Sustainable City Development under Urbanization in China

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List of Abbreviations

ADB	Asian Development Bank
CSD	Commission on Sustainable Development
DPSIR	Driving Forces-Pressures-State-Impacts-Response
EEA	European Economic Area
FCCC	The Framework Convention on Climate Change
IDA	International Development Association
ISO	International Organization for Standardization
MDGs	Millennium Development Goals
NDRC	National Development and Reform Commission
OECD	Organization for Economic Co-operation and Development
SCI	Sustainable City Index
SDGs	Sustainable Development Goals
SOM	Self-organization Map
UCI	Urban China Initiative
UN	United Nations
UNCED	United Nations Conference on Environment and Development
WCED	World Commission on Environment and Development
WSSD	World Summit on Sustainable Development

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Chapter I Introduction

This dissertation is a study of the sustainable urban development of Chinese cities. On the basis of an indicator framework, the research evaluates the urban sustainability and urban development pattern of 49 Chinese cities to study the relationship between urban forms and urban sustainable development. This chapter will demonstrate the background of the research, state the problems, specify the objectives and significance of the research, and explain the research methodology.

1.1 Introduction

Under the high rate of economic development and urbanization, a series of pressures have been exerted on our planet since the period of industrial revolution. However, with the industrialized countries be of great affluence, people of these countries began to cast doubt on the traditional economic growth model that heavily relies on consumption of natural resources. Therefore, the idea of sustainable development has become a catchword due to increasing concern on environmental problems. In 1987, the World Commission on Environment and Development (WCED) first defined sustainable development in the Brundtland Report. It defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987, P.47). Later in 1993, Agenda 21 emphasized that, “Humanity stands at a defining moment in history. We are confronted with a perpetuation of disparities between and within nations, a worsening of poverty, hunger, ill health and illiteracy, and the continuing deterioration of the ecosystems on which we depend for our well-being”(United

Nations, 1992, Par.1.1).

In addition to economic growth, the world is also experiencing an astonishing speed of urbanization triggered by industrialization. The 21st century is the era of the "city revolution". Cities play a significant role in the modern world because anthropic social and economic activities are congregating there (Mori & Christodoulou, 2012). Cities are the engine of social and economic growth: from 2010 to 2050, the top ranking 600 cities will contribute 65% of the world's GDP growth, and 440 emerging cities will account for 47% of the global GDP growth (Urban China Initiative, 2013) . Such a high rate of urbanization is the result of unprecedented economic growth and industrialization in the 21st century; the urban areas are rapid sprawling into the rural areas, with new construction of factories and enterprises, creating wealth and prosperous social development, attracting investment, promoting high technological development, and enhancing productivity and competitiveness (WCED, 1987). Currently more than half of the world's population is living in urban areas, from large megacities to small towns, indicating that urban areas have become the primary habitat for human beings (UN, 2007). Asia was predominantly rural, with only 17% of its 1.4 billion people living in cities or towns, while by the mid-2020, 55% of Asia's 2.7 billion people will live in urban areas (Asian Development Bank, 2012).

Admittedly, cities drive technological innovation, trade and business development, and promote residents' living standards. However, rapid urbanization has put tremendous pressures on the urban system with negative externalities, challenging the governments' power, resources and the reaction of government officials in the face of rapidly growing urban populations. Therefore, it is of crucial importance to explore development pattern especially in developing countries to realize sustainable urban development.

1.2 Policy context

During the 10^{th} Five-Year Plan (2001-2005), China gave priority to economic development and urbanization while ignored the significance of environmental protection. Without enough concern for environmental protection, the environment problems became increasing severe during the this period. And in the period of 11^{th} Five-Year Plan (2006-2011), the Chinese government began to be aware of the severe situation of environmental protection and changed its focuses from economic development to environmental protection and gave up the old way of “treatment after pollution”. Given enough attention, environmental protection made some progress and outperformed its goals set in the 11^{th} Five-Year Plan. In 2011, under new leadership, the Chinese government formulated the 12^{th} Five-Year Plan (2011-2016), which continues the indicator system and proposes energy efficiency goals in line with the United Nations Climate Change Conference in Copenhagen. During this period, president Xi’Jinping pointed out that lucid waters and lush mountains are invaluable assets, emphasizing the equal importance of environmental protection and economic development. In the 13^{th} Five-Year Plan (2016-2020), for the first time, “ecological civilization construction” is one of the ten development goals, emphasizing the significance of green development in China.

1.2.1 The Eleventh Five-Year Plan (2006-2011)

On April 17-18, 2006, the Sixth National Conference on Environmental Protection emphasized a comprehensive application of laws, economics and technology aiming to solve China’s environmental problems. Environmental protection needed to realize “Three Shifts”(Xinhua News Agency, 2006):

- Shift from the traditional development pattern that focusing on economic development while ignoring environmental protection by paying equal attention to the economy and environment and continuing development alongside environmental protection;
- Shift from the process of "treatment after pollution" to the developing economic and protecting environment at the same time;
- Shift from environmental protection mainly depending on administrative measures to comprehensively applying legal, economic, technological and necessary administrative measures, obeying economic and natural laws and improving work on environmental protection.

Table 1-1 shows the targets and accomplishments of the Eleventh Five-Year Plan on the aspect of environmental protection; there were several significant achievements during the Eleventh Five-Year Plan period. However, natural reserves and water supply resources in key cities did not reach their targets. Compared with the Tenth Five-Year Plan, the environmental quality has been improved a lot during the Eleventh Five-Year Plan period, however the situation of environmental protection in China was still severe.

Table 1- 1 The main targets and accomplishments of the Eleventh Five-Year Plan

Targets	Plan	Result
SO_2 reduction(million tons)	22.95	21.85
COD reduction (million tons)	12.70	12.38
Ratio of recycled industrial solid wastes	>60%	69%
Ratio of urban sewage treatment (secondary)	>70%	75.25%
Ratio of sanitary disposal of urban solid wastes	>60%	71.4%
Ratio of village environmental improvement	>20%	Basically reached the indicator
Ratio of state-level natural reserves meeting national standards	>25%	11.8%
Ratio of the water supply sources in key cities meeting national standards(in volume)	>80%	73%
Ratio of sections of surface water bodies monitored by state-level monitoring stations with water quality below Level V	<22%	18.4%
Ratio of sections of the seven largest rivers with water quality better than Level III	>43%	57.3%
Ratio of coastal areas with water quality better than Level III	>70%	72.9%
Ratio of key cities with air quality better than Level II for more than 292 days	>75%	95.6%
Ratio of effective annual exposure to radiation for residents living adjacent to nuclear power plants lower than the threshold of the national standard	<10%	9%

COD= Chemical Oxygen Demand;
SO_2=Sulfur Dioxide
Source: State Council of People's Republic of China, 2012

1.2.2 The Twelfth Five-Year Plan (2011-2015)

On March 5, 2011, the Chinese government published the Twelfth Five-Year Plan in order to strengthen economic development, deepen reform and opening-up by paying more attention to people-oriented development and by emphasizing the importance of comprehensively sustainable development. It pointed out that the urbanization rate will reach 52% by the year of 2015. Table 1-2 illustrates the specific targets of the Twelfth Five-Year Plan. On the urban environment aspect, the Twelfth Five-Year Plan pointed out that(Xinhua News Agency, 2011):

- **Promote the reduction of main pollutants:**

(1) Decrease discharge of new pollutants, appropriately control energy and resource consumption and promote the development of non-fossil fuel energy;

(2) Promote sewage treatment in urban areas;

(3) Promote the quality of auto fuel, encourage utilization of new clean fuels and develop urban public transport

- **Solve prominent environmental problems:**

(1) Promote the prevention of air pollution and monitor main air pollutants in the Beijing-Tianjin Hebei Region, Yangtze River Delta and Pearl River Delta;

(2) Enhance the protection of soil conditions and recover the soil of the suburbs of large cities

- **Promote the safe disposal of solid waste:**

  Improve domestic refuse disposal levels in cities, and by 2015, make the national decontamination rate of urban refuse 15%.

Table 1- 2 The environmental targets of the Twelfth Five-Year Plan

Indicators	**2015**	**Change from 2010 to 2015**
Total COD emission (million tons)	23.48	-8%
Total ammonia nitrogen emission (million tons)	2.38	-10%
Total SO_2 emission(million tons)	20.86	-8%
Total NO_x emission(million tons)	20.46	-10%
Ratio of sections of surface water bodies monitored by state-level monitoring stations with water quality below Level V	<15%	-2.7%
Ratio of sections of the seven larges rivers with water quality better than Level III	>60%	5%
Ratio of key cities with air quality better than Level II	>80%	8%

COD=Chemical Oxygen Demand
SO_2=Sulfur Dioxide
NO_x= Nitrogen Oxides
Source: State Council of People's Republic of China, 2016

1.2.3 The Thirteenth Five-Year Plan (2016-2021)

On March 17, 2016, the central government published the Thirteenth Five-Year Plan, which strengthens the significance of "green development" and "ecological civilization construction". In face of future rapid urbanization, especially in western China, the plan proposed the goals of a new type urbanization(Xinhua News Agency, 2016):

- **"Three 100 Million People" urbanization:**

  (1) Promoting 100 million rural migrants settling in cities;

  (2) Accelerating the reconstruction of urban village that 100 million people live in;

  (3) Guiding the urbanization of 100 million people that live in western areas.

- **Smart city:**

  Fully utilizing modern information technology and big data to build up a series of smart cities

- **Green and forest cities:**

  Generalizing the utilization of green buildings, green transportation, and energy distribution and new energy systems; accelerating the electrification of public transportation; promoting urban forest areas and constructing some model green cities, eco-cities and forest cities.

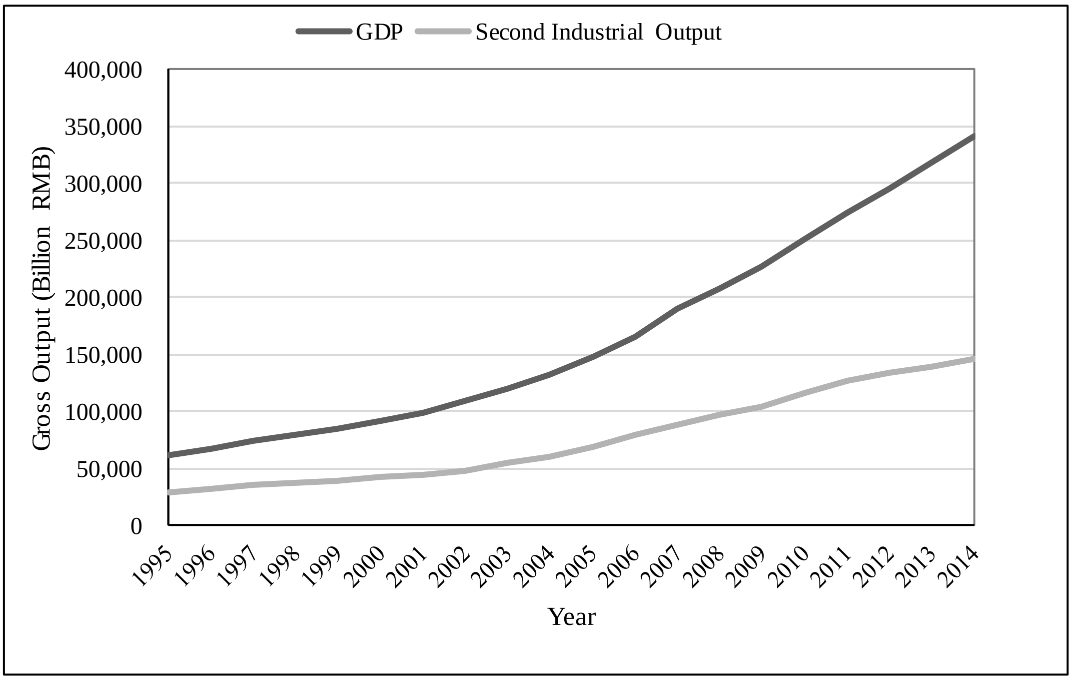
1.3 Problem statement

1.3.1 Economic growth and industrialization in China

Since the "reform and opening" policy implemented in 1978, China has undergone astonishing economic growth. From then, the Chinese government has treated technology as the core of its productivity. As shown in Figure 1-1, the real GDP of China has increased from 6.11 trillion yuan to 34.11 trillion yuan from 1995 to 2014 at 1995 constant prices, with an average increase rate of 8.9% annually. During the same period, the total output of the second industrial sector increased from 2.85 trillion yuan to 14.57 trillion yuan. Such a high speed of economic growth and industrialization is called the Chinese Economic Miracle by many scholars. However, behind this, there is the deterioration of ecosystems, pollution, and disparities throughout the country. As a whole, the development policy could be separated into three periods: the 1980s, the 1990s, and the 21st century. In the 1980s, China developed its economy at the expense of resources and the environment. In the 1990s, with the promulgation of China's Agenda 21: White Paper on China's Population Environment and Development, China went in a direction that protected the environment while developing the economy. However, in the 21st century, Chinese economic development has been accompanied by environmental problems. Since the winter of 2012, the eastern coastal areas have suffered from severe problems of fog and haze that have threatened the health of the average citizen. At the same time, the Chinese government put forward the 'On ecological progress' strategy[1] and pointed out that we must insist on the basic state policy of saving resources and protecting the environment, developing a beautiful China, and realize the Chinese nation's sustainable development. Therefore, during this century, the state made environmental protection a priority.

[1]2012.11, the 18th National Congress of the CPC initially put forward the "On ecological progress" strategy which illustrates the blueprint from 10 perspectives, including a program on improving land development, promoting the saving of resources, strengthening the ecosystem and environmental protection, and enhancing the building of ecological civilization systems.

Figure 1- 1 Economic Development and Industrialization in China, 1995-2014



Source: China National Bureau of Statistics, 2015

1.3.2 Urbanization in China

In 2010, the Chinese urban population surpassed the rural population for the first time. In 1950, nearly 90% of people in China lived in rural settlements, but by 2014 55% of the Chinese population settled in urban areas, and by 2050 the urban population will account for 80% of Chinese people (United Nations, 2014). In 1975 there was only one large city and majority of the cities were medium or small. From 1975 to 1990 the development of megacities and large cities was slow, and the majority of urbanization took place in medium and small cities. Currently, there are six megacities, and China has experienced rapid urbanization in all sizes of cities during the past decades.

Wang (2010) divided Chinese urbanization into three phases. The first phase was 30 years before reform and opening up, in which the urbanization rate lagged behind industrialization. During that period, the Chinese government gave priority to industrial development and the share of industry in the GDP increased from 17.6% to 44.4%, while the urbanization rate only increased by 5%. It is obvious that such unnatural development leads to low productivity, rural-urban isolation, income inequality, and underemployment.

The second phase was the period from the beginning of reform and opening up (1978) to the end of the 1990s. During this period, the Chinese government changed from limiting urban development to strictly control large city scale, reasonably develop middle and small cities, and actively develop small towns, and the urbanization rate increased to 33.3%. Nonetheless, the urbanization of this period was unbalanced because the amount of small towns and cities developed rapidly while large cities developed slowly.

The third phase is from the end of the 1990s to the present. During this period, the central government has revised urban planning policy and officially announced in 2011 the new policy that large, middle and small cities and small towns should develop concurrently. Therefore, encouraged by the policy, urbanization in this period has reached a balanced development.

In terms of city scale, there is no consensus in the literature about the proper size of cities that can generate better agglomeration benefits. Wang and Xia (1999) analyzed more than 600 Chinese cities and discovered that different scales of cities resulted in different extents of agglomeration economies and externalities. To be specific, large cities with one million to four million dwellers demonstrated the highest net scale benefits (agglomeration benefits minus externalities); however, when population exceeds four million, the net scale benefits gradually diminish. In addition, small cities with populations of less than 100 thousand had no net scale benefits. Au and Henderson (2005) also estimated the net urban agglomeration economies of Chinese cities. They argued that the relationship between urban agglomeration benefits and urban sizes is an inverted-U shape. Through analysis, they concluded that the average Chinese city is undersized, and the optimum city population size is 2.9 million to 3.8 million.

