expressed in terms of composite indices. At the end of the search, county level annual data (2006 to 2010) were obtained from several sources: American Community Survey (ACS) conducted by the U.S. Census Bureau, the Office of State Budget and Management (OSBM), State Climate Office of North Carolina, North Carolina Economic

Development Intelligence System (NCEDIS), North Carolina Department of Environment and Natural Resources (NCDENR), North Carolina Department of Transportation (NCDOT), Center for Disease Control and Prevention (CDC), and North Carolina State Center for Health Statistics (SCHS). Following are the sustainability indicators used in this research with their respective data sources.

ACS

- Population density
- Population 16 years and above with a university degree
- Percent of population with 3 or more vehicles
- Percent of population who drove alone to work
- Mean travel time to work
- Median income

NCEDIS

- Investment per capita
- Annual building permits
- Per capita consumer expenditure
- Air pollution (criteria air pollutants)

State Climate Office of North Carolina

- Ambient air temperature

NCDENR

- Per capita waste generated
- Per capita waste recycled
- Percent area conserved
- Impaired streams

NCDOT:

- Average annual daily traffic (traffic density)

CDC:

- Percent of adults obese

SCHS:

- Hospital discharges for asthma

It is interesting to note here that, in addition to these variables, many more were also studied to explore the possibility of including those into the analyses. However, those other variables were excluded because; either the data were not available or the data were not on the desired spatial and temporal scale.

CHAPTER IV

METHODOLOGY

The initial section of the methodology deals with the selection of sustainability indicators with the help of eDPSIR framework and causal network. The framework is used to streamline indicator selection by proving a better conceptual representation of how economic and environmental aspects of urban growth interact with each other. The procedure for this was modified from Neimeijer and de Groot (2008) and consisted of three steps.

1. Selection of abstract indicators
2. Use of eDPSIR framework and causal network to assess how well these indicators fit together as a set
3. Selection of specific indicators that best represent the abstract indicators.

4.1 Selection of Abstract Indicators:

Abstract indicators are those variables which relate to economic growth, environmental quality, or human well-being. For example, demographics, education, or enterprise are abstract indicators related to economic growth. Transportation, pollution,

and quality of life are the abstract indicators related to the quality of natural environment and well-being. These broad indicators generally point to the important factors which researchers must consider for better addressing their research questions. Abstract indicators provide a good starting point for the indicator selection process especially when the indicators have to be selected from a large pool of potential candidates.

Selection of abstract indicators relied on a combination of a review of literature and an assessment of all potential data sources, which provided a guide for identifying abstract indicators which could yield specific indicators (actual, measurable data) that could be used for examining economic and environmental relationships.

4.2 Use of eDPSIR Framework and Causal Network:

This step involved categorization of abstract indicators into driving forces, pressures, states, impacts, and responses. The categorization attributed each indicator a particular role which suggested how the indicator would influence the overall sustainability. This provided the basis to construct a causal network that builds upon the framework and makes the focus on indicator interrelationships explicit and central to the selection process.

The interrelationships were identified based on a review of literature. There are a number of studies available that discuss the relationships among a range of factors relevant to the aspects of urban growth investigated in this study. For example, researchers have discussed how increased use of private automobiles relates with air pollution, how sedentary lifestyles associate with obesity and overall health or, how

economic growth and prosperity generally elevates the quality of life. However, these kinds of discussions often have a narrow focus and as a result, these works continue to remain as disparate pieces of valuable information.

These bits of information are essential for the study of urban sustainability which is a phenomenon that emerges from numerous interactions among economic, environmental, and quality of life factors. By using the eDPSIR indicator framework and the causal network an attempt was made to compile the scattered information based on cause – effect relationships and put it in a context of sustainability of urban growth. The purpose was to gain a broader understanding that will allow each specific indicator to be assessed based on how well it fits in with other indicators (set level criteria). It was also anticipated that the use of indicator framework and causal network will stimulate inquiry that would extend the knowledge of causal relationships relevant to urban sustainability.

4.3 Selection of Specific Sustainability Indicators:

As opposed to the abstract indicators, these are the actual variables for which the data are collected. For example, total population, or population by age or race are the specific variables which can be used to quantify an abstract indicator, demographics. Ozone, nitrogen oxides, or carbon monoxide are some of the specific air pollutants that are used to quantify an abstract indicator, pollution.

Specific indicators were selected based on how well they represented the relevant abstract indicators. The selection was based on a number of criteria that allowed each specific indicator to be evaluated individually. These are referred to as individualistic

criteria and those used here were reviewed by Maclaren (1996) as the most commonly used. These criteria required each specific indicator to be scientifically valid, representative, unambiguous, relevant to the needs of potential audience, and based on accurate and accessible data.

Also, at this point in the indicator selection process, the eDPSIR framework and causal network played an important role by allowing each indicator to be assessed on the basis of set level criteria. This prevented the selection process from veering off course. For example, number of deaths by unintentional vehicle injuries may be used as an indicator to quantify negative impacts of increased traffic and urbanization. The indicator would satisfy the individualistic criteria and a researcher may get tempted to include it in the final set of sustainability indicators. However in a situation like this, the framework and causal network would allow us to check whether the indicator is relevant to research questions and if it fits well with other indicators. An attempt to suggest causal linkages between the number of unintentional vehicle injuries and, either economic, or environmental indicators, is farfetched. Therefore, an indicator like this would be rejected.

In addition to these, other factors like scale of the analysis, reliability of the data and comparability among the different data variables were also considered during the selection of specific indicators. Since sustainability evolves over space and time, it was necessary to analyze it on appropriate spatial and temporal scales. In this case, appropriate scales were those which allowed for the most detailed analysis with the

available data. Thus, based on the availability of specific indicators, the decision was made to analyze sustainability over a period of 2006 to 2010, at the county level.

Reliability of the data that were based on a survey of sampled population (e.g. economic indicators derived from the ACS) was checked by using the margin of error for each estimate and a formula below.

$$\text{Coefficient of Variation} = \frac{\left(\frac{\text{Margin of Error}}{1.645}\right)}{\text{Estimate}} \text{ X } 100$$

The coefficient of variation quantifies the amount of sampling error relative to the size of the estimate itself. A large sampling error in a small estimate reduces its reliability. Based on an ESRI white paper that discusses the use of coefficient of variation to assess the reliability of an ACS estimate (above formula), and the thresholds suggested in the same document, coefficient of variation less than or equal to 12 percent were considered reliable (ESRI 2011).

Another issue that influenced the selection of specific indicators was of comparability among different data. The data from the ACS was aggregated over the entire period of 2006 to 2010 whereas; most of the other data were available on the yearly basis. This required the yearly data to be aggregated over the five year period to match with the ACS derived indicators.

4.4 Principal Component Analysis:

The second part of the methodology addressed the second research question. The objective here was to identify the influence of each sustainability indicator on the overall urban sustainability. Such influence, which is specific to each indicator, is expressed as the weight. These weights for all selected sustainability indicators were derived using PCA based on a correlation matrix.PCA was run separately on the economic and environmental indicators which were standardized and normalized prior to input.Out of all the principal components that the PCA generated, only those that had the Eigen value greater than one were selected for further analysis. 'Eigen value greater than one' is a widely accepted criteria among researchers which, they use to extract only the components that explain sizeable proportion of variance in the original dataset and, discard all others.

Each principal component is a synthetic indicator that accounts for the actual indicators that comprise it. Also, these indicators influence the component, which provides it an ability to explain variance in the dataset. The influence of an actual indicator on the respective component is expressed in terms of the coefficient of correlation between the indicator and the component and, is called as the component loading.

The idea here was to use these component loadings as indicator weights to characterize the importance of each indicator for the overall sustainability. However, each indicator loads on each one of the selected principal components and, the loading

varies. Therefore, before the loadings could be used as the indicator weights, it was necessary to standardize the loadings. This standardization was done such that, each indicator has only one unique value that quantifies its importance for the overall sustainability. Furthermore, standardization brings the weights on the same scale (add up to one). This allows for meaningful comparison between the weights to discuss their relative influence on the overall sustainability.

Once the indicator weights were derived, the next step was to weight the indicator and derive composite indices; one to represent economic development and the other to represent the quality of the natural environment and the quality of human life. Indicators (standardized and normalized) were weighted by multiplying them with their respective weights. Then, all the weighted economic indicators were added together to derive the composite index that represented economic development in the study area. Similarly, all the weighted environmental indicators were added together to derive the environmental index that represented the environmental sustainability in the study area.

4.5 Comparison of Indices:

The final section of the methodology compared weighted indices with un-weighted indices. Un-weighted indices were derived by summing up standardized and normalized indicators. The indices were compared based on their statistical distributions, to examine whether the PCA based indicator weights influenced the outcome.

CHAPTER V

RESULTS AND DISCUSSION

5.1 Results of Research Question 1:

Results of the first research question consist of the selected sustainability indicators and the discussion of how they fit into the eDPSIR causal framework. The results and their discussion relies heavily on the review of literature however, it goes beyond a plain review as it weaves together disparate pieces of information about the indicators and their interrelationships. The discussion puts the information together in the context of urban sustainability which emerges from the interactions among the selected indicators.

5.1.1 Abstract Indicators - Economic Development

Based on the economists' understanding, the following abstract indicators of economic development were selected.

- Demographics
- Education
- Employment

- Wages, living standard
- Services and infrastructure
- Enterprise
- Research & development, innovation
- Competition and collaboration

Although it is difficult to find a precise, complete, and unanimously accepted definition of economic development, a majority of economists have a general consensus that the abstract indicators listed above are central to quantitative analyses of economic development (CaRDI2013; Cornell University's Community and Regional Development Institute accessed 7thJuly, 2013).

These indicators could shed light (depending on the availability of data) on different aspects of economy like vitality, resilience, and its potential for development. Demographic capital, employment, enterprise, infrastructure, and living standards determine how popular a place can become for work, leisure, and residence. Therefore, these indicators have been considered as determinants of economic vitality by a number of economic vitality programs maintained by many cities and metropolitan regions in the United States. Furthermore, these abstract indicators could also reflect on the resilience of an economy in the region. Hill et.al (2010) studied the determinants of economic resilience for regional economies in the United States. Their findings suggest that an

abstract indicator like demographics can serve as an indicator of economic resilience if, the diversity of cultures and skills sets among the population is measured. Similarly, an abstract indicator like employment may also reflect on economic resilience if the distribution of employment across economic sectors is measured. Finally, education, research and development, innovation, and enterprise reflect on the economy's potential to grow, especially in knowledge and service based economy. For example, a broad indicator like education could be measured to reveal the proportion of population with university degrees in science, technology, engineering, and mathematics (STEM). The proportion STEM graduates would indicate the potential of economic growth because it would attract high paying jobs and, fuel research and innovation. Similarly, when innovation is quantified in terms of number of patents acquired, successful research projects, or new value added services and products; it may indicate the potential of the economy to grow.

5.1.2 Abstract Indicators - Environment and Quality of Life

Literature was reviewed to identify the factors that are important to gain better understanding of environmental quality and its influences on the quality of life. The following factors were selected as abstract indicators of the state of the natural environment and quality of life.

- Intensity and spatial pattern of urban growth
- Transportation and commuting

- Air and water quality
- Noise pollution
- Energy and resources
- Ecosystem
- Quality of life

Goodland (1995) argues that environmental sustainability entails maintenance of natural capital so that, the natural systems continue to provide the necessary resources, assimilate wastes, and offer a better life experience to biotic components including humans. The indicators listed above are the factors central to any analysis relating with the maintenance of natural capital and its influence on human life.