1.3.3 Pressures under urbanization in China

As shown in Figure 1-2, the pressures of rapid urbanization in China are listed as follow:

- **Pressures on land**:

  In the next twenty years, in the face of 350 million new urban migrants, cities will experience rapid land exploration due to the increasing need for settlements, which will result in severe land sprawl and sharp degradation of cultivated lands.

- **Pressures on resources and the environment**:

  In addition to the decrease of cultivated land, the pressures on other natural resources and urban environment will also increase sharply. For instance, the increasing needs for water resource will intensify the problems of water shortage, and this issue will be especially serious for northern Chinese cities. In addition, the degradation of air quality has become another severe issue and the haze issue has become one of leading environmental issues in China that threaten the health of urban residents. In addition, the energy consumption has also increased sharply and currently China has surpassed the US to be the largest energy consumer around the world.

- **Pressures on the society**:

  Large number of rural migrants flood into urban areas, which will challenge the security of cities. In addition, the increasing population will lead social stratification due to uneven distribution of education resources and high level of house price.

- **Pressures on infrastructures and funds**:

  Urbanization will precipitate higher government expenditure. In the future, the central government will invest more on the infrastructure construction and public services such as education and health care. According to McKinsey (2013) the government will need to increase funding by 1500 billion CNY (accounting for 2.5% of urban GDP) to public services for the floating population by 2025.

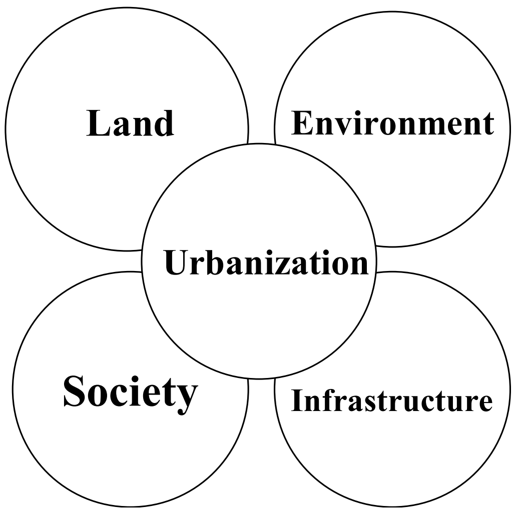
Hence, this study will focus on answering two main questions:

- How does the urban development pattern affect sustainable urban development?
- What kind of urban development pattern suits China in order to realize sustainable urban development in the future?

In order to answer the two main questions, the following questions need to be considered:

- What is the urban form of Chinese cities, compact or decentralized?
- What is current situation of sustainable urban development in Chinese cities?
- What is the relationship between urban form and sustainable urban development?

Figure 1- 2 Pressures of urbanization in China



Source: Urban China Institution

1.4 Objectives of the research

Firstly, this research constructs a composite sustainability index that can help policy makers to track and measure urban sustainability and formulate proper policies to realize sustainable urban development in China. Secondly, this research studies the urban forms of Chinese cities to explore the trends of urban development patterns in China. Thirdly, this research incorporates the urban development pattern and sustainable urban development to explore the relationship between urban forms and urban sustainability. Fourth, this research will provide suggestions and policies for future sustainable urban development in China. Therefore, the specific objectives of this research are as follows:

- To simplify, clarify and aggregate information (environmental, economic and social) and construct an assessment framework of sustainable development by selecting a set of indicators.
- Set up Key Performance Indicators (KPIs) for policy makers to evaluate future sustainable urban development.
- To clarify the sustainability of urban areas comparing different urban forms.

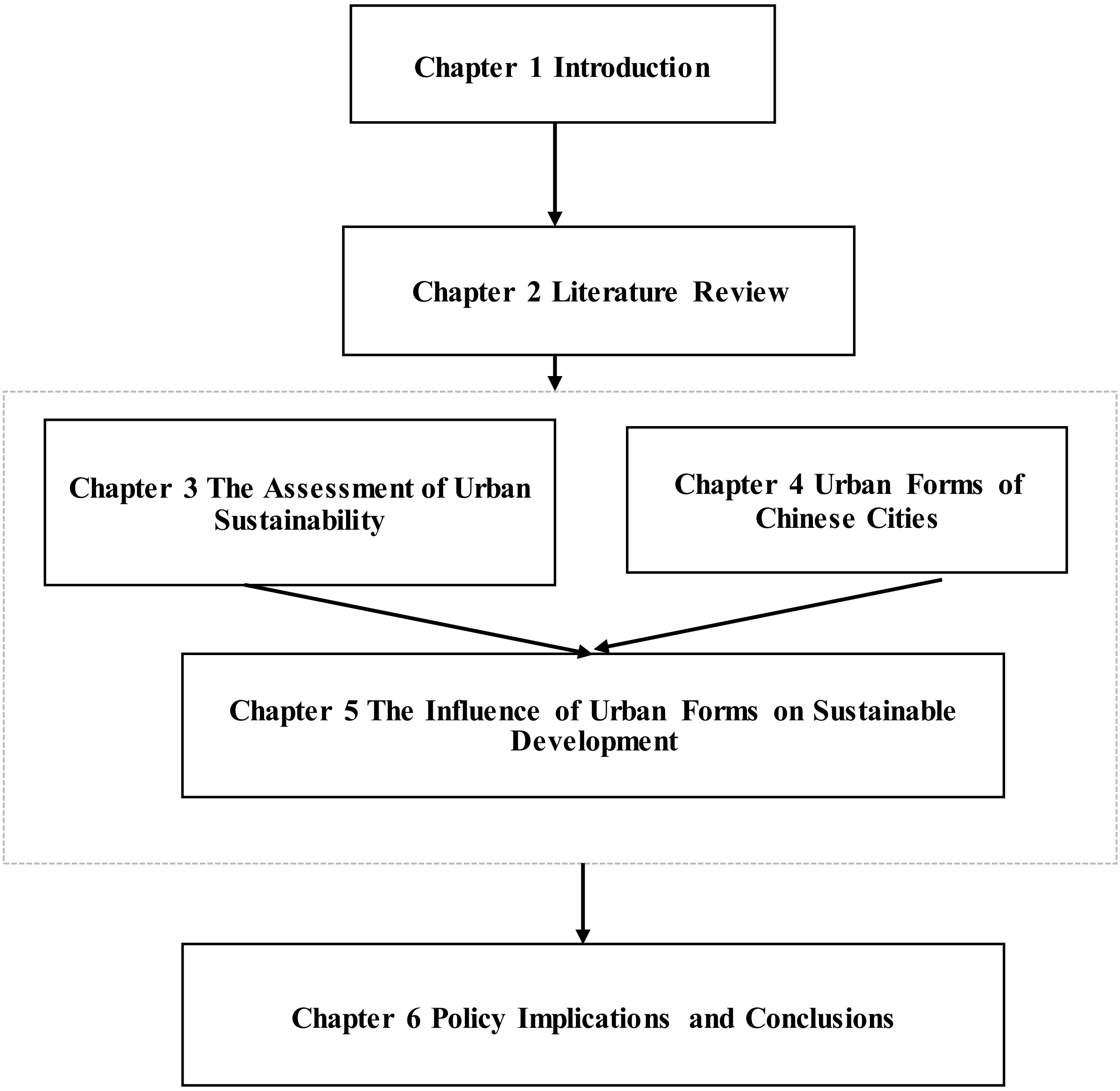
1.5 The significance of the study

With the rapid economic growth and urbanization of China, people are becoming more and more aware of sustainable development. The empirical analyses of previous studies enrich our understanding of sustainable development in urban areas. Most existing research in China pays more attention to an ideal model of sustainable urbanization which makes use of high technology and limits human activity. However, for the majority of Chinese cities such ideal eco-cities are utopian and difficult to realize. This research will focus on exploring a sustainable urbanization design that could be utilized in a larger area in China through the successful experiences of some developed countries. In addition, in terms of compact cities and sustainable development, most previous studies were from the viewpoint of developed countries, so the evidence from developing countries is scarce. Therefore, this research explores the relationship between different urban development patterns and urban sustainability in Chinese cities by means of qualitative and quantitative analyses. For the first time, this research proposes the hypothesis that there is an inverted-U shape relationship between urban compactness and urban sustainability. To be specific, this research assumes that at low level of urban compactness the increase of urban compactness will help to promote sustainable urban development. However, when the urban compactness reaches a certain level, urban sustainability will decrease with the increase of urban density. Through this research, I hope to provide a sustainable model to all urban areas in China that realizes a harmony between economic development and environmental protection.

1.6 Organization of this research

As shown in Figure 1-3, this research contains six chapters. Chapter I introduces the background, problem statements, objectives, significant, limitations and organization of the research. Chapter II reviews the concepts, current debates and policies on sustainable development, sustainable urbanization and urban morphologies. Chapter III is the assessment of urban sustainability. In this chapter, DPSIR(Driving forces-Pressures-States-Impacts-Responses) is utilized to discuss the sustainable development of 49 Chinese cities. Chapter IV illustrates the urban forms of Chinese cities, and Chapter V further analyzes the relationship between urban forms and sustainable urban development. Chapter VI is the conclusion section, in which I summarize the findings, provides policy implication and suggests future paths of study.

Figure 1-3 The organization of the research



Source: Author

Chapter II Literature Review

This chapter reviews the definition and assessment of sustainable development and sustainable cities in the first section. The second section then introduces the theories about urbanization and environmental impacts. The third section discusses the concepts and assessment framework of urban morphologies.

2.1 Sustainable development

For decades, human activities have profoundly changed our living environment. In the last century, economic development was given high priority in both developed countries and developing countries. During the past decades, both developed countries and some successful developing countries have made great progress in poverty reduction, GDP growth and technological innovation. In addition, along with the high economic growth, the urban population has undergone historically unprecedented increase. Currently, in the world, over half of the people are settling in urban areas and this data will increase by approximate 70% by the year of 2050 (UN,2012).

Yet with increasing attention to the degradation of environmental quality, the theme of the 21st century has been altered. Because of industrialization and urbanization, lots of side effects has emerged such as degradation of environmental quality, increase in natural resource consumption and pollutants emissions. The developed countries have benefited a lot from traditional natural resource-based develop; however, developing countries could not simply copy the successful development pattern of developed countries due to the limitation of natural resources. As a result, developing countries gradually fell into a vicious cycle in which they consume energy and resources, get poorer, and then consume more energy and resources, as illustrated by WCED: "Poverty is a major cause and effect of global environmental problems" (WCED, 1987, P.3). Therefore, people began to rethink the traditional resource-intensive model and wanted try to explore an equal, safe, and long-term development design. The UN convened the World Commission on Environment and Development in such a context in 1983. Four years later, the United Nations published the report of this conference, *Our Common Future*. Therefore, exploring a more environmentally friendly, resource-economizing way to realize further sustainable development has become one of the primary tasks around the world.

2.1.1 Sustainable development

The word of sustainability originated from the Latin word *sustinere*, which means "hold up". In dictionaries, there are three main meanings of sustain, "maintain", "support" and "endure". Although there is no significant difference between the definitions of sustainability and sustainable development, the former one implies an ideal situation or a set of conditions, while the later one refers to a process that moves towards sustainability.

Under the high rate of economic development and industrialization, large amount of problems emerged, such as population explosion, global warming, haze issue, natural resource scarcity, forest deterioration and the extinction of species. At this time, the concept of sustainability is used more in the sense of human, social and economic sustainability and always emerges in the phrase of sustainable development.

Step by step, from 1972 to 1992, UN hosted a series of conferences worldwide aiming to shape the theoretical framework of sustainable development. In 1972, the United Nations Conference on the Human Environment was held in Stockholm, which was the first international conference related to sustainability at the international level. Guided by this conference, the UN established the United Nations Environmental Programme (UNEP). Following this conference, many countries began to establish their own environmental protection agency. In 1980, the International Union for the Conservation of Nature, the World Wildlife Fund and the UNEP published the World Conservation Strategy to advance sustainable development.

In 1983, the UN convoked the World Commission on Environment and Development (WCED), which included participants from both developed and developing countries. This conference focused on the "accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development." (UN, 2012, p.6) Later, in 1987, WCED published *Our Common Future* which set out the most popular definition of sustainable development: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WECD, 1987, p.43).

Motivated by the Brundtland Report, five years later, the Earth Summit (or Rio Summit)[2] was convened in 1992. The Rio Summit mapped out the future of sustainable development through documents such as Agenda 21, the Rio Declaration on Environment and Development, the Framework Convention on Climate Change (FCCC), and the Convention on Biological Diversity.

In Agenda 21, sustainable development was redefined as "seeking the mutual goals of economic development and environmental protection for the purpose of fulfilling the basic needs for all" (UN, 1992, Par.1.1). In addition, it raised the importance of sustainable development in developing countries and established concrete goals, objectives, and

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[2]The Rio Summit included representatives from 118 countries. The Rio Summit adopted a series of documents, including the Rio Declaration (or Earth Charter), Agenda 21, the Framework Convention on Climate Change (FCCC), and the Convention on Biological Diversity. The Rio Declaration established principles related to the international environment and development.

activities to be implemented in three sections ("social and economic dimensions, conservation and management of resources for development, and strengthening the role of major groups" (UN, 1992)) in order to realize sustainable development. Moreover, Agenda 21 is a dynamic program, and "It will be carried out by the various actors according to the different situations, capacities and priorities of countries and regions in full respect of all the principles contained in the Rio Declaration on Environment and Development" (UN, 1992, p.3).

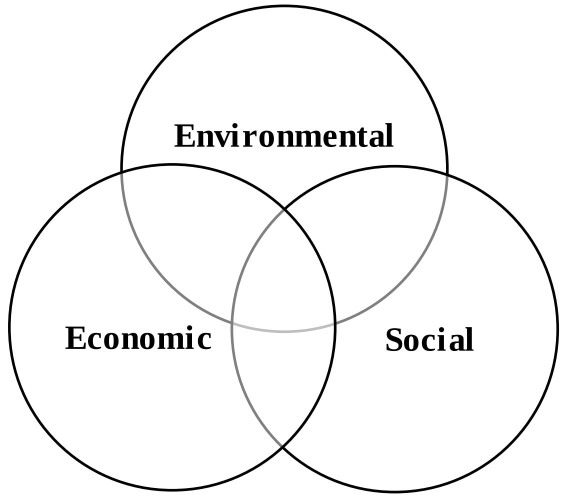
The Rio Declaration included 27 principles constructed upon the declaration of the United Nation's Conference on the Human Environment to pursue international agreements and partnerships for environmental protection. Among the 27 principles, Principle 7 became one of the most important claiming "common but differentiated responsibilities" for collaborating countries and organizations(UN, 1992).

Since then, a series of important conferences related to sustainable development have been held, such as the 1996 Habitat II or City Summit, the 1997 Earth Summit+5, the 2002 World Summit on Sustainable Development (WSSD), and the 2012 Rio Summit+20. The challenges of the Rio Summit "lay in two areas: first, too much of an emphasis on the 'environmental pillar' in the negotiations and secondly, all too little implementation of goals established under Agenda 21, particularly those related to development aid and cooperation" (UN, 2010,p.8). The WSSD, however, "did make a constructive change by focusing considerably more attention on development issues, particularly in integrating the MDGs (Millennium Development Goals) with sustainable development principles and practices" (UN, 2010, p.9).

2.1.2 “Three pillars” of sustainable development

Sustainable development is notoriously vague as a concept which has no consensus among scholars and organizations (Holden et al., 2008), but the most famous definition is that of the World Commission on Environment and Development (WCED): “sustainable development should “meet the needs of the present without compromising the ability of future generation to meet their own needs” (WCED, 1987, p.8). The inherent ambiguity of the concept of sustainability gives rise to numerous interpretations. The disagreements among supporters are based on their emphasis on what is to be sustained, what is to be developed, how to link environment and development, and for how long a time (Parris & Kates, 2003). Although there is no consensus among scholars about the concept of sustainable development, it is widely accepted that sustainable development pursues a proper balance among three pillars, economy, society and environment, in both spatial and temporal ranges. Accordingly, development must be equitable (between economic and social pillars), livable (quality of life), and viable (economic development should not degrade the capacity of ecosystems) (Tanguay, Rajaonson, Lefebvre, & Lanoie, 2010). Specifically, the environmental area includes ecosystem services, air quality, water quality and resources. The social sector consists of human health, environmental equity, education and food security. Finally, the economic sector contains employment, GDP growth and so on. As showed in the Figure 2-1, sustainable development is the intersection of the Venn diagram, showing that the economic, social and environmental sectors are interdependent.

Figure 2- 1 Three Pillars of Sustainable Development



Source: United Nations, 1992

2.1.3 Weak and strong sustainability

Under the broad definition of sustainability, two main approaches can be discerned: weak sustainability and strong sustainability. Although the goal of both is development without compromising the wellbeing of future generations, the demands for sustainable development are different. Weak sustainability requires the preservation of overall stocks of capital that allow substitution among environmental, human and economic capital. In the view of weak sustainability, natural capital is the same as other resources (Gutes, 1996). On the contrary, strong sustainability critically limits the consumption of natural capital and emphasizes the importance of environmental function. Therefore, strong sustainability does not accept substitutions among human, environmental and economical capital (Mori & Christodoulou, 2012).

2.1.4 The assessment of sustainable development

Indicators are useful tools for decision makers to conduct more effective actions by simplifying and abstracting information from raw data. Policy has a life cycle from identifying an issue to be solved to the design of the policy and its implementation, assessment and adaptation, and finally to its elimination or integration into another policy instrument (Moldan & Dahl, 2007). The indicators must meet the needs of each stage to support the policy life cycle with data, information and knowledge. Although a considerable number of sustainable city indicators have been explored, a key set of indicators that properly reflects the economic, social and environmental qualities have not yet been identified (Steg & Gifford, 2005). Therefore, to be effective, the indicators must be credible, legitimate in the eyes of stakeholders, and relevant to decision makers (Moldan & Dahl, 2007).

The challenge for the indicator-based approach is mainly to define a measurable framework and then select a proper set of indicators. The evolving assessment frameworks of the terms "sustainable development" and "sustainability" have already been explored by a variety of international organizations, countries and scholars, which have also acted as instruments to help decision makers to measure and calibrate sustainable development trajectory as well as make sound decisions and policies. Agenda 21 initiated the requirement for an integrated assessment framework, and the international community raised economic, social, and environmental pillars of sustainable development (UNCED, 1993; UN, 2002). In some frameworks, a fourth institutional pillar is added, such as in the framework for indicators designed by the Commission on Sustainable Development (CSD). Others prefer to treat sustainable development as a two-part framework reflecting the interaction between human activities and environment impacts (EEA, 1995; OECD, 1998; Prescott-Allen, 2001).

Although many approaches have been explored to assess sustainable development, the frameworks are lacking theoretical foundation and the selection of indicators is arbitrary.

2.2 Urbanization and urban sustainability

As the Brundtland Report illustrated regarding urban challenges, the economic system not only influences urbanization itself but also affects rural areas. Under the increasing speed of urbanization, most governments of developing countries need experience, the ability and finances to handle emerging problems such as water, air, education, transport and dwellings that go along with high population growth. Moreover, as a result of uncontrolled migration, cities have expanded at an unprecedented velocity which causes serious strains on the environment and economy. Cities built on arable land have led to serious problems in countries that lack productive agriculture land. On the other hand, urban problems are not only serious only in developing countries but also in developed countries. However, the industrialized countries' governments realized the importance of urban sustainability decades earlier than the developing ones; therefore, with the help of effective governance, advanced technology and strong economies, the urban pressures of developed countries are not as serious as those of Third World countries (WCED, 1987).

Chapter 7 of Agenda 21 (UN, 1992) provided a new orientation for sustainable urban development. The chapter pointed out, on one side, how the consumption patterns of developed countries led to problems in the earth's ecosystem; however, on the other side, it explained how developing countries are suffering from a lack in settlements as a result of limited resources, energy and economic growth. Under the limitation of finance, a majority of developing countries provide little to housing, services, social security and welfare. In addition, the International Development Association (IDA) and loans of the United Nations for urban development are often very limited. International assistance will help improve the living situation at a global level, and "at the same time the environmental implications of urban development should be recognized and addressed in an integrated fashion by all countries, with high priority being given to the needs of the urban and rural poor, the unemployed and the growing number of people without any source of income"(UN, 1992, Para. 7.3).

Hence, most governments, especially in developing countries, need the ability, funds and experience to provide new city residents with dwellings, services and facilities that meet the basic needs of life: housing, education and transport (WCED, 1987). As a result of overcrowding, cities need more land and resources to support new residents, which results in sharp decreases of arable land, water and energy resources. The high population density also leads to heavy traffic congestion, air pollution and resource scarcity. Although rural migrants help to solve the problems of urban labor scarcity in the manufacturing sector, highly skilled and educated talents are still in short supply (Urban China Initiative, 2013). If the current urbanization trend goes on without control, cities may face serious environmental pollution, resource scarcity and uneven social development. Therefore, the government needs to adopt effective policies to track measures and realize sustainable urban development.

2.2.1 Urbanization and urban growth

The underlying question for urban economics is why a city exists. Cities exist because technology has created production and exchange systems that provide humans with the material basis to challenge natural laws. O'Sullivan (2012) concludes that a city should satisfy three conditions to develop. First of all, the people outside cities must produce enough food to support themselves and urban residents. Secondly, urban residents must engage in production and produce some goods or services to exchange food with rural workers. Thirdly, a city must possess an efficient transportation system to make it convenient to exchange urban and rural products. In short, urbanization is because technology development increases the agricultural surplus, improves urban workers' productivity and boosts the efficiency of transportation and exchange.

In 1950, the urbanization rate was the highest in Oceania and North America, but the rate was less than 20% in Africa and Asia. It is predicted that by 2050 the urbanization rate will increase largely all over the world and Asia and Africa will experience the largest increase (UN, 2014).

In addition, concentration in large cities keeps rising. In 1950, only New York and London had populations greater than 10 million, but by 2015 twenty-nine cities belonged to this category and these agglomerations accounted for 12% of the world's urban dwellers. It is predicted that, by 2050, 41 megacities will exceed 10 million in urban population (UN, 2014).

What drives urban agglomerations to grow so rapidly? When geographical proximity can bring external benefits to firms and factories, these firms and factories cluster to exploit agglomeration economies, including localization economies at the industry level and urbanization economies at the city level (Button, 1976; O'Sullivan, 2012). Cities attract people and firms because they promote knowledge spillovers, learning, and social opportunities. Larger cities can offer better skill matches that result in higher productivity and wages. Agglomeration economies can generate self-reinforcing effects in a region; one firm moving to the city will encourage another firm to do the same (O'Sullivan, 2012).

Urbanization leads to two kinds of growth: economic growth and employment growth. Economic growth is defined as the increase of income per-capita. The increase of income is the result of capital deepening, increases in human capital and technological progress. Employment growth is defined as the increase of the total workforce of a city. However, rapid urban growth will bring about income and social inequality (Black & Henderson, 1999). Localized peer group effects, parental choices of neighborhoods, and human capital investments lead to geographic stratification of the settlements and result in social and income inequality (Benabou, 1993; Durlauf, 1996).

2.2.2 Theories on urbanization and environmental impacts

In recent decades, many theoretical attempts have been made to address the linkage between urbanization and its environmental impacts on urban systems. (Poumanyvong & Kaneko, 2010) presented three theories that describe the mechanisms that link urbanization and environmental impacts. On a national level, ecological modernization theory focuses on the effects of modernization, including economic, social and institutional alterations to the environment. This theory argues that at low to medium levels of modernization, energy and other resource pressures may increase with economic and social development. However, such problems can be minimized once modernization has reached a certain scale and innovative technology and industrial structures become available (Mol & Spaargaren, 2000). At the city level, the theory of urban environmental transition argues that environmental pressures vary based on the level of affluence (Mcgranahan et.al. 2001). As income levels rise, energy consumption-related issues become more prominent in affluent cities because of higher demand for electricity, heating, transportation and construction. Compact city theory, also at the city level, emphasizes the importance of urban design in realizing sustainable urban development. Sustainable urban design is high density, offers convenient public transportation as well as accessibility to local services and jobs and can be characterized as mixed use (Burton, 2002; OECD, 2012). The proponents of compact cities argue that they can increase energy efficiency by reducing motor vehicle dependency and travel distance (Burchell et al., 2000; Burton, 2001; Hillman, 1996; Thomas & Cousins, 1996). However, some critics insist that at extremely high densities, the advantages of compaction might prove to be disadvantages, i.e., congestion that leads to increased pollution, energy consumption, loss of amenity space and reduced privacy (Breheny, 1992; Knight, 1996).

2.2.3 Urban sustainability

In recent decades, the sustainable city has been a catchphrase in the field of environmental economics. The sustainable city also confronts the most popular definition of sustainable development (WCED, 1987). Here I further discuss the assessment of urban sustainability.

The assessment of sustainable city development has not been well established because the definition of city sustainability and the required conditions of city sustainability assessment system remains vague (Mori & Christodoulou, 2012). Multiple city sustainability assessments have been used by numerous organizations, scholars and companies from developed and developing countries(ARCADIS, 2015; Global City Institute., 2007; Simens, 2010; UN-Habitat, 2007; Urban China Initiative, 2013). ARCADIS (2015) proposed the Sustainable Cities Index to examine the sustainability of 50 international cities based on 22 indicators, incorporating the three dimensions of people, planet and profit. The Urban China Initiative (2013) selected 21 indicators from four areas, society, economy, environment and resources to evaluate the performance of 185 Chinese cities with respect to sustainable development. Tanguay et al. (2010) surveyed 23 studies of sustainable city assessment indicator frameworks in developed countries and discovered that 72% of the indicators are utilized for only one or two studies, and few indicators are present in more than five studies. This shows that the design of indicators differs in the purpose and understanding of city sustainability. Mori et al. (2012) proposed two principles in designing sustainable city indicators: to include indicators covering economic, social and environmental pillars, and to consider the direct and indirect externalities in other areas.

2.3 Urban Morphology

Urban morphology is an extension of urban planning, urban human geography, urban economics and urban history. Strictly speaking, urban morphology is the science of morphology but it is often used as a synonym of urban form. The word morphology originated from the Greek words *Morphe* and *Loqos*, which means “study of form”. Therefore, urban morphology studies the form of cities as human habitat (Moudon, 1997).

2.3.1 The development of the research on urban form

There is no consensus about the meaning of urban form among scholars. Broadly, urban form equals urban morphology, which analyzes urban features including urban spatial properties and urban social properties. Narrowly, the urban form is as limited as the urban spatial properties within a metropolitan region. To be specific, urban form is the spatial form and arrangement of fixed urban elements (Bourne, 1982) and is the urban spatial distribution and development pattern (Williams, Burton, & Jenks, 2000). Finding a proper urban form has always been the key issue of urban design.

The debate over urban form can be divided into three periods. As early as the period of industrialization, researchers debated over centralism and decentralism, trying to find a proper form under the high urbanization and economic growth triggered by industrialization. During this period, a large portion of the rural population migrated into urban areas to pursue higher income and living standards, and such population agglomeration drives rapid economic growth. However, during the post-industrialization period, the encroachment of urban land uses on non-urban land occurs in these industrial countries and as a result the spatial patterns of residential and nonresidential land use and the process of spreading urban development across the non-urban land far surpass population growth, resulting in low-density, leapfrog, widespread commercial strip development, and discontinuity. The consequences of such urban growth have been well documented in the literature: (1) investment in urban core areas and central city decrease; (2) increasing vehicle miles causes road congestion and air pollution due to high dependence on the private car; and (3) the loss of green areas and leisure places in or close to metropolitan regions. Therefore, as opposed to sprawling growth, compact cities and smart cities became the main stream of the urban design. The majority of the researchers called for a return to the compact city, an urban form of medieval fortress cities, or even ancient cities with constructed walls around the city for protection where the early urban residents were allocated residential areas, public roads and squares within the defensive walls (OECD., 2012). Although the compact city has diverse definitions, the characteristics and merits of such urban forms have been well documented in the literature. In contrast to urban sprawl, a compact city controls the outward expansion of urban area, revitalizes inner-areas, innovates design, preserves land, and redirects transportation (Burchell, Listokin, & Galley, 2000).

Therefore, new urbanism emerged in the US. The new urbanism mixed the traditional compact cities and modern lives to reconstruct a compact, green, mixed-use and walkable urban form. The new modernism continued the idea of compact and mixed uses and introduced a new kind of development pattern called Transit Oriented Development (TOD) and the idea of urban belts to realize more comfortable and harmonious urban lives.

2.3.2 The assessment of urban form

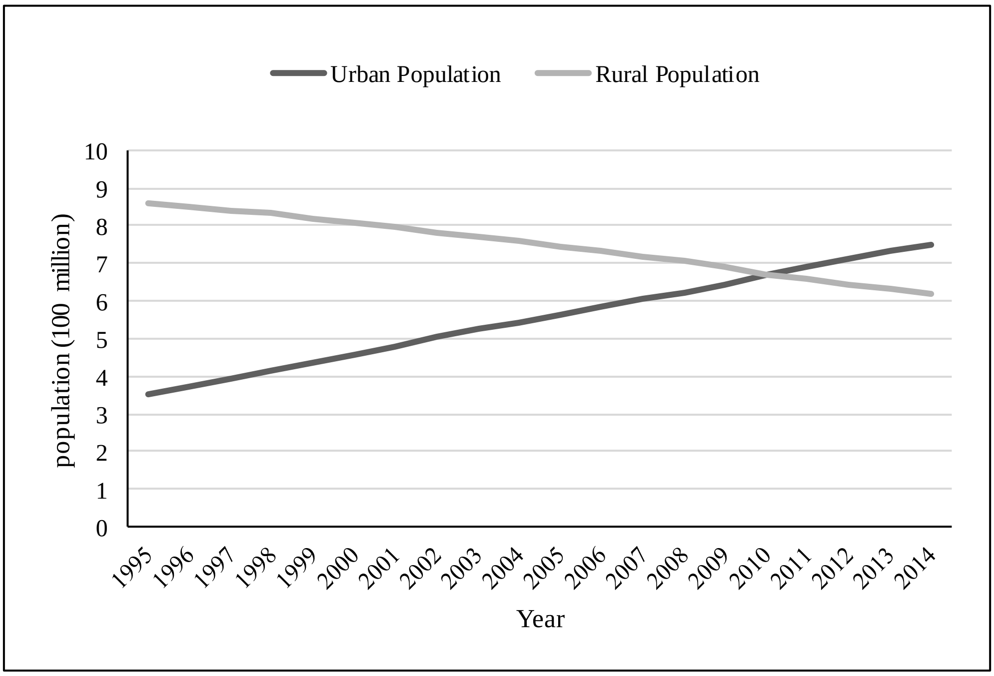
Increasing numbers of scholars, urban designers and organizations have joined the heated debate on the compact city and urban sprawl, and in order to justify their assertions, qualitative and quantitative methods are adopted. However, there is no unified method to measure the urban spatial transformation due to the vague definition of compact city and urban sprawl (Burton, 2002; Ewing, Pendall, & Chen, 2003). For measuring urban sprawl, for example, Galster et al.(2001) developed an assessment framework of urban sprawl with eight dimensions: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses and proximity. Ewing et al.(2003), utilizing principal component analysis (PCA), analyzed urban sprawl using three criteria: residential density, land use mix and degree of centering street accessibility. Yue et.al. (2013) assessed leapfrog growth, population density change, sprawl in street-towns, fragmented landscape patterns and inconsistency between actual development and urban planning in Chinese cities. In the measurement of compact cities, Burton (2002) built up an indicator system to measure the compactness of middle and small cities and towns in the UK considering three dimensions of land use: high-density, mixed use and intensified cities. OECD (2012) defines key indicators related to compactness including density, proximity, public transport system and accessibility to local services and jobs to assess the performance of OECD countries in order to improve policy frameworks for green growth in both developed and developing countries. Xie (2010) examines the compaction of

Beijing using three conceptual dimensions: density, mixed use and public transportation. Among these assessments, the researchers utilize different software tools from different fields, including the geographic information system tool Arcgis, the remote sensing tool Envi, the statistical tool SPSS, Excel, and others.