5.1.3 eDPSIR Framework and Causal Network

Sustainability is an emergent phenomenon and it cannot be truly analyzed by studying different indicators in isolation. Therefore, eDPSIR indicator framework and causal network were utilized as a formal mechanism to shed light on the interrelationships among economic and environmental indicators. The following sections explain how the abstract indicators were fit into the framework and discuss the causal network with the help of the selected indicators (Table 5). The discussion of causal linkages among the indicators relies on literature; however, it goes beyond a plain literature review as it weaves together the scattered pieces of relevant knowledge and

puts them into a broader context of urban sustainability. In so doing, the discussion emphasizes the use of eDPSIR framework and causal network as a central concept in the indicator selection process.

Table 5. Abstract Indicators and eDPSIR Framework

Driving Force	**Pressure**	**State**	**Impact**	**Response**
Demographics Enterprise Education Wages Employment	Life style preferences Land transformation	Air & Water quality Ambient temperature Transportation & commuting Energy & Resource use	Health impacts of pollution Ill effects of sedentary lifestyle Quality of life Impacts on biodiversity	Strategies to reduce undesired land transformation Policies to encourage efficient use of energy & resources

Driving forces are the needs and demands that, majority of the population believes, must be fulfilled to attain or maintain a desired living standard. Often, these factors indirectly influence the urban sustainability. Pressure indicators are the decisions and actions that people take to realize their preferred lifestyle but, which put stress on the natural environment. State indicators simply capture the state (condition or quality) of the physical, chemical, and biological components of the natural environment. Impact indicators capture how the humans and other living components of the ecosystem are affected by the changes in the state of the natural environment. Responses are the various kinds of actions that government or public takes to reduce undesired growth.

5.1.4 Linkages among Indicators

5.1.4.1 Driving force and pressure:

The interactions between driving force and pressure indicators can be summarized with the help of three prominent causal linkages. How economic growth influences people's lifestyle preferences and aspirations for the quality of life. How lifestyle preferences, coupled with economic growth, generate demand for products, services, and resources. And how provision of public services and core infrastructure, encourages economic growth, improving the living standards.

The relationships between economic growth and lifestyle preferences are a function of affluence, demand and supply. Economic growth is realized through the interactions among a number of driving forces. The demographic base serves as the foundation over which thrive a variety of socio-economic activities in an urban area. The size, richness, and diversity of the demographic base, creates a socio-economic environment that allows educational institutions, research organizations, or businesses to flourish and add value to the society and the economy. As people contribute to the economy through their activities in different economic sectors, they receive monetary rewards. These rewards are the resources which people trade to achieve a desired living standard. A healthy economy usually allows a majority of the population to be affluent enough so that people get opportunities to realize their preferred lifestyles.

Preferences for lifestyles summarize the ways in which people desire to lead their lives. The preferences encompass popular notions about social status, leisure, comfort, success, or attitude towards the natural environment, among many other aspects. These preferences often manifested as the conscious decisions and actions of people. For example, lifestyle preferences relevant to the focus of this research include choice of residential locations and kind of housing units, preference for a certain level of density of urban growth, preferred mode of transportation, and the notions about the modernity of lifestyle and the conveniences it offers. Realization of these preferences largely depends on the access to various resources (land, water, energy), services (education, health), and products (appliances and most household products). Thus, efforts to lead a preferred lifestyle create a huge demand for resources, services, and products which, encourages the respective economic sectors to supply for the demands fueling further economic growth.

5.1.4.2 Pressure and state:

Pressures bring about changes in the state or quality of physical, chemical, and biological components of the natural environment. Environmental pressures are often the conscious decisions and actions of people which emanate from their lifestyle preferences. With a preference for an urban lifestyle, higher proportions of people congregate in urban areas and generate a huge demand for basic infrastructure like buildings, residential units, or roads. This powerful demand drives the transformation of natural lands into built-up areas which, usually occurs at an unprecedented pace. Also, it is practically irreversible,

and stresses the natural ecosystems in many ways. Extensive deforestation is an obvious loss of natural capital and its ability to provide ecosystem services. Moreover, the land transformation fragments natural ecosystems and threatens their survival. For example, fragmented natural areas restrict the movement of pollinating agents (birds, animals) which play an important role in natural replenishment of the natural capital. With less than optimum pollination, the ecosystems health and survival becomes a concern.

The choice of residential locations and a preference for suburban living also puts pressure on the natural environment. It increases the demand for transportation and daily commuting. At the same time, public transit in most low density suburbs becomes unprofitable or impractical. These factors contribute to increased dependence and use of private automobiles. A necessity or a preference for private transportation means increased consumption of fossil fuels and increased emission of pollutants, and stress on the environment to cope up with the pollution. Land transformation, coupled with increased vehicular traffic, are responsible for most of water pollution. Impervious surfaces are responsible for increased surface runoff of water. As the water flows over roads, or roof tops, it picks up a variety of pollutants and since there is very little opportunity for the water to infiltrate into soil, a major proportion of this pollutant laden runoff drains into water bodies. US EPA has noted surface runoff as the major factor responsible for water pollution in urban areas. Also, water pollutants released by industries often pollute water bodies.

Similarly, a notion of what defines an urban lifestyle, comfort, luxury, or even social status influences popular desire to possess certain household products or equipment. The intensity of this desire is assessed with the help of consumer expenditure by category of products or services. Previous research has shown a clear causal linkage between the intensity of this desire and pressure on the environment. Webber and Perrels (2000) studied the influence of lifestyle preferences on the demand for energy resources (electrical energy and fossil fuels) and the related changes in the emission of pollutants. They conceptualized lifestyle as a desire to possess certain household products or equipments that enhance the level of comfort and / or luxury. They found that, preference for these products significantly increases the demand for energy resources and the related emissions also go up. In addition to electricity and fuel, the lifestyle increases the consumption of many other resources and production of wastes. A sizeable proportion of wastes generated in urban areas are landfilled which further leads to water pollution.

5.1.4.3 State and impact:

The relationships between the state and impact indicators depend on the carrying capacity of the natural system. Beyond a certain threshold, changes in the state of the system produce significant negative impacts on the quality of human life as well as on other biotic components of the natural environment. Exposure to air pollutants causes respiratory conditions including asthma. Although asthma can be triggered by some natural substances like pollen or even unhealthy indoor air quality, vehicular and industrial emissions remain the major causes for asthma.

Exposure to polluted water is among the causes of a number of gastrointestinal infections and skin diseases. However, these infections could also be caused by other, equally likely, causes such as food. Similarly, skin diseases may be caused a range of other factors (lack of personal hygiene, insects) making it difficult to ascertain polluted water as the cause.

Another factor which is closely related with economic growth and the associated urbanization is sedentary lifestyle. Lack of optimal level of physical activity, coupled with dependence of automobiles and commuting related stress, largely contributes to higher prevalence of obesity in urban residents. And, obesity often leads to other health conditions like cardio-vascular disease or diabetes.

5.1.4.4 Impacts and response:

The relationships between the impact and response indicators depend on how a particular response is perceived by the population. Whenever, an impact is considered to have significant negative influences on the quality of human life and other biotic components of the environment, planners and decision makers react to it by devising response strategies to address the concerns.

5.1.4.5 Response and D, P, S, and I:

The relationships among response indicators and other components of the indicator framework can be best characterized as the feedback mechanisms which help keep the economic and environmental systems on sustainable paths.

A response can be a policy, a law, or other forms of voluntary and non-voluntary initiatives targeted at certain factors which threaten sustainability.

A response to check the undesired land transformation of would encourage the conservation of natural lands. As the conservation strategies succeed, the extended benefits of maintaining natural areas reduce many other environmental pressures and concerns. For example, as larger proportions of natural lands are conserved, it reduces surface runoff, water pollution, and urban flooding. When a region's ecosystem largely remains intact, enhancements in air and water quality and, biodiversity are likely. Ample vegetation and less impervious surface area have also been found to reduce the intensity of urban heat island effect.

Significant improvements in the air and water quality would reduce the prevalence or severity of various health conditions that arise due to exposure to pollutants. Reduction in the intensity of urban heat island effect would provide a sense of comfort for the urban residents and, may even reduce the demand for electricity. As a sizeable proportion of the total energy produced is used by air conditioning systems reduction in the need for electricity would certainly ease environmental pressures. Improved state of the environment would also have positive influence on biodiversity. As explained earlier with an example of pollination, a diverse ecosystem is often a healthy ecosystem, the one that has the ability provide resources and accommodate and process wastes.

Furthermore, a response to address the environmental pressures exerted by inefficient use of resources and production of wastes would encourage or incentivize waste recycling. Increased recycling would lower the cost of landfilling, free up many acres of land for more productive uses, and reduce air and water pollution.

Strategies designed to reduce the dependence on private automobiles, commuting stress, higher travel times, and ill effects of overly sedentary lifestyle would strive to improve accessibility by promoting bike and pedestrian-friendly urban growth. A response like this has the potential offer wide-spread benefits. It will offer urban residents a chance to use other environmentally friendly modes of transportation. Bike and pedestrian-friendly growth would not only reduce pollution, but it is also likely to make commuting efficient and less stressful. Moreover, research has shown that the necessity to engage in physical activity as part of the daily routine, and a real possibility to do that actually motivates people to distance themselves from their sedentary lifestyles (Ewing et al. 2003).

Reengineered urban growth has the potential to encourage people to be physically active, reducing their likelihood of becoming obese and developing other related health conditions.

The eDPSIR framework and the causal network allowed the development of analytical problem solving logic. For example, the framework allowed the distinction to be made between driving forces and pressures. This is important because, driving forces represent the growth and prosperity, and do not directly stress the environment. In this

sense, driving forces are desired factors. Economic growth is not pursued with the purpose of degrading the natural environment. The degradation is an unintended consequence of the forces that drive economic growth. Therefore, distinction between driving forces and pressures makes it easier to identify the factors that the policies should target to manage. Similarly, the distinction between state and impact indicators provides an appropriate context to determine the significance of the changes in the state of the environment (or driving forces and pressures) with respect to well-being of humans as well as the ecosystem as a whole. For example, measuring ambient concentrations of pollutants without giving consideration to how it impacts people's health would not mean much. However, when the pollutant concentrations are studied on the context of health impacts and other concerns related to quality of life, it puts policy makers in a better situation to determine the significance of air pollution and devise policies to curb it.

5.1.5 Specific Sustainability Indicators

Building on the foundation laid by the abstract indicators, eDPSIR framework, and the causal network, specific indicators were selected based on how well each one of them represented the relevant abstract indicator and whether it satisfied the individualistic selection criteria (Table 6). The selection of specific indicators was influenced considerably by the issues concerning the availability of the data at the desired spatial and temporal scales.

Table 6. Specific Sustainability Indicators and eDPSIR Framework

Driving Force	Pressure	State	Impact	Response
Population Population density Per capita investment %Population with university degree Median Income % Population Employed	Annual building permits Consumer expenditure % Housing units with 3 or more vehicles % Population drove alone to work Impervious surface area	Air pollution Ambient temperature Impaired streams Travel time to work Traffic density Per capita solid waste disposed	Number of patients hospitalized for asthma % of obese adults	Managed natural areas % of solid waste recycled

5.1.5.1 Why are these indicators meaningful:

Population as a percent of total population of all counties

This indicator provides information on where the majority of the population is located and size of the demographic base of any particular county relative to the entire study area. This is a widely used indicator of sustainability of urban systems.