Chapter III The assessment of urban sustainability

During the past decades, China has experienced astonishing economic growth and urbanization along with the high speed of industrialization. However, behind such unprecedented development, environmental problems have become one of the leading issues in Chinese cities. Therefore, the idea of sustainable or green cities has become a catchword, whereas the assessments of urban sustainability in China are still few. Therefore, this research tries to assess the urban sustainability of 49 Chinese cities using DPSIR on the basis of the causal relationship of urban development.

Figure 3- 1 Urban and rural population change



Source: National Bureau of Statistics, 2015

3.1 Introduction

Figure 3-1 shows the trends of urban and rural population in China during the period of 1995-2014. As shown in Figure 3-1, during the 1995-2014 period, China's urbanization rate increased from 29.04% to 54.77%, with an average annual increase of 1.2%, which is still lower than the average urbanization level of developed countries, where approximately 70%-90% of people are living in urban areas. Table 3-1 illustrates the rate of megacity development in China, and in 2011 there were 127 megacities and 14 of them are super megacities whose population was more than 40 million. The rural-urban transformation has become a dominant feature of socio-economic change in China, and urban areas are flooded by large numbers of rural migrants on an annual basis. As a result of population growth, the national urban construction areas increased from 30,781 km^2 to 49,772 km^2 from 2004 to 2014. The urban areas are sprawling rapidly, therefore the urban environmental pressures increase considerably. As a result of increasing environmental pressures from urbanization, sustainable urban development has become one of the main strategies of the Chinese government in recent years.

Table 3- 1 Megacities in China, 2000-2011

	Total	>40 million	20-40 million	10-20 million
2000	90	8	12	70
2001	93	8	16	69
2002	102	10	21	71
2003	105	11	21	73
2004	108	12	23	73
2005	113	13	25	75
2006	117	13	24	80
2007	118	13	26	79
2008	122	13	28	81
2009	124	14	28	82
2010	125	14	30	81
2011	127	14	31	82

Source: United Nations, 2014

3.2 Methodology

3.2.2 DPSIR framework

Different approaches have been explored and utilized to evaluate the impacts of anthropogenic activities on the environment. The Press-State-Response (PSR) framework was developed by the OECD, which is based on the following causal relationship: human activities exert pressures on the environment, result in changes in the quality of environment (state), and finally society responds to these changes through environmental, economic and social policies (OECD, 1998). The European Environment Agency (EEA) slightly extended PSR in the DPSIR framework, which is used to structure a comprehensive model to analyze the interplay between the environment and socioeconomic activities. This framework is usually used to design assessment, select indicators, and communicate results to decision makers to improve environmental quality (Stanner et al., 2007). In DPSIR analysis, socioeconomic activities drive changes that exert pressures on the environment, then change the quality and state of the environment. These changes will influence, for example, human health, ecosystem functioning, the economy, and finally the response of society and policy makers to affect earlier parts (D, P, S, I) directly or indirectly.

From information to indicators, there is a clear need for indicators in each part of DPSIR, reflecting the casual relationship between human activities, environmental changes and social reflections. Driving forces represent the human activities in the pursuit of economic and social development, including demographic and socioeconomic indicators such as population growth, changes in production and consumption, and promotion of people's lifestyles. Through these changes of production and consumption, the driving forces exert pressures on the environment. These pressures include the uses of land and resources and the release of substances (emissions). Examples of pressure indicators are CO_2 emissions, energy consumption, water consumption by sectors, and arable land use for roads and construction. State indicators describe the transformation of the quality and quantity of the physical phenomena, the biological environment, and chemical concentration in a certain area. The state indicators are, for example, temperature, CO_2 concentration, and level of noise of living quarters. Impact indicators are used to reflect the environmental and social impacts resulting from the change of the environmental state. These indicators include resource availability, the crime rate, and adequate conditions for health. Response indicators deal with the responses of different groups and decision makers to prevent environmental degradation and social stratification and promote the efficiency of production, environmental conditions, and quality of life in adapting to the change of the environmental state. Examples of response indicators include expenditures on the environment, utilization of green power, and recycling of domestic waste (Stanner et al., 2007).

Since the DPSIR framework was first applied in the program of EEA, which was sponsored by the Dorbris Assessment of European Environment covering the issues of air, water and soil (EEA., 1995). It has been widely used by a considerable number of organizations and scholars to assess other environmental issues. This framework brings together the economic, social, environmental and institutional criteria into an integrated framework by establishing the cause-effect relationships between human activities and environmental, social and economic impacts. The DPSIR framework has been extended by other organizations and researchers to better understand specific issues obeying the causal links of the DPSIR model. Examples are DPSWR (Cooper, 2012), DPCER (Rekolaninen, Kamari, & Hiltunen, 2003), DPSER (Kelble et al., 2013), and DPSEEA (WHO., 2002), DPSIR+C(Zhang & Fujiwara, 2007).

3.2.2 DPSIR model of the Sustainable City Index (SCI)

The assessment framework was designed based on the casual relationship that people and firms cluster in urban area to exploit agglomeration economies, but such clusters cause social and environmental externalities (Au & Henderson, 2005; Black & Henderson, 1999; Button, 1976; O'Sullivan, 2012; Wang, 2010)

Driving forces: The unprecedented urbanization and urban growth is the driving force that exerts pressures and cause changes in the urban environment. Demographic change increases the demand for resources, infrastructure and settlements. Industrialization has also increased the land need to accommodate factories and their related service sectors (Jago-on et al., 2009).

Pressures: Urbanization and industrialization exert pressures on urban environmental and ecological systems. The pressures mainly include the consumption of resources and release of substances, such as energy consumption, water consumption, waste emissions and SO_2 emissions.

States: When the urban environment changes, the state of the environment also changes, such as the concentration of SO_2, NO_2 and particulate matter (PM10), noise and air quality. In this paper, environmental efficiency indicators are selected, such as energy efficiency and pollutants emission per unit GDP.

Impacts: As discussed before, urban growth causes not only environmental problems but also social issues. Cities attract large numbers of migrants from rural areas, influencing security and employment in urban areas. In addition, large needs for settlements increase the housing prices and rents significantly. Furthermore, overcrowding also challenges the urban transportation system and results in serious traffic congestion, and people have to spend more time commuting.

Responses: Responses are the means to improve the quality of urban systems, such as the government's expenditure in education, technology and medical treatment and public health.

3.2.3 Hypothesis of the DPSIR model

- H1**:** The high speed of urbanization, including economic and demographic development, increases environmental problems because of high resource consumption and pollutant emissions;
- H2: The pressures on the environment accompanied by the deterioration of the environmental state;
- H3: Urbanization improves the quality of life of the citizens;
- H4: The social response reduces environmental pressures;
- H5: The social response promotes the performance of the other four sectors.

3.2.4 Data Pre-processing

In an indicator-based framework, it is important to select proper data standardization methods. Here, I utilize 0-1 scaling to standardize the data; therefore all of the data can be transformed into 0-1 scales. In this way, the linear relation among the data does not change. In order to compare two years' data, I refer to the method of Sun, Liu, and Li (2009) to analyze the periods cross-sectional data.

Initially, this paper designed the evaluating objects as i and the evaluating indicators as j, and in t years (t = 1,2), then forms an original value matrix $\mathbf{X} = \left(x_{ij}^{t}\right)_{2m*n}$:

$$\mathbf{X} = \begin{bmatrix} x_{11}^{1} & x_{12}^{1} & \cdots & x_{1n}^{1} \\ x_{21}^{1} & x_{22}^{1} & \cdots & x_{2n}^{1} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1}^{1} & x_{m2}^{1} & \cdots & x_{mn}^{1} \\ x_{11}^{2} & x_{12}^{2} & \cdots & x_{1n}^{2} \\ x_{21}^{2} & x_{22}^{2} & \cdots & x_{2n}^{2} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1}^{2} & x_{m2}^{2} & \cdots & x_{mn}^{2} \end{bmatrix} \tag{3-1}$$

where $i = 1, 2, ..., m$, $j = 1, 2, ..., n$.

In order to eliminate the influence of magnitude and positive (the larger the better) and negative (the smaller the better) orientation, the data is standardized using equation (3-2) and (3-3) to get $\mathrm{R} = \left(r_{ij}^{t}\right)_{2m*n}$:

Positive indicator: $$r_{ij}^{t} = \frac{x_{ij}^{t}\text{-min}(x_j)}{\max\left(x_j\right)\text{-min}(x_j)} \tag{3-2}$$

Negative indicator: $$r_{ij}^{t} = \frac{\max\left(x_j\right)\text{-}x_{ij}^{t}}{\max\left(x_j\right)\text{-min}\,(x_j)} \tag{3-3}$$

Where x_{ij}^{t} represents the value of indicator j in city i in year t ; max(x_j) and min (x_j) is the maximum and minimum value of j indicator in all cities, respectively. Thus all the data is standardized in the range of [0,1] (Wang, Ma, & Zhao, 2014).

3.2.5 Entropy Method

Despite data standardization, another important process is defining weights for each indicator. There are two kinds of weighting methods: subjective weighting methods (Analytic Hierarchy Process, Delphi Method), and objective weighting methods (Principal Component Analysis， Entropy Method). The entropy method has been widely utilized in ecology, economics and finance, among others. Information entropy measures the amount of useful information based on the data. When the difference of the value of each indicator is high and the entropy is small, the weight of the indicator is high as well correspondingly and vice versa(Zou, Yun, & Sun, 2006). The way of calculating entropy is an objective way which can avoid objective influences by choosing the best indicators that can reflect the different sustainable development level among sample cities. In order make it comparable between two years, the entropy of j indicator is defined as (3-4):

$$e_j = -k\sum_{t=1}^{2}\sum_{i=1}^{m} f_{ij}^{t} \ln f_{ij}^{t}, \; i=1,2, \ldots, m \tag{3-4}$$

Where f_{ij}^{t} is the ratio of indicator j in i^{th} indicator: $f_{ij}^{t} = \dfrac{r_{ij}^{t}}{\sum_{t=1}^{2}\sum_{i=1}^{m} r_{ij}^{t}}$, $k = \dfrac{1}{\ln 2m}$.

In order to diminish the influence of 0 in the equation (2), the matrix **R** is translated into a new matrix $\mathbf{A} = \left(a_{ij}^{t}\right)_{2m*n}$:where $a_{ij}^{t} = r_{ij}^{t} + 0.0001$.

The weight of entropy of j indicator is defined as:

$$w_i = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{3-5}$$

Where $d_j = 1 - e_j$ is the consistency degree of the contribution of i^{th} object under indicator j.

3.3 Assessment Framework of Sustainable City Index

The indicators are selected based on the Sustainable Development Goals of the UN (2015), which includes a set of 17 Sustainable Development Goals (SDGs) to end poverty, fight inequality and injustice, and limit climate change by 2030. To be specific, the 17 SDGs are "no poverty, zero hunger, good health and well-being, quality education, gender equality, clean water and sanitation, affordable and clean energy, decent work and economic growth, industry, innovation and infrastructure, reduced inequalities, sustainable cities and communities, responsible consumption and production, climate actions, life below water, life on land, peace and justice, strong institutions, and partnership for the goals" (UN, 2015). Under the goal of sustainable cities and communities, the goals are:

- By 2030, provide access to adequate, safe and affordable housing and basic services for all;
- By 2030, guarantee the access to safe, efficient and convenient transportation systems for all citizens;
- By 2030, strengthen the sustainable urbanization and the participation of all countries;
- Improve the protection of cultural and natural heritage;
- By 2030, reduce the adverse environmental pressures per capita by enhancing national and regional planning;
- By 2030, make safe and green open spaces accessible to all, especially women and children;
- Uphold positive linkage between economic, social and environmental pillars;
- By 2020, significantly increase the amount of urban areas that adopt and implement the policies on resource efficiency, climate change, and resilience to disasters;

- Support least developed countries through means including financial and technical aids in constructing sustainable and resilient buildings in local areas.

The International Organization for Standardization establishes a set of 17 themes on sustainable community focusing on city services and quality of life. The 17 themes include "economy, education, energy, environment, finance, fire and emergency response, governance, health, recreation, safety, shelter, solid waste, telecommunication, transportation, urban planning, wastewater and water and sanitation" (ISO., 2014).

Therefore, this paper constructs the framework of indicators based on the UN SDGs and ISO 37120. Limited by the concrete condition of Chinese cities and data availability, only 27 indicators are selected in the DPSIR framework of urban sustainability (Table 3-2). To be specific, urbanization and economic growth drive the development of the urban areas and help to realize the goal of poverty reduction and economic development. In addition, on the aspects of environment state and pressures, the data of resources and pollution are selected to respond to the theme of energy and environment of both the SDGs and ISO. The indicators of impacts mainly include housing price, medical resources, welfare and education responding to the goals of affordable housing, safe and healthy life and education. In the response sector, the treatment of pollutants is response to both of the environment and governance and transportation system according to the second goal of sustainable cities of the SDGs. The data of this paper are taken from China Urban Statistics Year Book, China Statistical Yearbook 2014, China New Urbanization Report, the yearbook and government work reports of each province and municipal city, the local Statistical Bureau, Inspection Bureau, and Environmental Protection Agency

Table 3- 2 DPSIR Framework of Urban Sustainability

Rule Hierarchy	Component	Factor Hierarchy	Source	Positive or Negative	Weight
Driving forces	Economic Development Level	Unemployment Rate (%)	Year Book of Each Province and Municipal City	-	0.082
		Disposable Income Per Capita (yuan)	Year Book of Each Province and Municipal City	+	0.082
		GDP per capita(yuan)	Year Book of Each Province and Municipal City	+	0.078
		The Ratio of Tertiary Occupation (%)	Year Book of Each Province and Municipal City	+	0.018
		GDP Growth Rate (%)	Year Book of Each Province and Municipal City	+	0.027
	Demographic Growth	Population Growth Rate (%)	Year Book of Each Province and Municipal City	-	0.060
	Private Car	Private Car Ownership Per Person	Year Book of Each Province and Municipal City	-	0.029
Pressures	Resource Consumption	Energy consumption per unit GDP (ton of standard coal equivalent/ yuan)	Year Book of Each Province and Municipal City	-	0.019
		Water consumption per unit GDP (ton/yuan)	China Urban Statistics Year Book	-	0.011
	Pollutant Emission	SO_2 emissions per unit GDP (ton/yuan)	China Urban Statistics Year Book	-	0.015
		Waste water emission per unit GDP (ton/yuan)	China Urban Statistics Year Book	-	0.022
		Industrial dust per unit GDP (ton/yuan)	China Urban Statistics Year Book	-	0.005