Also, Rusk (1992) studied urban growth and sprawl in the United States and found population as a major driving force for urban growth and sprawl. The lifestyle preferences of the population as a whole are important determinants of the quality of natural environment in urban areas.

Population density

Population density is an indicator of spatial character of population growth and, researchers have associated lower densities with sprawled urban growth that impacts human health as well the natural environment.

Per capita investment

This indicates overall well-being of the economy and its potential for growth. It is reasonable to state that businesses and other investors invest their money only when they perceive economic climate of a certain place as promising and, as the one that has significant potential for growth in the foreseeable future. Per capita investment is an important indicator for the present research because, higher investments, in general, raise the quality of life. For example, investments create jobs, generate opportunities for smaller businesses, and provide means for the population to lead an urban lifestyle.

Percent of population with university degrees

Education attainment is a widely used indicator of economic development. A well-educated workforce and employers regularly seek each other and thus, higher education often translates into better paying jobs, sizeable earnings, and a better quality of life. Education attainment has become even more important in times like these when North Carolina's economy is evolving to become knowledge and service based economy.

In the new economy, educational qualification will be the most important factor that is likely to lead aspiring population to employment opportunities in emerging economic sectors.

Median income

Income is one of the most common, basic, and direct indicators of economic development. In a healthy and promising economy, people are rewarded with better monetary gains and benefits. With higher income people can lead a life with high standards of living. Therefore, higher incomes indicate economic well-being. Moreover, higher incomes often result in higher spending. This allows more money to circulate through the economy. As the money circulates, it fuels further economic development. The following is a simplistic example to prove this point. It is reasonable to state that, when people have money they perceive a number of goods and services as a necessity. This creates a demand for such goods and services. As a result, businesses and service providers enter the market to provide the goods, products, or service in return of monetary gains.

Percent of civilian population employed

It is essential to know the proportion of the region's employed population because; it directly indicates how viable the economy is. As a rule of thumb, a healthy economy has a higher proportion of its population employed.

Annual building permits

These data provide us information about the new housing units authorized by building permits[1]. This is one of the popular indicators used to quantify economic development. This is so because, housing market quickly responds to fluctuations in economic climate and gives out signals that allow researchers to shed light on the improvements or degradation in economic conditions. Moreover, a popular decision to make a certain county (or a place) their residence helps further economic development of that county as, the decision creates a number of opportunities for businesses and service providers of various kinds that complement this residential development (Building Permits: Useful Indicator or Meaningless information?; In Context 2001).

Consumer expenditure

These data provide us information on willingness of population to spend money to acquire the goods and services that they perceive as necessary to raise their quality of life. Higher consumer spending typically relates to a healthy and vibrant economy. And economists often use consumer expenditure (also called as consumer spending) as an indicator of economic development. Moreover, consumer expenditure is also a component included in the calculation of Gross Domestic Product (GDP).

Percent of housing units with 3 or more vehicles

Research has shown that the rate of ownership of private automobiles rises with increase in per capita income. Social scientists have also observed an overall increase in

the rate of ownership of private automobiles in the past decades in the United States with, most households owning more than one automobile (Brownson et. al 2005). Given this, percent of housing units that own 3 or more vehicles turns out to be a valuable indicator in this research. Most importantly, it indicates the proportion of total population that can afford to own 3 or more automobiles. Then, it allows us to speculate that it might actually be a necessity to own those many number automobiles to lead a comfortable life in some urban areas. If this is the case, then urban growth in those urban regions must be questioned. In addition to this, automobile ownership is found to be inversely related to the amount of physical activity that a typical urban resident engages in. serious lack of physical activity has been shown to increase the risk of health impacts caused by a sedentary lifestyle. And finally, a higher rate of ownership of private automobiles is likely to result in more of those being driven on the roads increasing the air pollution.

Percent of population driving alone to work

This indicates the proportion of population that preferred to drive alone instead of carpooling or, using public transit. Policy makers and scientists associate this kind of modal split with negative impacts on the natural environment.

Percent impervious surface area

Impervious surfaces create environmental concerns. The most important of those concerns is water pollution because; researchers believe that surface runoff is the major source of water pollution in the United States. This surface runoff often carries pollutants

such as chemicals and heavy metals from industries, animal waste, nutrients leached from farmlands, gardens, lawn, and other solids that degrade the quality of water. Some of these pollutants are carcinogenic; others may cause various diseases (e.g. gastrointestinal infections); while some pollutants are known to damage the aquatic life that thrives in water bodies into which these pollutants drain.

Impervious surfaces are also a concern because; they contribute to urban heat islands. Excessive temperatures make living uncomfortable for the residents in such urban areas and, researchers have also suggested that increased temperatures prove detrimental to avian and other wild life populations that might be present in and around major urban areas.

Air pollution

This indicator contains air quality index (AQI) data for five of the six criteria air pollutants, summarized annually for counties. AQI is one of the easier ways designed by EPA to communicate the information on air quality. AQI is based on the data collected by EPA for each of the following criteria air pollutants; ground level ozone, particulate matter, carbon monoxide, sulfur dioxide, and nitrogen dioxide. It is important to monitor these pollutants because; these are found everywhere and in most cases, are released into the atmosphere as a result of human activities. Moreover, researchers have suggested that exposure to higher concentrations of these pollutants causes a number of respiratory and other health issues.

Ambient air temperature

This indicator contains annual county wide temperatures. With ambient air temperature, the intensity of urban heat island effect is monitored. Research has shown that urban regions are typically warmer than their rural surroundings. And as stated earlier, urban heat island effect contributes to overall discomfort for humans and disturbs wildlife. In addition to this, urban heat island effect may have indirect impacts on the natural environment. Higher temperatures typically increase the demand for electricity as it is used up by air conditioning systems. More demand means more production of electric energy and, this production may increase air pollution, or greenhouse gas emissions.

Water quality – impaired streams

This indicator quantifies impaired stream length as a percent of total stream length in each county. If the percentage of impaired streams is relatively higher, water quality in the given county is a concern. This indicator is based on integrated water quality reporting categories prepared by NCDENR's Division of Water Quality (DWQ). In order to derive the reporting categories, the DWQ monitors a number of parameters which are important to maintain the water quality at the optimum level for a variety of uses such as, drinking water supply, use for food processing, fishing, or recreation. Then, each water body is assigned an integrated water quality rating that indicates the level of water pollution in it. Water bodies that belong to the categories 4 and 5 are officially considered impaired by the DWQ.

Maintaining water quality at the optimum level is important to prevent diseases, sustain aquatic life and resources, and for overall well-being of ecosystem and humans. However, water quality quickly becomes a concern with increasing urbanization. EPA states that, major threats to water quality in the United States come from non-point sources such as, urban land runoff, hydro modification and habitat alteration, and improper agricultural practices. Non-point sources introduce a variety of pollutants like sediments, oil and grease, pesticides and nutrients, and bacteria or viruses. On the other hand, major point sources of water pollution include industries and power plants. These are mostly responsible for polluting water bodies with heavy metals and other carcinogenic substances released as industrial wastes.

Mean travel time to work

This indicates the amount of time a worker would spend commuting to the work location. Travel time to work primarily serves as an indicator of spatial distribution of workers' residences and their work places (Census Bureau 2009). Many researchers have studied this spatial distribution to see how it influences overall job accessibility. They have generally found that, as travel time (or commute time) increases beyond a threshold, job accessibility reduces significantly. Thus, travel time and the spatial pattern of work and residential locations have an important influence on economic growth.

Moreover, travel time to work also serves as a general indicator of spatial pattern of urban growth and the degree of urban sprawl in an area. For example, Naess (2009) reviewed research that studies how spatial form of urban areas and locations of

residential neighborhoods influence urban commuting. The review suggests that dense and compact urban growth (with the least degree of urban sprawl) reduces commute distances, times, and overall use of automobiles.

Traffic density

This is a metric of number of vehicles per square mile. Generally, higher traffic densities slow the traffic down and this can be a reason for higher travelling times, stress that arises through commuting, and a general tendency of the population in the area to avoid outdoor physical activities.

Per capita Municipal Solid Waste (MSW) generated and disposed

MSW typically constitutes plastic, metals, glass, paper, organic materials, and other waste products collected by municipalities. It excludes waste generated in industries and in construction and demolition activities.

MSW is a widely used as a sustainability indicator because of two main reasons. First, it represents the amount of resources (including some natural resources) consumed to produce the product that has generated the waste. And second, the amount of waste generated and disposed relates to the undesired consequences of waste disposal such as, pollution of land and water resources, spread of diseases, or consumption of land along with monetary expenses incurred by constructing and maintaining landfills.

MSW as an indicator of urban sustainability attains even more importance as popular research suggests that, the quantity of MSW generated depends on the intensity

of urban development, proportion of urbanized population, and a consumption-intensive lifestyle. With the current pace of urbanization (and the affluence associated with it), the World Watch Institute (WWI 2012 - http://www.worldwatch.org/global-municipal-solid-waste-continues-grow. Accessed 5/24/2013) predicts the total MSW generated globally, will double by 2025. WWI also mentions that the rate at which MSW is generated in developed nations is about 2 kilograms per person per day. Even more interesting is the fact that, at about 621,000 tons of MSW generated per day, the United States is its largest producer.

Per capita waste recycled

This indicator particularly relates to the management of waste products and, in current scenario of waste production, recycling has attained enormous importance. Researchers at UNC Charlotte (http://www.unc.edu/~shashi/Infrastructure/solidwastemanagement.html) highlight the need to recycle the waste as they mention that, North Carolina produces more waste than the state's landfills can accommodate. As a result, the state is left with no choice but to export its waste to other states.

The quantity of waste recycled per capita definitely has an environmental aspect to it. Greater the quantity of waste that gets recycled would mean cleaner environment, efficient use of resources. In addition to this, when more and more waste gets recycled it offers indirect benefits to health, economy, and land use issues.

Rate of total number of hospitalizations to treat asthma

Percent of population that had to be hospitalized to treat asthma is an indicator of one of the major and most common health condition caused by exposure to polluted air. Even though asthma can be caused by other factors such as natural dust, pollens, tobacco smoke, or even cockroach droppings; recent research highlights anthropogenic air pollution (most importantly vehicular air pollution) as the major factor that triggers asthma in adults as well as in children (Frumkin 2002, Natural Resources Defense Council 2013: http://www.nrdc.org/health/effects/fasthma.asp; accessed on 5/25/2013).

Vehicular air pollution introduces the criteria air pollutants (which are considered in this research) into the atmosphere. These pollutants trigger asthma attacks; a serious issue in the United States. NRDC (2013) notes that, about 20 million Americans suffer from asthma. Approximately 5000 die of asthma each year. Asthma in school going children results into an estimated loss of 14 million school days per year whereas, adults suffering from it loose about 12 million work days every year. This entire struggle lands approximately 2 million people in emergency rooms each year.

Percent of obese adults

Ewing et.al (2003) studied if obesity was in any way related to spatial form of contemporary urban areas. They found statistically significant positive association between obesity and the degree of urban sprawl. Their research suggests that, people in urbanized areas do not get the required amount of physical activity. Therefore, a majority

of this urban population weighs more, is likely to be obese, and run higher risk of hypertension. In addition to this, many other researchers have shown that with obesity, increases the risk of heart disease, diabetes, and certain forms of cancer.