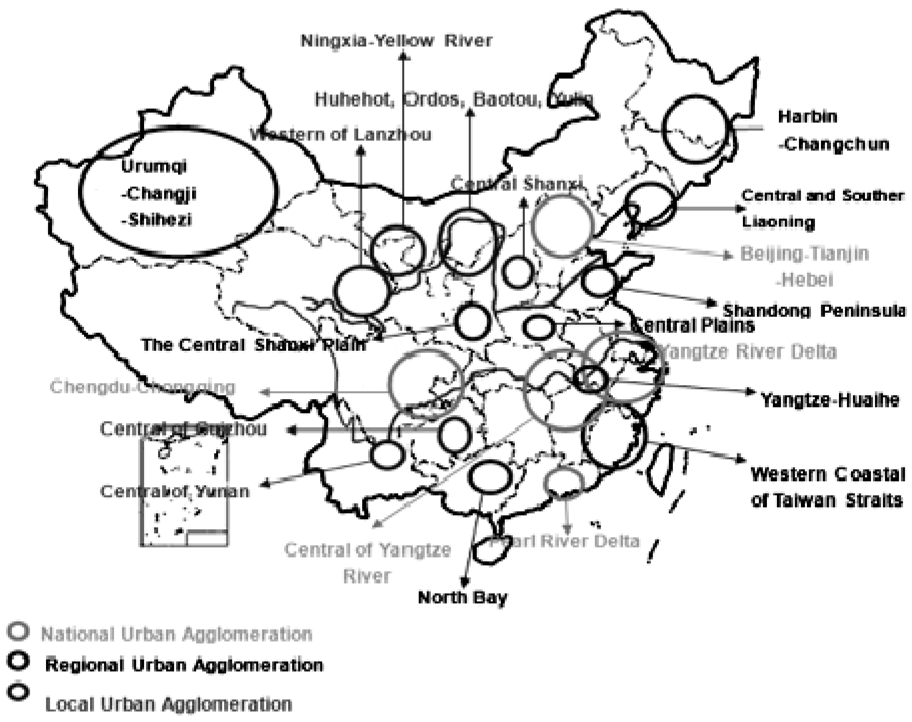
State	Air Quality	SO2 concentration (mg/m^3)	The Report of Local Environmental Protection Agency	-	0.017
		NO2 concentration (mg/m^3)	The Report of Local Environmental Protection Agency	-	0.011
		PM10 concentration (mg/m^3)	The Report of Local Environmental Protection Agency	-	0.009
		Number of days of air quality equal or above grade Ⅱ (days)	The Report of Local Environmental Protection Agency	+	0.022
	Urban Green	The Ratio of Green Area	Year Book of Chinese Cities	+	0.029
Impacts	Density	Population Density of Construction Area(person/ km^2)	Urban China Initiative	-	0.028
	Housing	Ratio of House Price to Disposable Income	China Real Estate Year Book	-	0.011
	Welfare	Urban Pension Coverage (%)	Urban China Initiative	+	0.057
	Education	Ratio of Primary Education Teachers to Primary Students	China Urban Statistics Year Book	+	0.053
	Doctor Resource	Number of Doctors Per Capita	China Urban Statistics Year Book	+	0.049
Responses	Pollution Treatment	Comprehensive utilization of solid waste (%)	China Urban Statistics Year Book	+	0.022
		Sewage treatment rate (%)	China Urban Statistics Year Book	+	0.016
		Decontamination rate of urban refuse (%)	China Urban Statistics Year Book	+	0.010
	Technology Investment	Science and technology input/GDP (%)	China Urban Statistics Year Book	+	0.099
	Public Transportation	Average times of using public transportation per person per year	China Urban Statistics Year Book	+	0.118

3.4 Study Areas

3.4.1 Urban Agglomerations in China

Figure 3-2 demonstrates 20 emerged or planned urban agglomerations in China. Among these urban agglomerations, five of them are national urban agglomerations, nine are regional urban agglomerations and six are local urban agglomerations. Currently, there are 10 emerged urban agglomerations: Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta, Central and Southern Liaoning, Shandong Peninsula, Western Coast of the Taiwan Strait, Central Plains, Central Shanxi Plain, Chengdu-Chongqing and Central of Yangtze River; the others are planned by the National Development and Reform Commission (NDRC).

Figure 3- 2 Urban Agglomerations in China



Source: Author

3.4.2 Study Areas

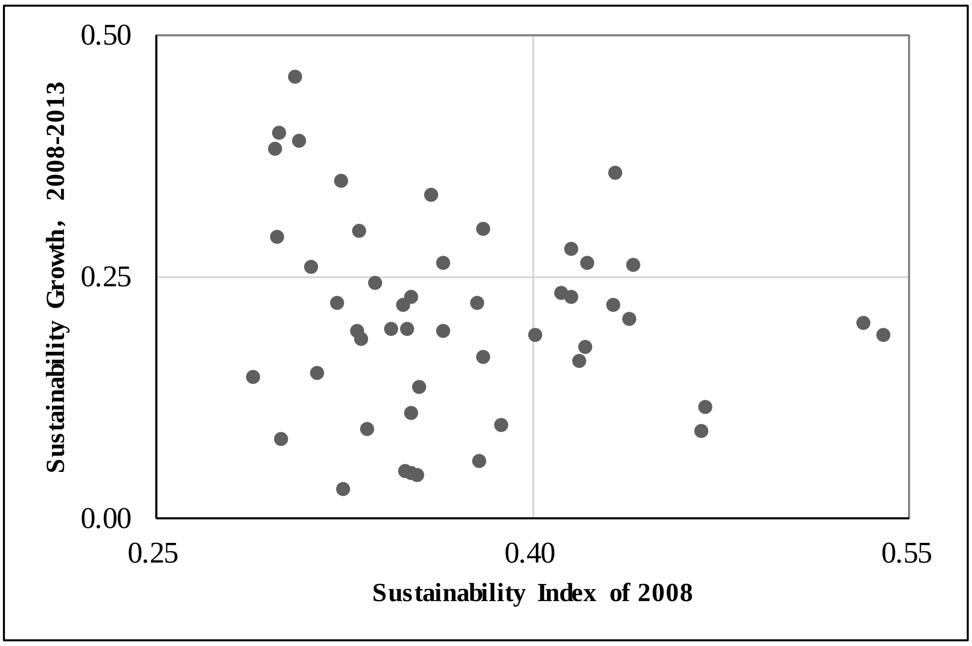
This research assesses the urban sustainability of 49 main Chinese cities, and these cities cover 20 urban agglomerations in China: four municipalities (Beijing, Tianjin, Shanghai and Chongqing), 26 provincial capital cities (Shijiazhuang, Taiyuan, Huhehot, Shenyang, Changchun, Harbin, Nanjing, Hangzhou, Hefei, Fuzhou, Nanchang, Jinan, Zhengzhou, Wuhan, Changsha, Guangzhou, Nanning, Haikou, Chengdu, Guiyang, Kunming, Xi'an, Lanzhou, Xining, Yinchuan and Urumuqi), five cities specifically designated in the state plan (Dalian, Qingdao, Shenzhen, Xiamen and Ningbo), five coastal cities and port cities (Nantong, Yantai, Weihai, Zhuhai and Beihai), three resource-dependent cities (Daqing, Baotou, Tangshan), and seven specially selected influential cities (Wuxi, Suzhou, Zhongshan, Dongguan, Luoyang and Guilin). Lhasa, limited by data availability, will not appear in the ranking. In addition, because the statistical standards of Hong Kong and Macao are inconsistent with the mainland, this research will not include these two cities.

3.5 Results

On the whole, all of the 49 cities experienced positive sustainable development from 2008 to 2013, and some of the cities reached high sustainability growth, with 30% to 50% improvement, while some of the cities developed slowly. Figure 3-3 illustrates the growth of sustainability from 2008 to 2013 of 49 cities that are separated into four groups; group one are the cities with lower sustainability (less than 0.4) and lower growth rates (less than 0.25); group two includes the cities with higher sustainability (more than 0.4) and lower growth rates; group three are those cities with lower sustainability and higher growth rates (more than 0.25), and group four's cities had both a higher level of sustainability and growth rate. In group one, the majority of the cities are inland cities (e.g. Yinchuan, Kunming and Guilin) whose economic development is limited by their resources and locations, while the others are northern and northeastern resource-based and industrial cities (e.g. Tianjin, Shenyang and Baotou) whose economic development level is higher but suffer serious resource and environmental problems. In addition, in group two all of the cities are coastal cities (Beijing, Shanghai and Shenzhen) which rank at the top of the sustainability index and enjoy the benefits of earlier economic opening. Group three (Changsha, Nanjing and Fuzhou) are cities which are developing rapidly in recent years with good policy support and rational industrial structures, and only four cities (Guangzhou, Zhuhai, Hangzhou, Ningbo) belong to group four and reflect a desirable tendency of sustainable development. With respect to each component, the driving forces of urbanization have increased in all cities; however, the pressures exerted from urbanization on the environment rose, accompanied by the decline of the environmental state. Divided by GDP (2008), the average sustainability score of small and middle (GDP smaller than 200 billion yuan), large (200-500 billion yuan), and super economies (larger than 500 billion yuan) are 0.38, 0.39, and 0.46 respectively.

On the whole, as shown in Table 3-3, in 2013 Shenzhen, Beijing, Zhuhai, Guangzhou, Ningbo, Weihai, Dalian, Haikou and Suzhou's performance ranked highest among the 49 cities; all of the cities are located in eastern China and eight of them are coastal cities. This is because the eastern coastal areas enjoyed the benefits of earlier economic opening, policy support from the central government, and exceptional advantages of geography. In addition, these cities are more attractive to highly competent people, with high salaries and more opportunities for young people. Therefore, the coastal areas develop with vitality and have become the most successful region in China.

Figure 3- 3 Sustainability growth from 2008 to 2013



Source: Author

Within the top ten cities, the urban density ranged from 4000 to 14000 per square kilometer and the majority had a density between 7000 and 10000 per square kilometer. Among the top performing cities, the GDP per capita ranged from 90-130 thousand yuan, with the exception of Haikou, with only 40 thousand yuan per capita. The highest GDP per capita is around 150 thousand Yuan, which is not that high compared with some cities, meaning that high economic development cannot necessarily guarantee sustainable development, and a balanced development among all pillars is needed.

Table 3- 3 Top 10 cities in Sustainability of 2013

Rank	City	Sustainability	Location
1	Shenzhen	0.64	Eastern
2	Beijing	0.64	Eastern
3	Zhuhai	0.59	Eastern
4	Guangzhou	0.55	Eastern
5	Hangzhou	0.53	Eastern
6	Ningbo	0.53	Eastern
7	Weihai	0.53	Eastern
8	Dalian	0.53	Eastern
9	Haikou	0.52	Eastern
10	Suzhou	0.51	Eastern

Source: Author

As discussed above, the top ten performing cities benefit from the earlier start of economic opening, but the current performance does not necessarily reflect a better growth rate of sustainability. Table 3-4 demonstrates the top ten cities' improvement in sustainability, and the results contradict those of the best performing cities in that the majority of the cities are located in the west, except Zhuhai, Ningbo and Wuhan. The high-speed sustainable development of western cities is the result of the develop-the-west strategy, abundant natural and labor resources, and the experience of eastern cities' development. In addition, the high speed of tertiary vocational education development reinforces the retention of talents in western areas. Although the sustainable development of the west is much higher than the majority of the eastern cities, the level of sustainability is still behind coastal cities.

Table 3-4 Rank of Sustainability Growth, 2008-2013

Rank	City	Sustainability	Location	City scale by population
1	Guiyang	0.46	Western	Medium
2	Nanning	0.40	Western	Medium
3	Xian	0.39	Western	Large
4	Lanzhou	0.38	Western	Medium
5	Zhuhai	0.36	Eastern	Medium
6	Wuhan	0.35	Central	Medium
7	Fuzhou	0.34	Eastern	Medium
8	Nanjing	0.30	Western	Medium
9	Nantong	0.30	Central	Medium
10	Xining	0.29	Western	Medium

Source: Author

Among the worst performing cities (Table 3-5), six of the cities are located in the center and west cities, and the majority of them are resource-based cities. These resource-based cities, especially eastern cities, also show a slow sustainable development during the five years, meaning that development that mainly depends on resources could not maintain sustainable development. It is urgent for the highly resource-based cities to transform their industrial structure or there is a danger of resource scarcity in these areas.

Table 3- 5 Bottom 10 cities in sustainability, 2013

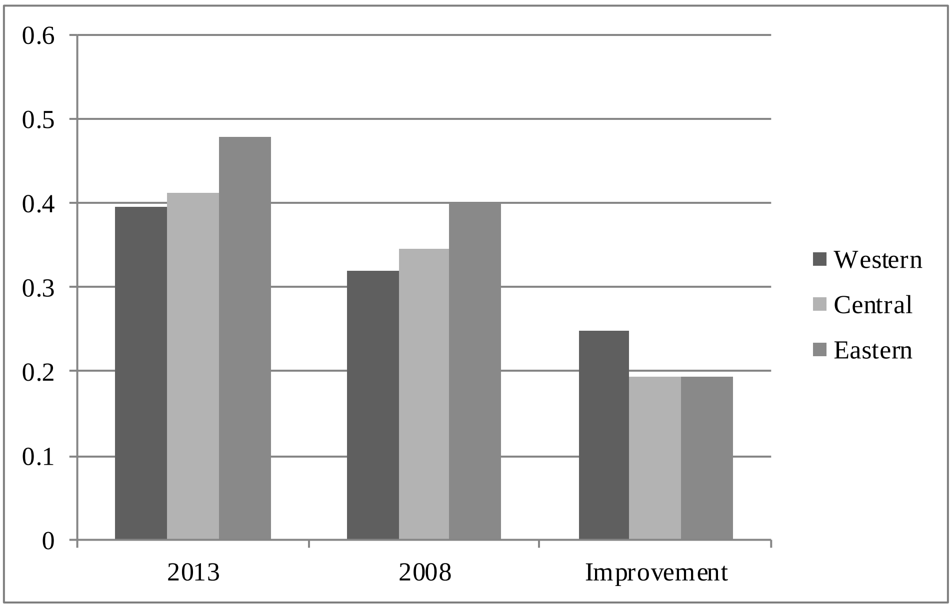
Rank	City	Sustainability	Improvement	Location
40	Taiyuan	0.39	0.11	Central
41	Xining	0.38	0.29	Western
42	Baotou	0.37	0.05	Western
43	Changchun	0.37	0.05	Eastern
44	Huhehot	0.37	0.05	Western
45	Haerbin	0.36	0.09	Eastern
46	Luoyang	0.36	0.15	Central
47	Shijiazhuang	0.33	0.03	Eastern
48	Chongqing	0.33	0.15	Western
49	Tangshan	0.32	0.08	Eastern

Source: Author

3.5.1 Regional Sustainable Development

In 2013, there was an apparent correlation between the level of sustainability and the location. As discussed above, with respect to the best performing cities, the eastern coastal cities show a high level of sustainability, while the western cities reflect a high rate of sustainable development. Figure 3-4 demonstrates the average score in the level of sustainability in 2008 and 2013, and sustainable growth for 2008-2013 respectively. The majority of the eastern cities performed well and retained the highest sustainability level among all regions. They were followed by central cities, and western cities still lag behind the other two regions. However, the average improvement rate in the sustainability of western cities is higher than central and eastern China, and the level of western cities' sustainability is approaching central cities.