As far as North Carolina is concerned, about 57% of the state's residents are obese. In addition to direct health impacts, obesity has some indirect effects. It increases health care costs, generally decreases productivity at work, and most importantly, obesity is about to emerge as the primary cause of preventable deaths in North Carolina (North Carolina Health and Wellness Trust Fund 2013);http://www.fittogethernc.org/aboutObesity.aspx; accessed on 6/2/2013).

Percent of land area conserved

This indicator quantifies the total number of acres of natural land conserved in each county as a percentage of the total land area of that county. The proportion of conserved natural area captures the response of county governments, public, and stakeholders to the pressures of urbanization in order to "protect the water quality, wetlands, drinking water sources, natural beauty, and ecological diversity of North Carolina as well as provide opportunities for public recreation" (Annual report of the Million Acre Initiative 2009).

The acreage of conserved natural land is provided by the NCDENR's Million Acre Initiative (MAI). MAI works to conserve important natural areas for wildlife habitats, agricultural lands, and recreational and working forests. These efforts are

designed to help the ecosystem maintain its functions and resources. Expected benefits of a healthy ecosystem are, improved air and water quality in the state, enhanced biodiversity, more recreational opportunities for the population and a chance to experience a higher quality of life.

And finally, conservation of natural landscapes has become more important than ever, in the wake of rapid urbanization. Annual report of MAI (2009), notes that North Carolina has some counties that have been tagged as the fastest growing in the entire nation. This growth brings urbanization and, natural areas are irreversibly transformed into anthropogenic land uses, threatening the integrity of natural landscapes.

5.2 Results of Research Question 2:

The second question used the sustainability indicators to investigate the sustainability of urban growth in the study area. It was believed that each indicator would uniquely influence the overall sustainability and therefore, principal component analysis (PCA), because it is less subjective compared to other indicator weighting schemes, was utilized to derive the specific influence that each indicator has on the sustainability.

Before the variables were subjected to PCA, they were categorized as economic and environmental indicators and then they were standardized and normalized. The standardization was necessary because, the data were measured on different scales, and comparison among the raw data was not possible. So, the data were transformed with the

help of functions like percentage, per capita, or per square mile. This standardization brought the data on the same relative scale and facilitated meaningful comparison. Similarly, it was necessary to normalize the data as the PCA assumes normality of input. The data were normalized by calculating the z scores. Then, correlations among the variables were checked to ensure that at least some of the variables are fairly correlated. This was necessary because, PCA groups like variables into a fewer number of synthetic variables called principal components and, if input variables are fairly correlated, PCA is likely to be robust. So, it was essential to determine how much correlation among variables was enough for the PCAs. While addressing the same point, Hertz-Dunno (unpublished dissertation) reviewed the works of Wambach (2010) and determined that the correlations greater than 0.3 among some of the input variables were sufficient for PCA to produce acceptable results. This research has used the same criteria. Most of the correlations among the sustainability indicators used in this research were above the threshold. However, correlations among environmental indicators were, in general, on the lower side compared to correlations among economic indicators. This is probably because, the economic indicators are measured and monitored more systematically and completely, as one has better control and understanding of how economic systems behave. On the contrary, environmental indicators seem to have some gaps in the way they are measured and monitored. This may be because, one can neither measure all aspects of environmental systems, nor one has significant control over how natural systems behave.

After the necessary processing and checks, separate PCAs based on correlation metrics were run on the economic and environmental sustainability indicators. The outputs of both PCAs were checked to see if any variables had unreasonably lower communalities. Communalities quantify the amount of variance in each variable that is explained by the extracted components. A value lower than 0.5 indicates that less than 50% of the variance in the original input variable is explained by the extracted components and hence, researchers exclude such variables.

In case of economic indicators used in this research, only one (per capita investment) had a communality of 0.491(Table 7).

It was lower than the threshold however, the variable was not excluded because, the communality was very close to the threshold and the variable measured an important aspect of economic growth. On the other hand, all environmental indicators had communalities greater than 0.5 (Table 8).

Table 7. Communalities – Economic Indicators

Indicators	Initial	Extraction
Zscore: Total population of a county as a percentage of the total population of 53 counties combined together.	1.000	.881
Zscore: Population density 06-10 as people per sq. mile	1.000	.905
Zscore: Per capita investment in each county, averaged over the period of 2006 to 2010	1.000	.491

Zscore: Percent of Population 25 years and above with a university degree. University degree derived by combining percent population with bachelor's and graduate or professional degree. Source ACS 2006-2010	1.000	.872
Zscore: Median Income (Dollars) from ACS 2006-2010	1.000	.896
Zscore: Employed population 16 years and above as a percent of total population of each county for 2006-2010	1.000	.686
Zscore: 'PercentTotPermit' - Number of building permits issued in each county during 2006 - 2010 as a percent of 'TotPermits0610'	1.000	.797
Zscore: Consumer expenditure on retail goods in each county as a percentage of total consumer expenditure in all 53 counties combined otgether. (percent of grand total)	1.000	.925
Zscore: Housing Units which have 3 or more vehicles, as a percentage of total housing units in each county.	1.000	.892
Zscore: Percent of Commuters Who Drove Alone to Work.	1.000	.865

Table 8. Communalities – Environmental Indicators

Indicators	Initial	Extraction
Zscore: Impervious Surface Area As a Percentage of Total Area of Each County	1.000	.903
Zscore: Ambient Air Temperature (Countywide)	1.000	.700
Zscore: Impaired Stream Length as a Percentage of Total Stream Length in the County	1.000	.662
Zscore: Traffice Density for the period of 2006-2010, expressed in number of Vehicles per square mile	1.000	.829
Zscore: WstDisPCpt = MSW Disposed (Tons) Per Capita during the period 2005-2006 to 2010-2011	1.000	.726
Zscore: TravelTime_Pct = Percent of the 24 hour day spent in commuting or travelling to work.	1.000	.536

Zscore: Average of Rate of Hospitalizations for Asthma for the period of 2006 – 2010	1.000	.702
Zscore: Average percent of obese adults over the period of 2006-2009	1.000	.811
Zscore: Managed Area in each county as a percentage of the total area of that county	1.000	.723
Zscore: Tons of Waste recycled on average in each county over the period 2005-2006 to 2010-2011	1.000	.569
Zscore: Difference between the mean AQI for Oz 07-10 and the AQI for Oz for a particular county 07-10	1.000	.625
Zscore: Difference betweenthe mean AQI for CO 07-10 and AQI for CO for a particular county 07-10	1.000	.807
Zscore: Difference between the mean AQI for NO2 07-10 and the AQI for NO2 for a particular county 07-10	1.000	.780
Zscore: Difference between the mean AQI for PM10 07-10 and the AQI for PM10 for a particular county 07-10	1.000	.591

PCA generates as many principal components as there are input variables however, only a first few of those components account for most of the variance in the original dataset. Thus, researchers have to determine the number of principal components which need to be subjected to further analysis. In this research, principal components that had Eigen value greater than one were selected. Such components explain the variance accounted for by more than one variable in the original dataset and therefore, are considered important from the standpoint of reduction in dimensionality of the original dataset.

Even though this research did not focus on the dimension reduction, it was still necessary to select only those principal components that accounted for maximum variance in the dataset so that, the loadings on only those components could be processed further in order to derive the weights for sustainability indicators.

PCA of economic indicators generated 3 principal components that had Eigen value greater than one and the cumulative variance explained by those components was 82.076% (Table 9). On the other hand, PCA of environmental indicators generated 5 principal components that had an Eigen value greater than one and, the cumulative variance explained by those components was 71.169% (Table 10). PCA commonly explains around 70% to 80 % cumulative variance. In this case, the variance explained by the PCA of environmental indicators is above the arbitrarily defined threshold; however, it is considerably lower than the variance explained by the PCA of economic indicators. This is probably because the underlying construct of environmental indicators, as suggested by the relatively lower correlations among environmental indicators.

Table 9. Principal Components - Economic Indicators

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Compo-nent	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.610	56.100	56.100	5.610	56.100	56.100	4.498	44.980	44.980
2	1.380	13.797	69.896	1.380	13.797	69.896	2.044	20.444	65.424
3	1.218	12.180	82.076	1.218	12.180	82.076	1.665	16.652	82.076
4	.869	8.692	90.767						
5	.373	3.732	94.499						
6	.262	2.619	97.119						
7	.133	1.332	98.451						
8	.096	.962	99.413						

9	.040	.396	99.809						
10	.019	.191	100.000						

Table 10. Principal Components - Environmental Indicators

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.180	22.712	22.712	3.180	22.712	22.712	2.760	19.717	19.717
2	2.414	17.242	39.954	2.414	17.242	39.954	2.447	17.479	37.196
3	1.900	13.568	53.522	1.900	13.568	53.522	1.687	12.047	49.243
4	1.362	9.727	63.249	1.362	9.727	63.249	1.609	11.493	60.737
5	1.109	7.920	71.169	1.109	7.920	71.169	1.461	10.433	71.169
6	.880	6.289	77.458						
7	.735	5.250	82.708						
8	.700	4.998	87.706						
9	.461	3.291	90.998						
10	.427	3.050	94.047						
11	.360	2.574	96.621						
12	.267	1.909	98.530						
13	.175	1.253	99.783						
14	.030	.217	100.000						

Loadings on the selected principal components were utilized to derive specific indicator weights. As, a principal component groups like variables, each variable provides the component its ability to account for a certain proportion of variance in the original dataset. This influence of a variable is expressed in terms of a correlation coefficient between the variable and the component, and is known as loading. This research used these loadings as the unique influence that each indicator (original variable) has, on the overall sustainability.

However, before these loadings were used as indicator weights, they were transformed with the help of following formula;

$$\text{Final weights} = \left[\frac{\sum L_{ij}^{2} \times 100}{\sum_{i} L_{ij}^{2}} \right] \times 100$$

Where:

L_{ij}: loading of indicator i on a selected principal component j

$\sum_i$: total of 'sum of squared component loadings' for each indicator i

a. For each indicator, its loading on each of the selected principal component was squared. All squared loading for each indicator were added together to derive a sum of squared loadings which was unique to each indicator.
b. These squared loadings were further added up to derive the grand total.
c. Then, each value which represented the sum of squared loadings for any particular indicator was expressed as a percentage of the grand total.
d. The percentages were multiplied by a factor of 100, and were used as weights.

As a result of this transformation, every indicator has a unique weight based on the variable's loadings on all of the selected principal components (Table 11 & 12). This is very similar to how the communalities are calculated. The weights were further transformed so that they sum up to one. This made them comparable with one another

and, allowed comparison about their relative importance on the overall sustainability. Finally, indicators were weighted by their respective weights and, the weighted indicators were added together to derive two composite indices; one for economic growth (economic index) and the other for natural environment and the quality of life (environmental index).