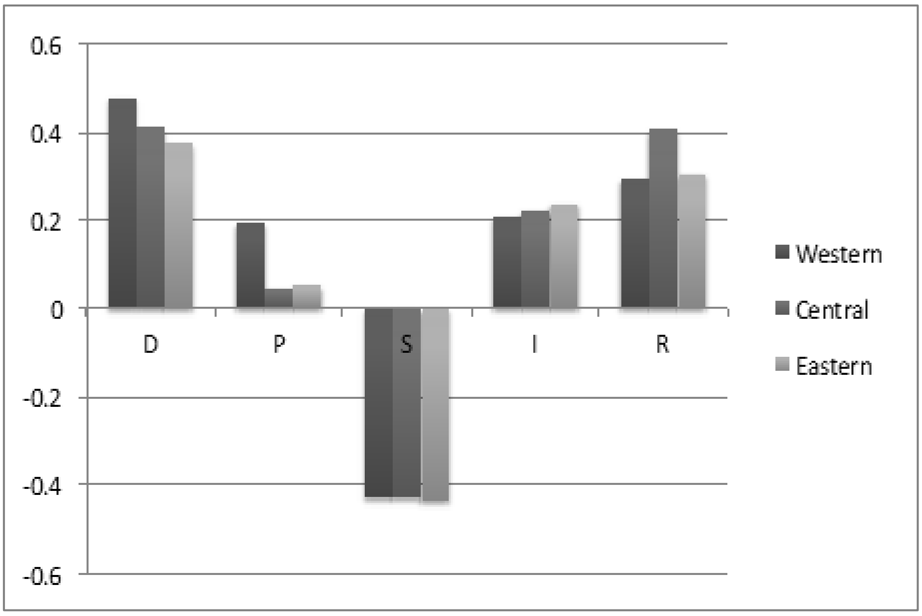
Figure 3- 4 Sustainable Development by Region



Source: Author

Figure 3-5 demonstrates the sustainability improvement with respect to each category of DPSIR in different regions from 2008 to 2013. Eastern cities developed fastest in terms of social impacts, but the lowest in environmental state. Central cities improved significantly in the responses sector but lowest in decreasing resources efficiency. Western cities experienced the fastest economic development but slowest social development. Table 3-6 illustrates the three best performances cities in each region. Among western cities, Guiyang has experienced significant sustainable development from 2008 to 2013 and ranks in the top among western cities while two cities of Inner Mongolia, Baotou and Huhhot, have changed slightly since both of them are high resource-based cities. In addition, Changsha remains the top ranked among middle cities and Zhuhai had become one of the best performance cities in 2013 with the largest sustainable development.

Figure 3- 5 Sustainable Development of Each Category by Region, 2008-2013



Source: Author

Table 3-6 Top Three Cities of Each Region

Region	2013	2008	Improvement
Western	Guiyang, Xian, Yinchuan	Baotou, Chengdu, Huhhot	Guiyang, Nanning, Xian
Central	Changsha, Wuhan, Hefei	Changsha, Nanchang, Hefei	Wuhan, Hefei, Changsha
Eastern	Shenzhen, Beijing, Zhuhai	Beijing, Shenzhen, Haikou	Zhuhai, Fuzhou, Nanjing

Source: Author

As with the previous results, the eastern urban agglomerations perform better in sustainability than other areas; however, the sustainability of western urban agglomerations has developed faster. Among the top 10 urban agglomerations, large cities and megacities play an important role in driving the sustainable development of the whole urban agglomerations, such as the Pearl River Delta urban agglomeration and Yangtze River Delta urban agglomeration. However, the Beijing-Tianjin-Hebei urban agglomeration is an exception in this area, as Beijing is one of the top performing cities, while the cities of Hebei province all rank at the bottom. In other words, Beijing's sustainable development is negatively affecting the development of surrounding areas. Therefore, Beijing's development is not an example of strong sustainable development.

Table 3-7 Rank of Urban Agglomerations in 2013

Rank	Urban Agglomerations	Sustainability Growth (2008-2013)
1	Pearl River Delta	Central of Guizhou
2	Yangtze River Delta	The Central Shanxi Plain
3	Western Coastal of Taiwan Strait	Western of Lanzhou
4	Central and Southern of Liaoning	Urumqi-Changji-Shihezi
5	Shandong Peninsula	Ningxia-Yellow River
6	North Bay	Yangze Huaihe
7	Central of Guizhou	North Bay
8	Central of Yangtze River	Central Plain
9	Yangtze-Huaihe	Yangtze River Delta
10	Beijing-Tianjin-Hebei	Shandong Peninsula

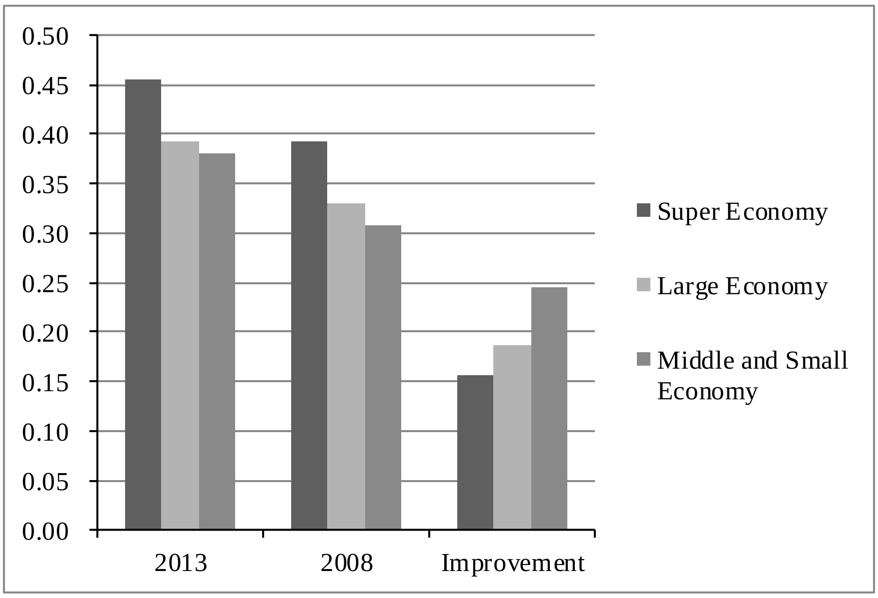
Source: The Author

3.5.2 Sustainable Development by City Scale

This paper divides cities using two kinds of classification, by population and by GDP. For population size, megacity, large city, medium city and small city are the cities with more than 10 million, 5-10 million, 1-5 million and under 1 million urban inhabitants respectively. For GDP, a super city's GDP is larger than 500 billion yuan, large cities are those with GDP from 200-500 billion yuan, small and medium cities are smaller than 200 billion yuan.

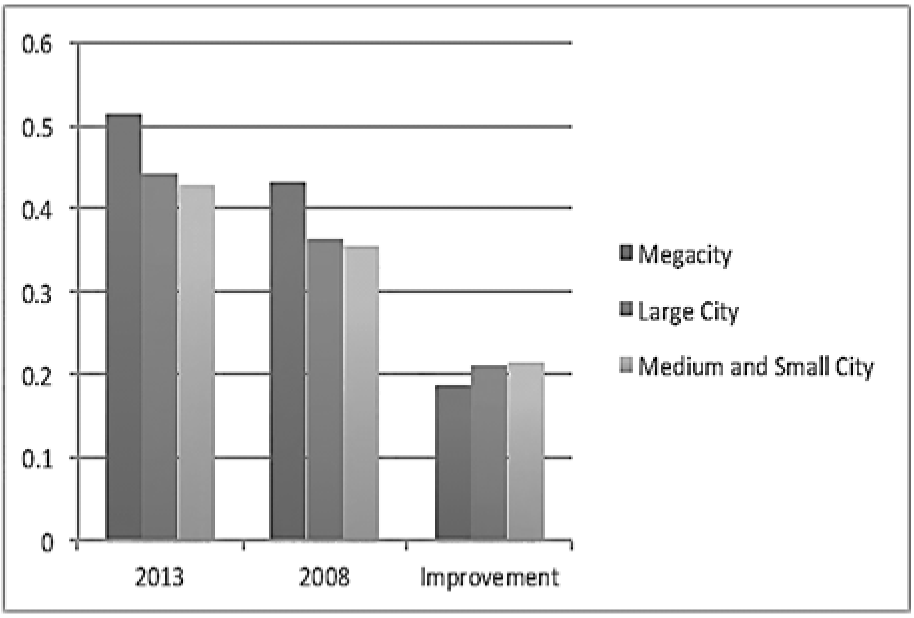
Divided by GDP (Figure 3-6), super economies demonstrate better performance in sustainability than other economies, while the average development speed of medium and small cities is faster. Similarly, based on Figure 3-7, the average sustainability of megacities is higher than large, medium and small cities, while medium and small cities improve more than the other cities. The advantages of larger cities remain, while the potential of small economies also cannot be ignored.

Figure 3- 6 Sustainable Development by City Scale (GDP)



Source: Author

Figure 3- 7 Sustainable Development by City Scale (Population)



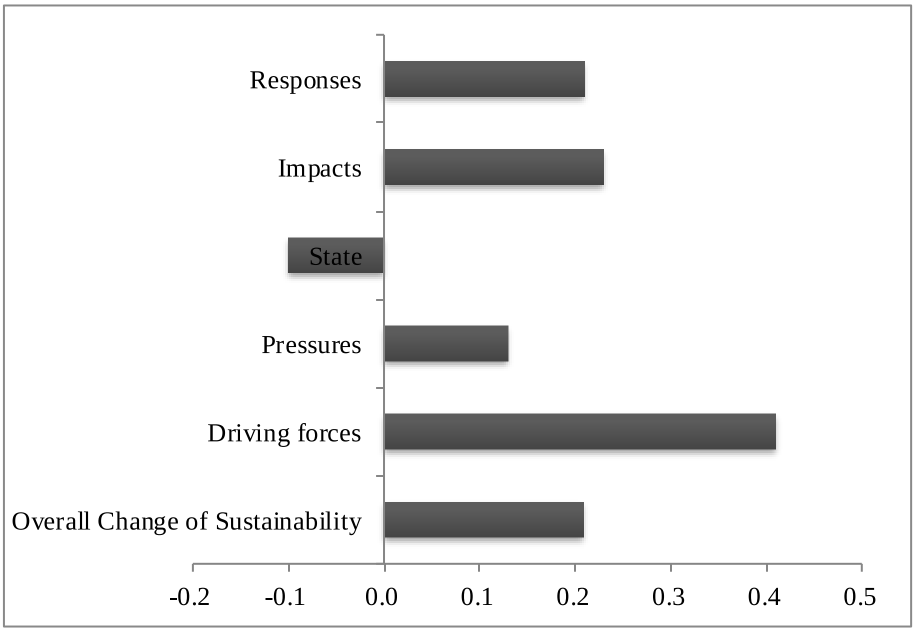
Source: Author

3.5.3 The absolute change of DPSIR framework

Figure 3-8 illustrates the change of each sector of the DPSIR model. From 2008 to 2013 the driving forces contributed a large proportion of sustainable development with a high speed of economic growth and demographic change, and the environmental efficiency has also been increased. Nonetheless, the state of the environment declines with the increase of resource consumption and pollutant emissions because of the significant increase of pollutants from 2008 to 2013 (Figure 3-9).

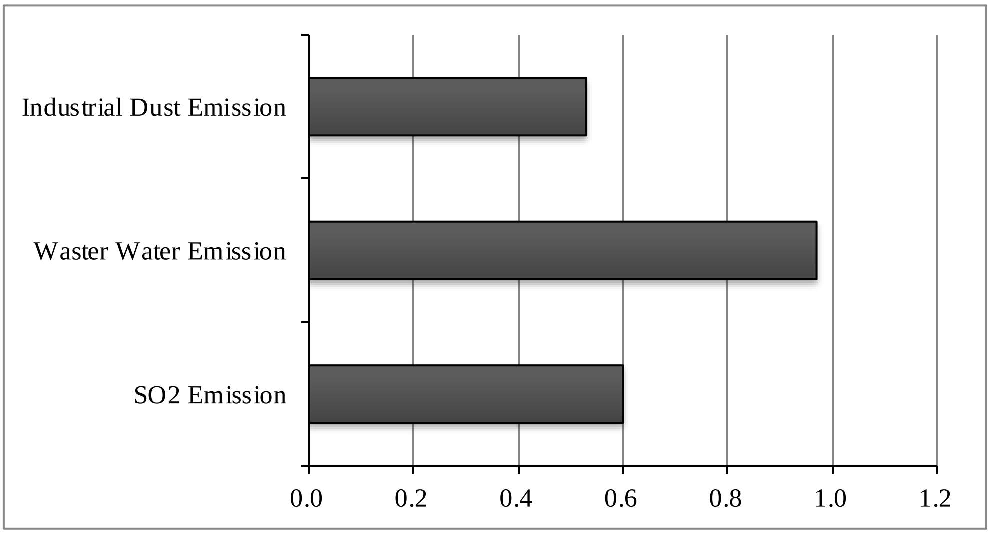
Although the environmental state deteriorates with urbanization, the quality of life of the citizens has been promoted because of economic development. Even though the response of society increased, the environmental degradation remains and the environmental quality keeps deteriorating. The result can verify the assumption of the DPSIR model that the promotion of economic development will result in the increase of environmental pressures. The environmental pressures are followed by serious environmental pollution, and influence the quality of life. However, the quality of life is also highly dependent on the development of the economy; therefore, although the environmental state is poor in some coastal cities, the quality of life remains at a high level. The responses of society can help improve the environmental efficiency and decrease pollutants; however, more responses are needed to improve sustainable development.

Figure 3- 8 Change of DPSIR



Source: Author

Figure 3- 9 The absolute change of resources consumption and pollutant emissions, 2008-2013



Source: Author

3.8 Conclusion

The study applies the DPSIR model to assess the sustainability of 49 Chinese cities in 2008 and 2013. The DPSIR model is a tool to analyze sustainable development based on a causal relationship between each sector. It was found that from 2008 to 2013 all selected cities show an increase in terms of the level of sustainability and eastern cities remain better performing than central and western cities. All of the cities perform well in economic development and such development drives sustainable development; however, the pressures from economic growth on environmental protection and social development is increasing. In addition, the sustainable development of Chinese cities is weak sustainable development where the economic growth is sacrificing the natural resources and environment. Moreover, the sustainable development is unbalanced among Chinese cities, the eastern cities perform better due to the earlier opening up, and western cities are approaching central cities for recent years due to the China western development strategy. Therefore, in order to reach the goal of equity, the central government needs more effort to develop the central and western areas, and cooperation between local governments is also needed. Moreover, DPSIR can be utilized for analyzing special environmental issues based on the actual situation of each city to formulate targeted policies.

Chapter IV Urban form of Chinese cities

With the evidence of 277 Chinese prefectural-level cities, this chapter will study the urban development pattern of these cities. First, I select five indicators based on previous studies to analyze the development pattern of cities. Then I cluster data with a Self-organizing Map (SOM) to recognize the urban morphologies (or development pattern) of Chinese cities and illustrate the characteristics of each morphology.

4.1 Key indicators to measure urban form

As mentioned in Chapter II, many researchers have endeavored to select proper indicators to assess urban sprawl or urban compactness. This research extended the five indicators' framework of Guo (2012) and selected the proxy indicator for each dimension of urban morphology according to previous researches in developed countries. The indicators are listed as follows:

- *Density:* the most widely used indicator of urban form (Burton, 2002; Chen, Jia, & Lau, 2008; Ewing, Pendall, & Chen, 2002; Galster et al., 2001; OECD., 2012). In addition, Galster et al. (2001) pointed out that residential density is more useful than nonresidential development. Therefore, I selected both population density and residential density to assess the urban density. The two indicators of density here are:

PD= Urban population/ Urban area (4-1)

RD= Urban population/ Residential areas (4-2)

Den= (PD+RD)/2[3] (4-3)

[3] The urban density is the average of population density and residential density after standardization. The standardization

- *Concentration*: the concentration indicator measures the proportion of the population living in development areas to total urban areas. The concentration reveals whether the urban population is located in limited areas or spread evenly throughout (Galster et al., 2001). Population concentration is utilized as the proxy indicator for concentration. The specific description of the indicator is listed as follows:

Con= Population in developed areas/ Urban population (4-4)

- *Mixed-use*: this is also an important indicator to measure the urban form (Burton, 2002; Dieleman & Wegener, 2004; Galster et al., 2001; OECD, 2012). Dieleman and Wegener (2004) also called the mixed-use of lands the multifunctional land use. The mixed-use of land is one of the core characteristics of compact city policy and can be found in most high density metropolitan areas, especially in those cities with high accessibility (Dieleman & Wegener, 2004). Here, the mixed-use of land is defined as varieties of functions of land. In biology, the diversities of species have been well documented, there are a series of methods for measuring species diversities such as the Simpson index, Richness index, Shannon index, and Gini-Simpson index. The Shannon index has been well utilized in recognizing the diversity of land use and the specific equations is as follows:

$$\mathrm{MU} = -\sum_{i=1}^{m} (P_i)\ln(P_i) \tag{4-5}$$

Where MU represents Shannon's index and P_i is the percentage of i^{th} kind of land. Based on the data availability, the lands are divided into 9 groups including residential areas, public services areas, business areas, industrial areas, warehouse areas, traffic areas,

method will be illustrated in 4.3.

public facility areas, green areas and other areas.