Table 11. Weights: Economic Indicators

Indicators	**Weight**
Total population	0.1011
Population Density	0.1099
Per capita investment	0.0740
Percent of Population 25 years and above with a university degree	0.1065
Median Income	0.1083
Employed population 16 years and above	0.0820
Percent Total Permit	0.0954
Consumer expenditure	0.1124
Housing Units which have 3 or more vehicles	0.1070
Drove Alone to Work.	0.1035

Table 12. Weights: Environmental Indicators

Indicators	**Weights**
Impervious Surface Area	0.0771
Ambient Air Temperature	0.0721
Traffic Density	0.0825
Impaired Stream Length	0.0670
MSW Disposed (Tons) Per Capita	0.0743
Travel Time	0.0558
Average of Rate of Hospitalizations for Asthma	0.0702
Average percent of obese adults	0.0813
Managed Area	0.0752
Tons of Waste recycled	0.0625
Air Pollution: AQI Oz	0.0617
Air Pollution: AQI CO	0.0805

Air Quality: AQI NO2	0.0801
Air Pollution: AQI PM10	0.0596

The indices are objective metrics that quantified economic and environmental dimensions of growth in the study area. Indices allowed for comparison between the two dimensions of growth, and helped us determine the intensity of resource conflict over the geographic space.

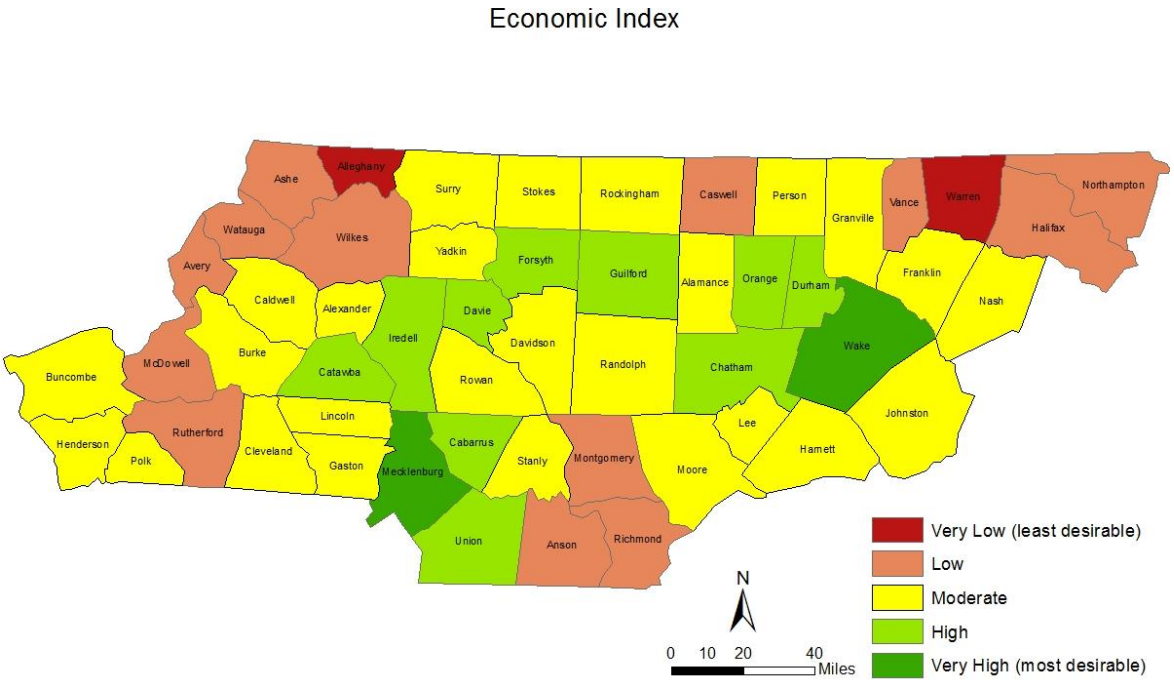

Figure 4. Economic Index

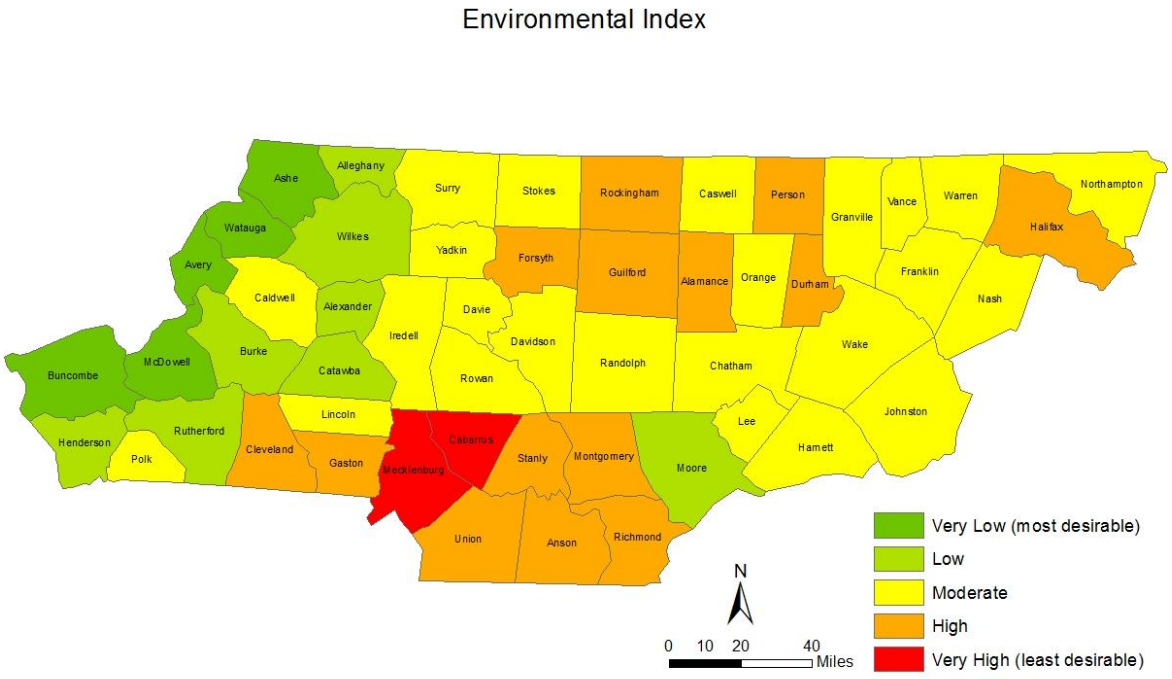

Figure 5. Environmental Index

The hypothesis was that higher economic growth and associated urbanization (Figure 4) would have negative impacts on the quality of the natural environment and the quality of human life (Figure 5), compromising the sustainability of growth. The hypothesis did hold true however, the intensity of the conflict between the economic and environmental dimensions varied over geographic space.

As expected, counties which show high or very high economic growth are those in which major cities are located. Since these cities, then, emerge as the hubs of socioeconomic activities, the surrounding counties also become functionally attached to the hub and experience higher economic growth and urbanization. There are 3 clusters of high growth counties which also have significant impacts on the sustainability of the environment and the quality of life.

5.2.1 High Growth Cluster - 1

The first cluster consists of Wake, Durham, Orange, and Chatham counties (Figure 4). Wake County shows very high economic growth whereas, other counties in the cluster show high growth. Economic factors like university education, employment, income, and consumer expenditure seem to have influenced the high economic growth in these counties. In addition to these factors, larger demographic base and a popular choice to make Wake County a place of residence appears to have fueled its economic growth even further. Research Triangle Regional Partnership (RTRP 2013: http://www.researchtriangle.org/regions/wake. Accessed on 8/23/13) notes that, wake county is among the fastest to experience urban growth in the entire united states. Entrepreneurs have preferred Wake County for their businesses because of the healthy business climate. Moreover, the housing market in the county is preferred by investors and, the public schools and universities are highly regarded nationally and internationally.

The prominent economic sectors that have fuelled the economic growth in the county are government, education, healthcare, computer technology, biotechnology, and financial services.

In case of Durham county, per capita investment appears to be the strongest contributor to its high economic growth, among other factors such as educational attainment, employment, and consumer expenditure. Higher investments that are made in Durham county can be explained by studying how the economy of the county has evolved and grown. The county has grown to be one of the nation's top technological hubs with its industrial growth concentrated in sectors like life sciences and advanced healthcare, information technology, and electronics.

The economic growth in Orange County appears to be slightly less intense, in relative terms, as the county has a blend of urban and rural character. The most important factor that have fueled economic growth in Orange county is the proportion of population that have attained higher education and, which is skilled and talented to contribute to the emerging knowledge and service industry based economy. This higher educational attainment in the county is attributed to the positive influence of the University of North Carolina at Chapel Hill, one of the top public colleges in the United States.

Chatham County seems to be benefited with its adjacency to economic hubs such as Raleigh and Durham. The major factors that have contributed to higher economic growth in the county are reasonably higher income and, the growth is largely a result of industries that specialize in manufacturing and technology.

The higher economic growth in these counties was expected to produce significant negative impacts on the natural environment and on the quality of life of residents. The results differ slightly from the expectation; the environmental impacts in Wake, Chatham, and Orange counties are not as severe. These counties show moderate impacts. However, Durham County shows high impacts on the natural environment and quality of life (Figure 5).

Wake County, in particular, was expected to have higher waste disposal with minimal recycling, more impaired streams, and higher air pollution. However, impervious surface area and traffic density are the only two factors that appear to have produced moderate impacts on the environment and quality of life in the county. Better environmental conditions, at present, in Wake County may be attributed to effective implementation of the sustainability plan that is targeted at increasing the efficiency of resource use by reducing and managing the solid waste generated in the county, protecting water resources, and reducing the impervious surface area. It seems that the county has been successful in addressing the issues related to solid waste and water quality. However, the county government has expressed its concerns about the pace and intensity of its urban growth. The experts involved with the county's sustainability task force believe that the signs of stress on the natural environment in the county are increasingly becoming apparent and the action towards sustainability of growth is becoming increasingly important.

Chatham and Orange counties also show moderate, as opposed to high, impacts on the natural environment and the quality of life. Chatham County has significantly lower proportion of impervious area. The dominant land cover in the western half of the county appears to be managed green spaces whereas; majority of the eastern half seems to have natural vegetation. The county also disposes relatively lower proportion of wastes and these factors may have contributed to improve the environmental quality in the county. At the same time, air pollution by carbon monoxide may be the one factor to produce some impacts on the natural environment (Chatham County Dept. of Environmental Health 2013; accessed on 8/23/13). Similarly, Orange County also has lower proportion of impervious surfaces and lower waste disposals. These factors have likely contributed towards the betterment of the environmental quality. However, Orange County possibly has water quality issues as indicated by higher proportion of impaired streams. This water pollution may be attributed to a higher proportion of managed or manmade green spaces in the county as, pesticides or other chemicals that are used to maintain these green spaces usually find their way into water bodies and pollute the water.

Durham County, on the other hand, stands out because of the high impacts on its environment and quality of life. The major factors that seem to have influenced environmental quality in this county include higher proportion of impervious surface area, higher traffic density, and air pollution by both carbon monoxide and particulate matter.

5.2.2 High Growth Cluster - 2

The second high growth cluster includes Guilford, Forsyth, and Davie counties (Figure 4). All three show high economic growth. In general, the demographic base, university education, and consumer expenditure appear to have fueled high economic growth in these counties. The growth in Guilford and Forsyth counties can be attributed to the emergence and growth of industries that manufacture computer and electronic products, electrical equipment, transportation equipment, chemicals and pharmaceuticals. In addition to manufacturing, other economic sectors like education and healthcare, real estate, and logistics and distribution have also contributed to the economic growth in these counties. These economic sectors required population to possess different, probably updated, skills to thrive continue the growth. This demand was arguably an opportunity for the educational institutions in the county to actively participate in the process of economic growth by empowering the population with the required skills. The prospects of continued economic growth in these counties have probably attracted even more people in to the area who aspire for a modern, urban lifestyle, as indicated by relatively higher population and popular choice to make either one of these counties a place of residence.