- *Public transportation*: OECD (2012) concluded one of the key characteristics of a compact city is that the urban developed areas is connected by public transportation. Dieleman and Wegener (2004) pointed out that high mixed use of lands can often be associated with Transit Oriented Developments (TOD). TOD model has been more and more important in the field of urban design and urban planning and be of significance in preventing urban sprawl. The TOD model encouraged mixed-land use with public transport stations and promote walkability and accessibility in daily lives. Due to data availability, here I utilized the ownership of buses per person as the proxy indicator for public transportation;

  Tran= Buses/ Urban population (4-6)

- *Green areas*: as mentioned in Chapter II, the new urbanism emphasizes the idea of green belts to improve the living environment of urban areas. Therefore, following the idea of new urbanism, following Guo (2012), here I selected the ratio of green areas to represent green belts, and the specific form is as follows:

  GA= Green land/Built-up areas (4-7)

4.2 The clustering methodology

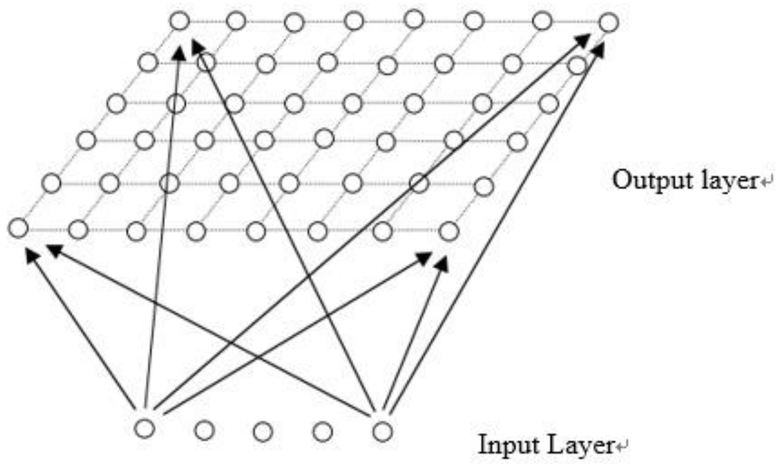
4.2.1 Introduction to SOM

The SOM was developed by Kohonen in 1982 and became one of the most popular neural network models in data mining. SOM is a kind of neural network that is based on unsupervised learning and no human intervention is needed. The SOM clusters through training by itself and clusters the input data automatically.

The SOM is constructed by input layer and output layer (competitive layer). The input layer consists of n units (neurons) and output layer contains m units (neurons), organized as a two-dimensional or three-dimensional plane as shown in Figure 4-1. The SOM is also called the typology-preserving map since it can preserve the typological relationships of the neighbors.

As can be seen from Figure 4-1, the typical SOM is a hierarchical structure with two layers, input and output. The input layer is utilized to receive and transmit information, and then input the information through weight vectors. The output layer is also called the competitive layer, which explores the similarity among the input data, finds laws for them, clusters the data and arranges the trained data in a line or two-dimensional planar configuration. The SOM tries to mimic the operation of the brain and trains the network to cluster the input data into groups.

Figure 4- 1 The network typology of SOM



Source: Kohonen (1982)

4.2.2 The training of SOM

As illustrated above, the SOM consists of two layers: input layer and output layer. The input layer has a set of units, and each unit i represents d dimension, for example, in this research units represents cities that have five dimensions. Each vector $\mathbf{x}_i=[x_{i1},x_{i2},\ldots,x_{id}]$ represents each unit i. These units link to near units based on a neighborhood relationship. The training of SOM is an iteratively process. Each output unit j has been linked with input vector by a weight vector, which is represented by $\mathbf{w}_j$. The distances between each input vectors $\mathbf{x}$ and $\mathbf{w}$ can be calculated:

$$\|\mathbf{x}_i-\mathbf{w}_b\|=\min\{\|\mathbf{x}_i-\mathbf{w}_j\|\} \tag{4-8}$$

where $\mathbf{w}_b$ represents the best matching units(BMU).

Then the weight of BMU is updated in order to near x_i and neighbor radius is getting smaller. After repeated iterations, similar input vectors are allocated into the same output units and finally similar vectors are clustered into the same output neuron. In other words, after neuron network learning the similar vectors have same BMU. Therefore, the cities have same characteristics can be clustered into same group and apart from the cities with different characteristics.

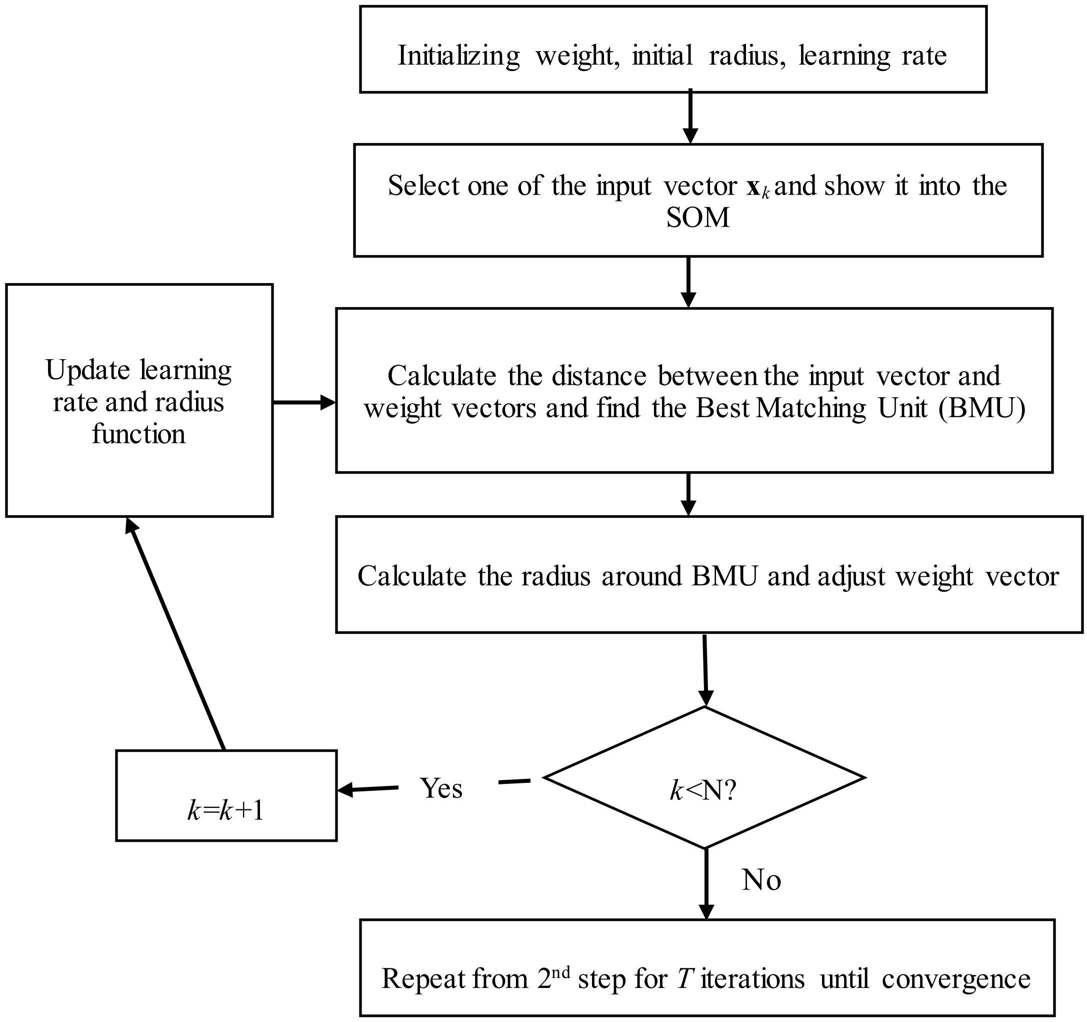
4.2.2 The Algorithm of SOM

It is assumed that the input layer has n nodes, d dimensions, the output layer has m nodes, and the input pattern is defined as $\mathbf{x}_k = \left[x_1^k, x_2^k, \cdots, x_d^k\right]$, where k=1, 2…n. The weight links input layers' nodes and output layers' nodes and is defined as $\mathbf{w}_j$= $\left[w_{1j}, w_{2j},\ldots, w_{nj}\right]$, where j is output nodes, j=1, 2…m, and the total number of iterations is T.

The SOM tries to accomplish two tasks:

- Cluster the input vectors;
- Arrange similar input patterns in same or similar output units.

Figure 4- 2 The learning process of SOM

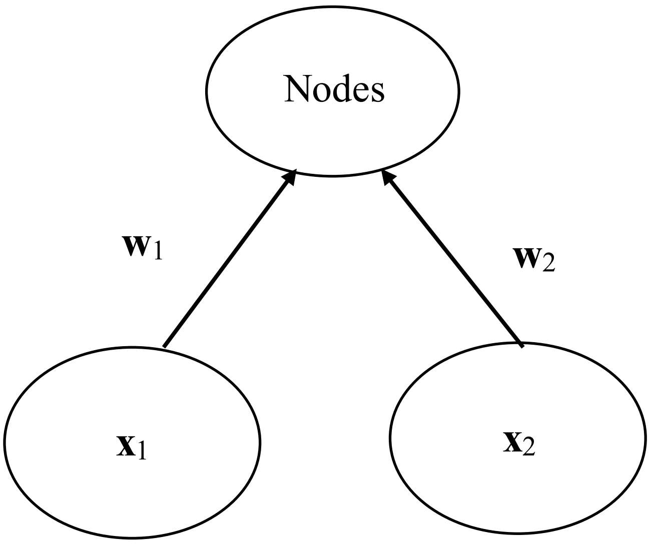


Source: Author

Figure 4-2 shows the learning process of SOM. The specific flow is listed below:

- *Step 1:* Choose a random weight for each node and the weight range from 0 to 1 (Figure 4-3), set an initial neighborhood *Nc* (0), confirm learning rate $\eta(0)$ between the interval of 0 to 1; set the amount of iterations T, and normalize the input vector and weight vector.

Figure 4- 3 Initializing the weight of each node



Source: Author

- *Step 2*: Select a random input vector $\mathbf{x}_k$ and input it into SOM.
- *Step 3*: Calculate the Euclidean distance of input vector $\mathbf{x}_k$ and weight vector $\mathbf{w}_{kj}$, and choose the minimum distance as the winning neuron. The calculation of Euclidean distance is listed below:

$$Dist = \sqrt{\sum_{d=1}^{D}(\mathbf{x}_k - \mathbf{w}_{kj})} \quad (4\text{-}9)$$

- *Step 4*: Adjust the weight vector of nodes that are inside the winning nodes:

$$\mathbf{w}_{ij}(t+1) = \mathbf{w}_{ij}(t) + \eta(t)hc,j(t)(\mathbf{x}_i - \mathbf{w}_{ij}(t)) \quad (4\text{-}10)$$

Where $\eta(t)$ is learning rate, $h_{c,j}(t)$ is neighborhood function, which is decreasing with time, c represents the winning neuron.

- *Step 5*: Update the learning rate and neighborhood function:

$$h_{c,j}(t) = \exp(-\frac{{d_{cj}}^2}{2r^2(t)}) \quad (4\text{-}11)$$

Where d_{cj} is the distance between the winning neuron and any active output neuron j that is inside the neighborhood, r is radius:

$$r(t+1) = \mathrm{INT}((r(t)-1)*(1-\frac{t}{T}))+1 \quad (4\text{-}12)$$

$$\eta_{(t+1)} = \eta_{(t)} - \frac{\eta_{(0)}}{T} \quad (4\text{-}13)$$

- *Step 6:* Repeat step 2 until the network reaches convergence.

4.3 Data sources and data processing

The data for urban population, urban areas, green areas, and each function of urban land is derived from the China Urban Construction Statistical Yearbook in 2013. The data for public transportation is from the China City Statistical Yearbook in 2013.

In order to make all of these indicators comparable, I select 0-1 scaling to standardize the data. In addition, all of the standardized data is multiplied by 100 as to make it easier for calculation in SOM. The equation of standardizing is:

$$R = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \times 100 \quad (4\text{-}14)$$

Where x represents each indicator of the urban form.

4.4 The clustering results of SOM

The SOM clustering of Chinese cities is conducted by MATLAB R2014a. In order to select the proper number of nodes, I introduce map entropy (ME) that is based on the idea of information entropy from the field of information economics. The larger the map entropy is, the more it can explain the distribution of all data. The calculation of map entropy is:

$$ME = \frac{\sum_{i=1}^{N} \frac{c_j}{M} \log(\frac{c_j}{M})}{\log(N)} \tag{4-15}$$

Where M represents the number of input nodes, N is the amount output nodes, c_j is the times of output node j that is selected as BMU. Therefore, after comparing the amount of output nodes from 3 to 25, it is found that five output nodes can contain the most information to explain the urban data, and the map entropy of it is 0.994. In addition, the number of iterations is 2500 in order to reach convergence. Therefore, the Chinese cities are clustered into five groups and each group can be treated as a kind of urban form. The specific result of clustering is shown in Table 4-1:

Table 4- 1 The result of SOM clustering

Urban form	Sample Cities
Morphology 1	Beijing, Taiyuan, Hohhot, Shenyang, Dalian, Changchun, Shanghai, Fuzhou, Nanjing, Jinan, Changsha, Guangzhou, Shenzhen, Chengdu, Kunming, Lanzhou, Urumqi
Morphology 2	Datong, Dandong, Mudanjiang, Ma'anshan, Jiaozuo, Xiangyang, Zhaoqing, Pingdingshan, Wuxi, Hefei, Zhoushan
Morphology 3	Shijiazhuang, Tangshan, Langfang, Baotou, Chifeng, Wuhan, Beihai, Xian
Morphology 4	Nantong, Xiamen, Rizhao, Chongqing, Yulin, Weinan
Morphology 5	Liuan, Zhongshan, Xianmen

Source: Author

4.5 Results

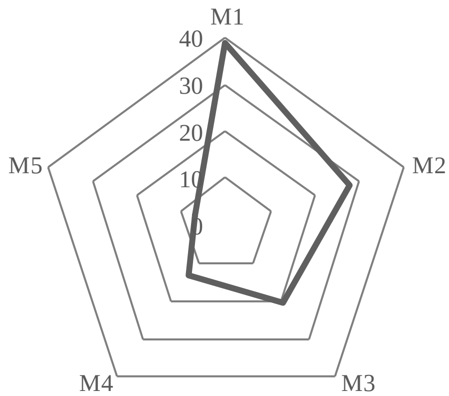
Generally, the selected 277 Chinese cities can be clustered into five groups, and each group represents one type of urban form. Table 4-2 illustrates the characteristics of each urban morphology as follows. In order to make it easier to be observed, I utilize a radar chart to illustrate the performance of five morphologies for each aspect. Figure 4-4 illustrates the performance of each urban morphology for the criteria of public transportation. According to Figure 4-4 and Table 4-2, the level of public transportation varies from 6.94 to 38.87. Morphology one (M1) has the most convenient public transportation, while Morphology five (M5) reflects a low development of public transportation.