Davie County is slightly different from Guilford and Forsyth counties. Even though Davie County shows high economic growth, it is marginally lower compared to the economic growth in other two counties in this cluster. The results indicate that, the important factors that have contributed to economic growth in Davie County are income,

consumer expenditure, and the number of households that own 3 or more automobiles. Davie county Economic Development Commission identifies agriculture as the central economic sector for the county. Even though other economic sectors like manufacturing, logistics and distribution, and education and healthcare exist, they do not appear as strong as these sectors in Guilford and Forsyth counties. It appears that a major portion of the financial well-being of the residents of Davie County actually relies on the business or other activities conducted outside the county because, the data (households with 3 or more vehicles) and the commuter flows between Guilford, Forsyth, and Davie counties clearly indicates that, majority of the population commutes outside the county (to Guilford or Forsyth), arguably for business, employment, or education.

Results indicate that, higher economic growth in these three counties have produced negative impacts on the natural environment and the quality of life in this region. Guilford and Forsyth counties show high impacts whereas; Davie County shows moderate impacts on the environment (Figure 5).

The prominent environmental concern both Guilford and Forsyth counties share is perhaps rapid transformation of natural lands into built-up impervious areas. Guilford County has slightly more impervious surface area compared to Forsyth. Other prominent environmental concerns in the two counties are air pollution and the issues related with inefficient use of resources and waste management. The intensity of air pollution in both the counties is more or less the same and it can be attributed to vehicular traffic and industrial emissions. As far as the quantities of wastes that are disposed in each county

are concerned, Forsyth County disposes more wastes but, recycles only minimal quantities. On the contrary, Guilford County disposes slightly less quantity of waste in the first place and still manages to recycle reasonable quantities of those wastes.

Compared to Guilford and Forsyth counties, environmental impacts in Davie County are less severe probably because, it is comparatively more rural. This may explain the lower impervious surface area and lesser quantities of wastes that are disposed-off in the county. However, impaired streams and air pollution by nitrogen dioxide may have created some water and air quality issues in Davie County. Water pollution may be attributed to the dominant land use in the county, which is either agriculture or managed green space (e.g. turf). And, it is reasonable to state that, the fertilizers, pesticides, or other such chemicals used to maintain agricultural lands and other managed vegetation eventually find their way into the water bodies and pollute water. And, air pollution is perhaps the result of considerably higher vehicular traffic, as majority of the population commutes for daily business.

5.2.3 High Growth Cluster - 3

The third cluster of high growth counties consists of Mecklenburg, Cabarrus, Union, Catawba, and Iredell (Figure 4). Mecklenburg County shows very high economic growth comparable to that of Wake County, whereas other counties in the cluster show high economic growth.

In general, economic factors like income and consumer expenditure have contributed to the economic growth in all five counties in this cluster. However, there are additional factors which also seem to have encouraged the economic growth in these counties.

Mecklenburg County has the largest demographic base and, majority of its population holds a university degree. Also, the county's economy is supported by both manufacturing sector as well as service sector (Charlotte Regional Partnership CRP 2013: http://charlotteusa.com/business-info/charlotte-usa-overview/mecklenburg/, accessed on 8/26/13). This arguably created a huge demand for workers with technical skills that are required to work in manufacturing facilities and also, for personnel with management or other professional qualifications that are required to excel in the knowledge and service based economy. This seems to have attracted the maximum number of people to Mecklenburg County, as indicated by the popular choice to make it a place of residence. Also, the county is home to a recognized state university and other educational institutions.

Similarly, Union County also seems to be a relatively popular place to live, and this popular choice appears to have fueled its economic growth in addition to the other factors mentioned earlier. In Cabarrus and Catawba counties, higher employment and a popular choice to depend on private automobiles appear to be the stronger determinants of economic growth, when compared with other factors. Catawba County also has a relatively higher percentage of per capita investment. Finally, Iredell County also has

higher per capita investment along with the largest proportion of households (in the cluster) with 3 or more vehicles. It is interesting to note that, as one moves away from a socioeconomic hub in the region, people tend to own more vehicles and tend to prefer private transport over any other mode.

This economic growth seems to have produced significant negative impacts on the natural environment and the quality of life in this region, with Mecklenburg and Cabarrus counties showing the highest impacts (Figure 5). Mecklenburg County is the main economic hub in this high growth cluster and has among the highest proportions of impervious surface area. The urban growth has spread in all directions from the central business district. The fragmentation of natural lands is noticeable. Also, a number of freeways and state highways converge in the county which likely increases the vehicular traffic that passes through. This may explain the higher traffic density and, air pollution caused by carbon monoxide and nitrogen dioxide. Moreover, significantly larger demographic base, coupled with higher economic growth, may be a reason behind the extraordinarily higher quantities of wastes that are disposed-off while insignificant quantities are recycled.

In case of Cabarrus County, the most pressing of environmental concerns appears to be inefficient use of resources. Cabarrus County generates large quantities of wastes and a very small proportion of that is recycled.

This may be attributed to the presence of extraordinarily larger centers of socio-economic activities located in the county, like the Concord Mills, in addition to overall urban character and the vicinity of the Cabarrus County to a major socioeconomic hub like Charlotte. Moreover, the air quality in Cabarrus County also seems to be the second major environmental concern after waste disposal.

The other counties in the cluster show high impact. In case of Union County, the important environmental concern seems to be air pollution from carbon monoxide and nitrogen dioxide. Iredell County shows moderate impacts on the environment and the quality of human life. Water and air pollution, and asthma appear to be the important environmental concerns in this county. Water pollution in Iredell County may be attributed to number golf courses, country clubs, or other such places which have extensive land areas under manmade green spaces. And, the chemicals used to maintain these green spaces often reach water bodies and pollute the water. Air pollution in the county is probably a result of vehicular traffic that passes through the county using the freeways and highways.

Catawba is the only county in this cluster that has better environmental quality. This is mainly because exceptionally higher proportion of waste that this county recycles compared to the quantities it disposes-off. The environmental factor that may possibly impact the environment and the quality of life in Catawba County is impervious surface area and managed green spaces.

Similar to these high growth clusters, there are three other clusters of low growth counties. As per the hypothesis, these counties should ideally have better environment and higher quality of life.

However, the hypothesis did not hold true uniformly. Even though one of these low growth clusters indeed has better environment and quality of life, the other two show moderate impacts on the environment.

5.2.4 Low Growth Cluster - 1

The first low growth cluster includes Alleghany, Ashe, Wilkes, Watauga, Avery, McDowell, and Rutherford counties (Figure 4). Of these, Alleghany shows very low growth whereas; other counties belong to the low growth category. Most area in this cluster is protected by state parks or national forests and this explains the significantly lower economic growth in the area and better quality of natural environment (Figure 5).

5.2.5 Low Growth Cluster - 2

The second low growth cluster includes Vance, Warren, Halifax, and Northampton counties (Figure 4). Among these, Warren shows very low growth whereas; other counties show low growth. The overall lower economic growth in this cluster may be explained by the fact it lacks major centers of economic activities like educational and research institutes, or industrial facilities. The dominant land use in this cluster appears to be small-scale agriculture. Additionally, this low growth cluster is perhaps overshadowed by significantly higher growth in the nearby cluster that includes Wake, Durham, Orange,

and Chatham counties. This seems like a plausible explanation because; the low growth cluster is close to the economic hubs (Raleigh, Durham etc.) such that, it experiences competition for growth and resources. However, not close enough to benefit from the spill-over of growth. At the same time, the low growth cluster is not far enough from the major economic hubs in the vicinity so that, it could emerge as an independent high growth cluster.

Contrary to the expectation, the counties in this low growth cluster show moderate impacts on the environment and the quality of life, except Halifax County which shows high impacts (Figure 5). In general, the environmental factors that have impacted the quality of life in this cluster are obesity and, relatively higher travel time which likely increases the commuters' exposure to pollutants. This may be explained by the need or tendency of the majority of the population in this cluster to commute longer distances to get to bigger cities in the vicinity, as indicated by a relatively higher proportion of households with 3 or more vehicles and a higher proportion of people who drive alone. As a result, these commuters likely get higher exposure to air pollutants which may be a reason behind the higher incidences of asthma in this cluster.

5.2.6 Low Growth Cluster - 3

The third low growth cluster includes Montgomery, Anson, and Richmond counties (Figure 4), and all three show high impacts on the environment (Figure 5). Montgomery County appears to have water quality issues as indicated by considerably higher percentage of impaired streams in the county. Likely reason for this is the number

of active or abandoned mines located in this county. These are open cast mines and it is very much likely that the run-off from these mines or the water that percolates into the soil is loaded with substances that pollute the water bodies in Montgomery County. Anson County seems to have an air quality issue and carbon monoxide appears to be the main factor responsible for that. Probably, exposure to polluted air has impacted the respiratory health of the population as indicated by higher asthma incidences in Anson County. As far as Richmond County is concerned, major environmental factors that appear to have impacted the environment and quality of life are air pollution, inefficient use of resources, and higher incidences of asthma. Air quality in Richmond County is affected by carbon monoxide and this may be a result of higher proportion of population that prefers to drive alone in private automobiles and the freeway traffic that passes through the county. Given this, it is reasonable to state that, the residents of Richmond County get higher exposure to polluted air and this causes higher incidences of asthma, which appears to be a severe concern in the county. In addition to this, Richmond County generates higher quantities of wastes but recycles significantly less quantities even though; it is difficult to identify a likely reason for this.

Besides these clusters of high and low growth, most of the remaining counties show moderate economic growth (Figure 4) with moderate impacts on the environment and the quality of life (Figure 5). These counties are usually away from the major economic hubs and have slightly lower incomes, consumer expenditure, and population with university degree. However, it is noticeable that, these counties usually have more households that own 3 or more vehicles and population that prefers to drive alone. This

might be a result of poor public transportation in distant areas that are more rural in character. Or, the need for these people to commute to an economic hub in the vicinity to take advantage of better educational facilitates, jobs, or other amenities. Even though the environmental quality and the quality of life in these counties are not severely impacted, there are certain environmental concerns that need to be managed before they evolve into serious environmental issues. For example, a few of these counties have higher obesity and incidences of asthma (Granville and Nash) while some others seem to have water quality issues (Surry, Yadkin, and Caldwell).

The goal of the second research question was to determine whether the growth in the study area is economically viable and environmentally sustainable. The composite indices did attempt to answer the question. The indices are the metrics that would inform experts as well as common public about the sustainability of growth and would also help them determine their priorities (economic growth or protection of natural environment) to ensure that the growth in their county remains sustainable.

Most counties in the study area showed moderate economic growth and moderate impacts on the natural environment and the quality of life. The overall growth in these counties must be considered sustainable since it may be impractical to have economic growth with no environmental impacts at all. A relatively healthy natural environment in these counties gives residents and the government an opportunity to emphasize economic growth without having to worry about the immediate degradation of the environment and the quality of life.

However, the governments in these counties must continue to assess the stresses on the environment and quality of life so that, the sustainability does not decrease with continued growth.

On the other hand, the high growth counties that have shown high or very high environmental impacts would be better off if they prioritize the protection of the natural environment and the quality of life, while maintaining the economic growth as high as possible. However, this represents a major challenge faced by these high growth counties as these are expected to grow and urbanize even further in the foreseeable future, increasing the intensity of the conflict between economic growth and natural environment. These counties have acknowledged the need for them to work their way towards sustainable development, as indicated by their sustainable development plans. A brief review of these plans and progress reports indicates that, the plans are bringing about expected changes such as, reduction in waste disposal, improvements in land use, and water or air quality. Therefore, it is reasonable to hope that, these counties, with the continued success of their commitment for sustainable development, would spearhead the success story of the entire region studied in this research.

Finally, there are some low economic growth counties that have exceptionally better environmental quality (first low growth cluster). Most area in these counties is protected by national or state parks and therefore, these counties are likely to maintain their natural capital and attract nature lovers.

The governments of these counties probably need to protect the integrity of these forests, especially along their boundaries where aggressive urbanization typically encroaches onto forest or natural lands.

5.3 Results of Research Question 3:

The third question compared weighted sustainability indices (Figures 6 & 8) with un-weighted indices (Figures 7 & 9). The comparison was deemed necessary since researchers lack consensus about any one method to weight sustainability indicators, and the comparison was expected to, at least, encourage the debate about finding a widely accepted method of weighting indicators.

It was expected that, weighted indices would be slightly different than un-weighted indices but, not drastically different. The weighted indices appear to mask some of the variance in economic and environmental performance, as indicated by lower standard deviation. This is because, the transformation that had to be applied to PCA-derived weights before they could be meaningfully compared with each other. On the other hand, un-weighted indices appear to reveal relatively more variation in economic and environmental performance, as indicated by considerably higher standard deviation.

However, analysis of statistical distribution of index values produced by both methods is similar to each other and there are no significant differences, with the exception of only a few counties. This suggests that, even though statistical weights are objective, they may not always be able to express the unique importance of individual

sustainability indicators because; the necessary transformations of the data and the weights scale the indices such that their influence gets masked.

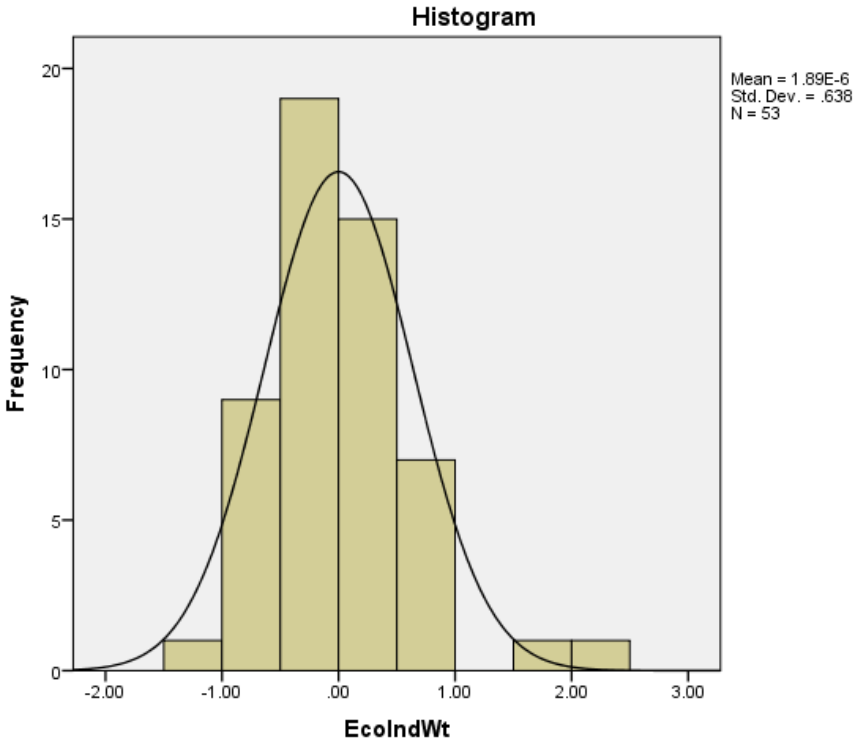

Figure 6. Statistical Distribution of Weighted Economic Index

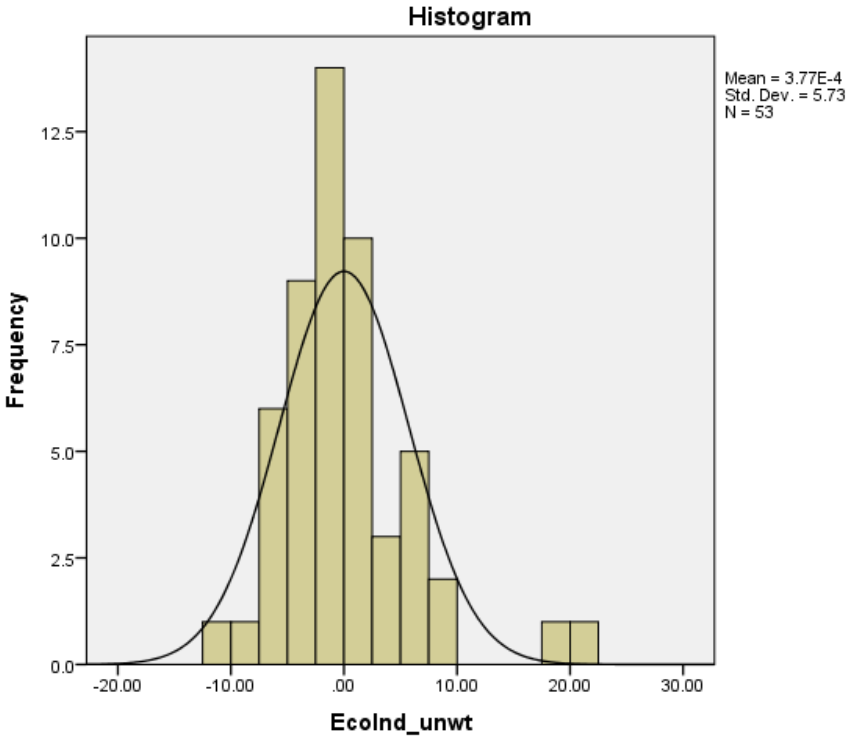

Figure 7. Statistical Distribution of Un-weighted Economic Index

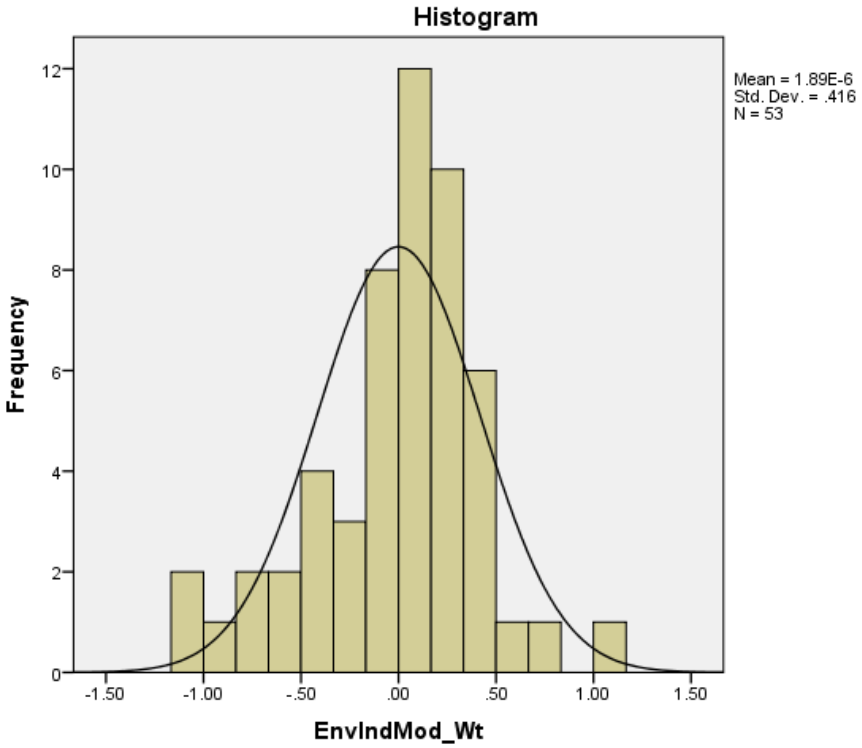

Figure 8. Statistical Distribution of Weighted Environmental Index

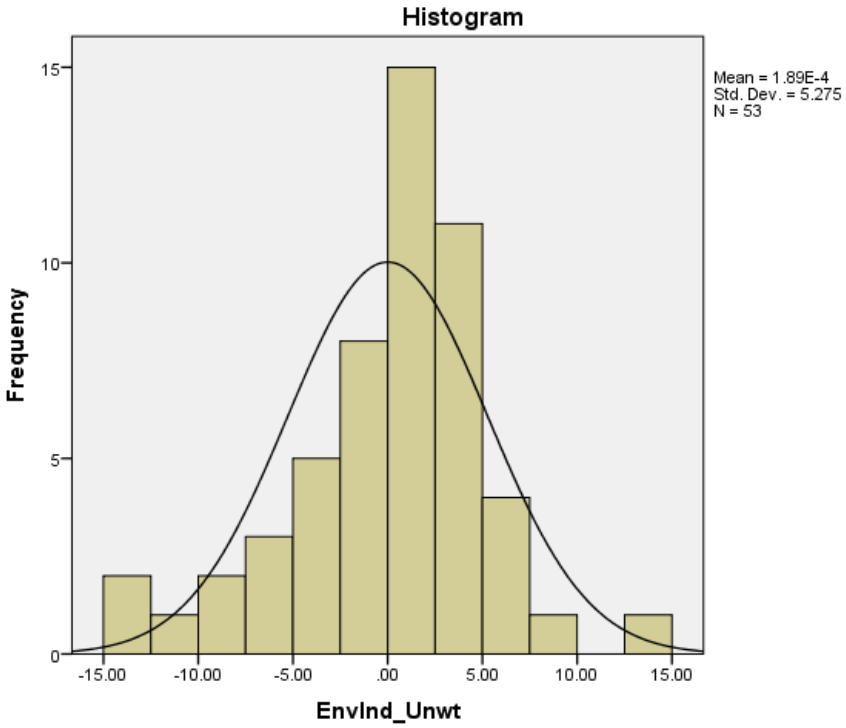

Figure 9. Statistical Distribution of Un-weighted Environmental Index

CHAPTER VI

CONCLUSIONS

6.1 General Conclusions:

This research conceptualized sustainable urban development as an emergent phenomenon, the one that emerges out of many interactions among economic and environmental components of an urban system. These interactions are best expressed as conflicting priorities that demand planners, politicians, and even common public to weigh their options and decide the future course of action towards sustainable growth. However, addressing and capturing the conflict is a difficult task. It requires information so that stakeholders can make decisions, to be communicated in an objective, comprehensible, and effective way. To achieve this, the study implemented a quantitative method to compare economic and environmental dimensions of urban growth over geographic space. The study also focused on an approach to communicate information in a way that experts and the general public can easily comprehend. The comparison was conducted with the help of sustainability indicators and by producing composite indices to express results. The overall goal of the research was achieved as the sustainability indices revealed the spatial patterns that indicated how economic growth relates with the quality of natural environment.

Also, the study identified different county clusters based on the comparison and shed some light on the factors which the counties need to monitor closely in order to keep the future growth and urbanization sustainable.

The results indicated that education, employment, income, and consumer expenditure are the most common factors that influenced economic growth in the counties in general. However, underlying economic sectors which were instrumental for economic growth in the three high growth clusters differed slightly. For example, growth in the High Growth Cluster 1 is supported predominantly by high-tech industries like computer and information technology, financial services, biotechnology, healthcare, and education. On the other hand, manufacturing sector (transportation equipments, chemicals and pharmaceuticals, computers, electronics, and electrical equipments) was perhaps mainly responsible for higher growth in the High Growth Cluster 2. In the High Growth Cluster 3, both manufacturing and service based economic sectors fueled higher economic growth. All three high growth clusters have similar concerns regarding the environmental quality and quality of life. Undesired land transformation, air quality and water pollution are common to all three. However, inefficient resource use seems to be a concern particularly in High Growth Cluster 2 whereas, traffic congestion appears to be one additional environmental concern in the High Growth Cluster 3. On the other hand, counties in the Low Growth Clusters have to deal with different environmental and quality of life issues. A concern common to all these clusters is higher rate of vehicle ownership and higher travel times. The other concerns include higher obesity and asthma.

This study addressed important issues related with the efficient use of sustainability indicators and composite indices, as they have been identified in the literature. The users of indicators and indices have expressed their concerns about the process of indicator selection. They note that the selection process is ambiguous and lacks a well-defined structure. As a result, scholars select indicators based on their knowledge or judgment and, they do not always document the logic that influences their choice of sustainability indicators. This affects the credibility of indicator based assessments in general, prevents reconstruction and meaningful comparison among them. To make selection of indicators a systematic process, this research proposed the use of eDPSIR indicator framework as an integral part of the selection process. The indicator framework made the selection process systematic by improving the understanding of a vague concept like sustainable development. For example, without the indicator framework, sustainable development is defined as balanced growth. This leaves the analyst and an observer unsure of how to measure the balance and this causes the ambiguity in its measurement. However, the indicator framework reduced the vagueness as it conceptualized sustainable development as a process that involves drivers, pressures, state, impacts, and responses. This idea clarified what the indicators should measure and if they fit together with others. This made it easier to narrow down on the economic and environmental factors that were important to study sustainability of urban growth in the study area. Moreover, the framework allowed us to incorporate set level selection criteria, in addition to the individual selection criteria that are commonly used. This selection procedure ensured that each sustainability indicator has a definite role and place in the

entire constellation of indicators and also, on an individual level, each indicator represents an objective metric of at least one aspect of the growth.

The next issue addressed in this research dealt with the indicator weights. Researchers acknowledge that, the magnitude of each indicator's influence on the overall sustainability varies however; subjective methods that are commonly used to quantify the specific influence of each indicator are criticized for obvious reasons. Therefore, this study used a statistical method, Principal Component Analysis to determine indicator weights. The idea was to avoid subjective judgments as far as possible. This was mostly achieved, except in a few cases, where somewhat subjective decisions had to be made. For example, the threshold that defined the enough correlations among the indicators, or the threshold to accept or discard variables based on the communalities did have some element of subjectivity in them. Nonetheless, transformed indicator weights did allow comparison among the indicator as to which, in general, has more influence on the overall sustainability. However, use of PCA to determine indicator weights did have some limitations. Its robustness depended entirely on the data. For example, PCA of environmental indicators explained considerably lower proportion of variables compared to the variance explained by the PCA of economic indicators. This was believed, primarily, a result of the underlying construct of environmental indicators which may have resulted as the data pertaining to those indicators came from diverse and independent sources. Considering this, PCA may produce better results when the data are collected from the sources that follow a similar set of rules as far as the collection and production of the data is concerned.

Nonetheless, the composite indices effectively summarized the information pertaining to disparate indicators into a single meaningful metric. The indices like these are better tools that convey the dynamics of multidimensional issues in a way that even non-experts can easily understand. The composite indices are definitely an advantage over conventional ways of reporting sustainability (changes in individual indicators) as the indices are an eye catcher and, they paint a bigger picture which cannot be neglected in the process of policy decision making. However, it is advisable to keep an eye on the individual indicators while interpreting the composite indices, to avoid drawing overly simplistic conclusions.

The indices and the methodology used to derive them helped answer some of the critical arguments that are extended towards the composite indices. Critics argue that a composite index must include all aspects of sustainable development in order to fully quantify sustainability (Booysen 2002). The composite indices developed in this study focus on economic and environmental dimensions of sustainability and leave other dimensions out. However, this clear focus lends the indices their ability to convey the information effectively (Mori and Christodoulou 2012). If an index combines information from a very large number of indicators which relate to different dimensions of sustainability, the index quickly becomes confusing and loses its appeal. The idea in creating an index is not just aggregating disparate indicators but, to aggregate them while preserving their meaning.

Critics also question the way researchers interpret the composite indices. They argue against the interpretation of indices in relative terms and state that, it would be promising to provide absolute meaning to a particular index value. Critics support their argument by saying that, components of an urban system should be ideally evaluated with reference to set thresholds. Even though this works in some cases, thresholds cannot always be defined because; it is difficult to relate absolute threshold values with the amount and limits of human activities. It requires many assumptions. On the other hand, interpreting the index value in relative terms allowed us to quantify sustainability in each county compared to the sustainability in all counties in the study area. This approach did not require a far-fetched effort to provide a specific meaning to a particular index value and thus, reduced the likelihood of making erroneous interpretations. Therefore, it was determined that, interpreting the indices in relative terms was advisable in absence of a widely accepted scale of reference that may allow researchers to provide a meaning to an index value. Moreover, relative interpretation is simpler and is recommended when the target audience includes common people.

The last issue about the use of indicators and indices that is discussed in this study relates with the comparison between two indicator weighting schemes. Researchers have criticized both subjective and objective methods to weight indicators because; each is believed to have its own shortcomings. A few scholars have attempted to bypass this criticism by proposing to use no indicator weights (or, equal weights) at all. No particular indicator weighting scheme enjoys universal acceptance by experts and the confusion prevails. In an attempt to address the confusion, this research compared PCA derived

indices with those derived by aggregating un-weighted indicators. The two indices were similar to a greater degree than expected. It appeared that the necessary transformation of the data and scaling of the indicator weights influenced the ability of weighted index to highlight the influence of individual indicator as it portrayed the relationship between economic growth and environmental quality in the study area.

6.2 Limitations and Future Directions:

Like any other research work, this study also has some limitations. Since sustainable development is a broad concept, reporting it requires data from a number of different sources. The data collected by independent sources differs with respect to the collection methodology, survey design, spatial scale and update frequency, and accuracy. Any research has to work around these issues since it is practically impossible for any one institution or organization to collect data pertaining to a large number of factors that may be important to study sustainability of growth in urban areas.

Furthermore, as this research discussed the relationships among indicators and compared economic growth with the quality of natural environment, it did not explicitly account for spatial and temporal delays that sometimes characterize the indicator relationships. Also, the time period 2006 to 2010, over which this research assessed the sustainability, includes recession years. The recession may have affected economic performance of counties.

Finally, the indicator framework utilized in this study helped to structure the causal network and highlight the causal linkages between different indicators. However, it mostly depends on the review of literature and is descriptive in nature. It may be possible to improve this research in future by analyzing the causal linkages with the help of dose-response functions. This approach would quantitatively explain the linkages and would possibly strengthen the description of the linkages among sustainability indicators. This research idea may also be extended to study the interactions between economic growth and environmental quality from the standpoint of urban ecology.

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APPENDIX A

CORRELATION METRICS

	Total population	Population density	Per capita investment	Education (University Degree)	Median Income (Dollars)	Employment	Annual Building Permits	Consumer expenditure	Housing Units which have 3 or more vehicles	Commuters Who Drove Alone to Work
Total population	1	.930**	.145	.612**	.581**	.557**	.935**	.753**	-.567**	-.093
Population density	.930**	1	.275*	.640**	.564**	.591**	.813**	.740**	-.626**	-.135
Per capita investment	.145	.275*	1	.075	.067	.103	.067	.089	-.153	.179
Education (University Degree)	.612**	.640**	.075	1	.660**	.667**	.607**	.809**	-.592**	-.587**
Median Income (Dollars)	.581**	.564**	.067	.660**	1	.683**	.643**	.907**	-.108	-.099
Employement	.557**	.591**	.103	.667**	.683**	1	.529**	.702**	-.204	-.290*
Annual Building Permits	.935**	.813**	.067	.607**	.643**	.529**	1	.759**	-.494**	-.123
Consumer expenditure	.753**	.740**	.089	.809**	.907**	.702**	.759**	1	-.346*	-.240
Housing Units which have 3 or more vehicl	-.567**	-.626**	-.153	-.592**	-.108	-.204	-.494**	-.346*	1	.396**
Commuters Who Drove Alone to Work	-.093	-.135	.179	-.587**	-.099	-.290*	-.123	-.240	.396**	1

Correlations among economic indicators

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

	Impervious Surface Area	Ambient Air Temperature (County wide)	Impaired Stream Length	Traffice Density	MSW Disposed (Tons) Per Capita	Travel Time	Rate of Hospitalizations for Asthma	Obesity	Managed Area	Waste recycled (Tons)	AQI Oz	AQI CO	AQI NO2	AQI PM10
Impervious Surface Area	1	.233	-.165	.954**	.555**	-.227	-.056	-.324*	-.217	.323*	-.051	.261	.321*	-.059
Ambient Air Temperature (Countywide)	.233	1	.098	.171	.112	.182	.157	.266	-.583**	-.164	-.015	.362**	.134	.009
Impaired Stream Length	-.165	.098	1	-.142	-.065	.185	-.203	-.063	-.094	-.078	.243	.064	.129	.051
Traffice Density	.954**	.171	-.142	1	.528**	-.207	-.074	-.348*	-.141	.229	-.065	.291*	.274*	-.031
MSW Disposed (Tons) Per Capita	.555**	.112	-.065	.528**	1	-.397**	.197	-.227	-.001	.208	.003	.067	.067	-.290*
Travel Time	-.227	.182	.185	-.207	-.397**	1	-.075	.298*	-.330*	-.388**	.002	-.063	.131	.105
Rate of Hospitalizations for Asthma	-.056	.157	-.203	-.074	.197	-.075	1	.509**	-.120	-.319*	-.094	.004	-.260	-.125
Obesity	-.324*	.266	-.063	-.348*	-.227	.298*	.509**	1	-.272*	-.540**	.016	-.278*	-.133	.060
Managed Area	-.217	-.583**	-.094	-.141	-.001	-.330*	-.120	-.272*	1	.170	-.177	-.204	-.395**	-.017
Waste recycled (Tons)	.323*	-.164	-.078	.229	.208	-.388**	-.319*	-.540**	.170	1	-.143	-.018	.060	.070
AQI Oz	-.051	-.015	.243	-.065	.003	.002	-.094	.016	-.177	-.143	1	-.109	.268	-.067
AQI CO	.261	.362**	.064	.291*	.067	-.063	.004	-.278*	-.204	-.018	-.109	1	-.055	.170
AQI NO2	.321*	.134	.129	.274*	.067	.131	-.260	-.133	-.395**	.060	.268	-.055	1	.228
AQI PM10	-.059	.009	.051	-.031	-.290*	.105	-.125	.060	-.017	.070	-.067	.170	.228	1