Table 4-2 Urban features of five urban morphologies

	Public transportation	**Density**	**Green area**	**Concentration**	**Mixed-use**
M1	38.87	21.60	20.45	90.04	43.30
M2	27.83	21.07	21.23	72.22	33.01
M3	20.57	19.72	16.32	54.70	34.40
M4	13.58	24.63	13.98	40.30	45.80
M5	6.94	34.97	5.58	21.06	37.99

Source: Author

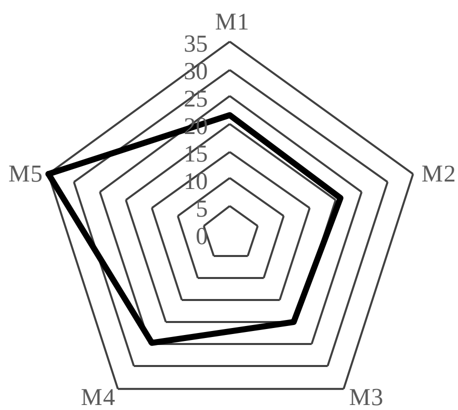
Figure 4- 4 The performance of public transportation of five urban morphologies



Source: Author

Figure 4-5 shows the level of density of the five urban forms. On the basis of Figure 4-2 and Table 4-2, the population density ranges from 19.72 to 34.97. The density of M5 is highest among all forms, which is followed by M4; the density of M1, M2 and M3 are at the medium level, that is, around 20.

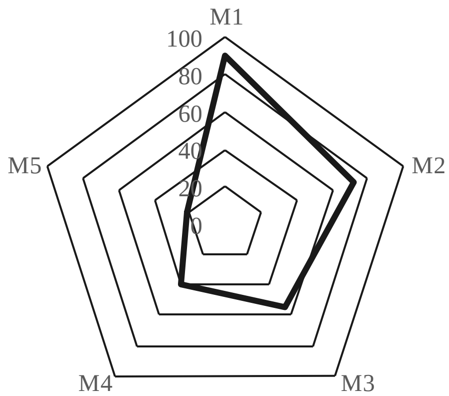
Figure 4- 5 The level of density of five urban forms



Source: Author

Figure 4-6 is the performance of five urban forms in the area of concentration. As can be observed from Figure 4-6 and Table 4-2, the M1 and M2 has the highest level of concentration, meaning that the contamination by urban activities is lower in these areas. In addition, M3 and M4 are at the medium level of concentration, while M5 is at a high level of urban sprawl.

Figure 4- 6 The level of concentration of five urban forms

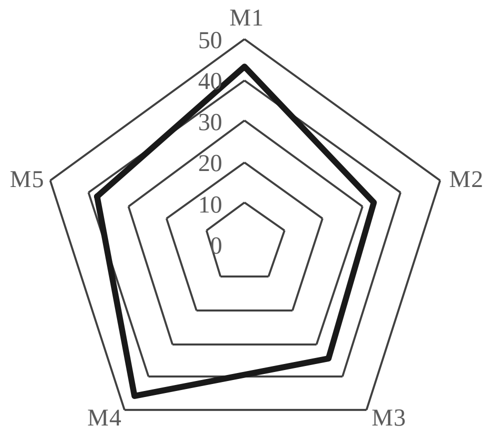


Source: Author

Figure 4-7 is the performance of the five urban morphologies in the mixed-use indicator. The level of mixed use ranges from 33.01 to 45.80. M4 performs the best on the criteria of mixed use, followed by M1, M5 and M3, and M2 shows the lowest level of mixed-land use among all urban morphologies.

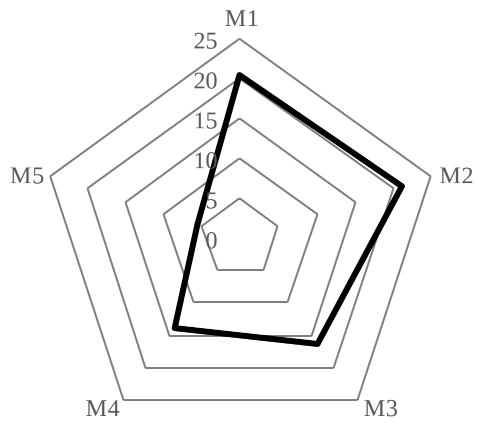
Figure 4-8 demonstrates the level of green area of all morphologies. As shown in Table 4-2, the average score of green area development varies from 5.58 to 21.23. M1 and M2 show best in respect to green area development, while M5 ranks at the bottom of all morphologies

Figure 4- 7 The level of mixed use of five urban forms



Source: Author

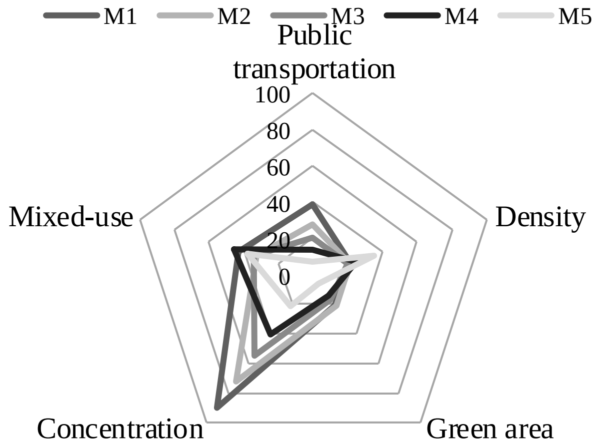
Figure 4- 8 The level of green area of five morphologies



Source: Author

Figure 4-9 and Table 4-3 compares the features of five urban morphologies. According to Figure 4-9 and Table 4-3, the urban morphology that has a higher level of concentration reflects a better level of development of public transportation and ratio of green area. In addition, the high rate of concentration does not necessarily reflect a high level of urban density, showing that some Chinese cities are undergoing urban sprawl.

Figure 4- 9 The comparison of five urban morphologies



Source: Author

Table 4- 3 The features of five urban morphologies

	Public transportation	Density	Green area	Concentration	Mixed-use
M1	High	Low	High	High	High
M2	Medium	Low	High	High	Low
M3	Medium	Low	Medium	Medium	Low
M4	Low	Medium	Medium	Medium	High
M5	Low	High	Low	Low	Medium

Source: Author

4.5.1 Urban morphology one

The urban morphology one includes 65 cities, and Figure 4-10 shows the distribution of urban morphology one. Urban morphology one can be attributed to the cities with high level of development and on both urban construction and economy. The majority of capital cities and municipalities belong to this morphology, such as Beijing, Shanghai, Shenyang, Taiyuan, Changchun, Nanjing, Fuzhou, Jinan, Changsha, Guangzhou, Chengdu, Xining, Yinchuan and Urumqi.

Figure 4- 10 Distribution of urban morphology one

Source: Author

Therefore, as shown in Table 4-4, the GDP, GDP per capita, wage and economic density are much higher than those of the other four urban morphologies. In these areas, population significantly clusters into urban areas and both population density at the city level and in urbanized areas are highest among all urban forms, while the residential density is the lowest, meaning inside the cities the residential areas are highly developed. With the support from local government, the capital cities always have convenient transportation systems. The development of residential areas can be explained by the highly development of public transportation system and increasing need for settlements because of migration. The lower residential density is always related to low floor area ratio and high rate of urban green. In addition, the high level of public transportation also related to the high level of mixed-use of these cities. Moreover, the ratio between population concentration and land concentration is at medium level and the density of sub urban areas is much lower than central urban areas. Therefore, the living quality of urban morphology one is better than other areas.

Table 4- 4 Features of M1 cities

	Maximum	**Minimum**	**Average**	**Standard Deviation**
GDP (billion yuan)	2133.92	15.00	251.28	434.30
Population (10,000 person)	2425.70	25.70	273.03	443.35
GDP per capita (yuan)	220441.6	21943.64	77569.68	40708.56
Urban size (km^2)	19459	132	2555.92	3607.47
Population concentration/ Land concentration	104.81	0.90	9.14	19.14
Residential density(person/km^2)	69528.89	13142.04	32291.82	11276.21
Population density(person/km^2)	7106.06	42.60	1551.33	1372.66
Public transportation (buses/person)	28.38	2.33	10.30	4.40
Economic density (100 million yuan/km^2)	7.26	0.01	1.17	1.22
Wage (yuan)	95029.65	25545.88	51292.63	14051.36

Source: Author

4.5.2 Urban morphology two

There are 49 Chinese cities categorized into urban morphology two and Figure 4-11 illustrates the distribution of these cities. This kind of morphology can be attributed to monotonous and high level of urban sprawl. Among these cities, the majority of the cities are small- and medium-size cities. In this category, most of the cities are single industrial structure that highly relies on natural resources or heavy industry, such as Datong, Ping dingshan and Ma'anshan. Therefore, compared with other morphologies, the utilization of land is more monotonous due to a low level of mixed-use land. As the majority of the cities are relying on natural resources and heavy industry, the GDP per capita, wage and GDP density are also higher. As the urban areas of these resource-based cities are not large and the population density of these areas is higher. The developed resource-based cities also have convenient public transportation and lower residential density. However due to the single industrial structure, majority of the residential areas shows a trend of sprawling to suburb areas and the density of suburb areas is higher than other morphologies.

Figure 4- 11 Distribution of urban morphology two

Source: Author

Table 4- 5 Features of M2 cities

	Maximum	**Minimum**	**Average**	**Standard Deviation**
GDP (billion yuan)	1314.66	8.31	12.72	207.67
Population (10,000 person)	1008.10	20.30	168.65	196.89
GDP per capita (yuan)	196514.40	30034.24	67647.83	34694.37
Urban size (km^2)	7399	138	1807.87	1667.64
Population concentration/ Land concentration	55.60	1.09	6.39	9.82
Residential density(person/km^2)	85035.80	17513.13	38364.61	12414.16
Population density(person/km^2)	7995.05	81.15	1214.19	1264.44
Public transportation (buses/person)	19.53	3.34	7.93	2.79
Economic density (100 million yuan/km^2)	3.30	0.05	0.76	0.67
Wage (yuan)	69591.28	30049.34	48509.67	8261.82

Source: Author

4.5.3 Urban morphology three

Figure 4-12 describes the location of 64 Chinese cities belonging to urban morphology three such as Shijiazhuang, Langfang, Tangshan. Urban morphology three represents the cities at medium level of urban development with a kind of high density development inside the urban central area. The urban size of these cities varies from 269 km^2 to 14,446 km^2. At the urban scale, the population density is lower than morphology one and two; however, the ratio of population compaction to land compaction is much higher than in other morphologies. Even though the concentration of population is not high in these areas, the residential density and population density in central urban areas are very high, such as in Shijiazhuang, Wuhan and Ningbo. The development of urban land lags behind the agglomeration rate of population, therefore result in increasing needs for construction.

Figure 4- 12 Distribution of urban morphology three

Source: Author

Table 4- 6 Features of M3 cities

	Maximum	Minimum	Average	Standard Deviation
GDP (billion yuan)	726.67	2.73	103.4	42.77
Population (10,000 person)	1022.5	21.6	154.81	89.2
GDP per capita (yuan)	152238	12632.13	51528.34	42630.37
Urban size (km^2)	14446	269	2525.06	2194
Population concentration/ Land concentration	346.39	0.59	14.33	3.95
Residential density(person/km^2)	144192.4	13832.4	43874.41	42415.32
Population density(person/km^2)	3297.69	14.95	820.91	726.23
Public transportation (buses/person)	14.18	1.79	5.83	5.36
Economic density (100 million yuan/km^2)	2.34	0.002	0.48	0.26
Wage (yuan)	104544.1	30517.09	47066.25	44764.75

Source: Author

4.5.4 Urban morphology four and Urban morphology five

Figure 4-13 and Figure 4-14 shows the distribution of cities belonging to urban morphology four and morphology five. As shown in Figure 4-13 and Figure 4-14, the majority of the cities are located in central and western areas. Majority of the cities in these two forms are small and medium size cities. Urban morphology four is the typical urban forms of the majority of central and western cities that are at low level of urban development. Urban morphology five represents those cities with limited natural resources or landlocked cities. According to Table 4-7 and Table 4-8, from the criteria of economy, the GDP, GDP per capita, economic density and wages are at a low level. The overall urban density is low while the density in urbanized area is high, showing that these areas are still highly compact; however, the urban area is sprawling to realize economic development. In addition, the rapid construction of urban areas limits the development of public transportation, and therefore the accessibility of these cities is still low.

Table 4- 7 Features of M4 cities

	Maximum	Minimum	Average	Standard Deviation
GDP (billion yuan)	962.23	6.66	85.35	145.76
Population (10,000 person)	2295.5	25.8	189.61	332.21
GDP per capita (yuan)	86945.45	16945	42567.11	17858.95
Urban size (km^2)	31849	439	2761.4	4563.43
Population concentration/ Land concentration	36.40	0.70	7.49	8.39
Residential density(person/km^2)	117543.9	32049.69	57435.28	15353.82
Population density(person/km^2)	2973.87	113.14	815.75	539.88
Public transportation (buses/person)	8.50	1.23	4.34	1.85
Economic density (100 million yuan/km^2)	1.92	0.03	0.37	0.35
Wage (yuan)	61153.94	34460.9	46477.71	6607.40

Source: Author

Figure 4- 13 Distribution of urban morphology four

Source: Author

Table 4- 8 Features of M5 cities

	Maximum	Minimum	Average	Standard Deviation
GDP (billion yuan)	701.02	6.81	58.39	10.54
Population (10,000 person)	637.7	30.3	161.39	114.76
GDP per capita (yuan)	109929	8977.325	30803.88	22041.82
Urban size (km^2)	5861	392	2750.4	1289.56
Population concentration/ Land concentration	50.47	0.64	8.01	10.51
Residential density(person/km^2)	201666.7	41254.86	92092.92	34514.49
Population density(person/km^2)	3353.14	107.41	748.00	656.84
Public transportation (buses/person)	8.46	0.67	2.84	1.79
Economic density (100 million yuan/km^2)	2.38	0.02	0.27	0.42
Wage (yuan)	67490.17	29627.55	43785.40	7245.14

Source: Author

Figure 4-14 Distribution of urban morphology five

Source: Author

4.6 Conclusions

In this chapter, 277 Chinese prefectural-level cities are divided into five groups through SOM. The results show that there is an apparent relationship between urban forms and economic development. Urban morphology one includes the majority of municipalities and capital cities. Urban morphology one is an urban form with high overall population density, low residential density, a convenient public transportation system, high mixed-use of land, and a high level of green area development. With the rapid economic growth, these cities have good infrastructure and the residential areas develop rapidly. Urban morphology two is a kind of urban form with monotonous land use. In this category, the majority of the cities are resource-based or heavy industrial cities. Urban morphology three shows the characteristic of high density in the built-up areas(central urban areas), while the surrounding areas is sprawling at a rapid speed due to high population pressure in the central urban areas. Urban morphology four and five represent the urban forms of the majority of central and western cities. The economic development level of these cities is lower and they are still at the primary stage of urbanization. Therefore, the sprawl trend of these cities could not be avoided.

Chapter V. The influence of urban forms on sustainable development

This chapter is an extension of chapters III and IV and goes on to discuss the relationship between urban morphologies and urban sustainable development. First, this chapter briefly reviews the intense debate over sustainable urban forms on compact, decentralized and compromised cities. Second, the relationship between urban forms and sustainable development is discussed. Finally, the proper development pattern for a sustainable city will be addressed.

5.1 The compact city as a sustainable urban form

5.1.1 Urban sprawl

Over the past decades, urban sprawl and its impacts have attracted a great deal of attention from urban planners and decision makers (Frenkel & Orenstein, 2012), due to the encroachment of urban land uses on non-urban land, which is not only occurring in Chinese cities but also a common phenomenon all over the world (Ye et al., 2015; Yue et al., 2013). Both the popular and scholarly literature describe urban sprawl as the spatial patterns of residential and nonresidential land use and the process of spreading urban development across the non-urban land far surpassing population growth, resulting in low-density, leapfrog, widespread commercial strip development, and discontinuity (Dieleman & Wegener, 2004; Ewing et al., 2002; Galster et al., 2001; Tsai, 2005). The consequences of such urban growth have been well documented in the literature: (1) the investment in urban core areas and central city decreases; (2) increasing vehicle use causes road congestion and air pollution due to high dependence on the private car; and (3) the loss of green areas and leisure spaces in or close to metropolitan regions (Ewing et al., 2002).

5.1.2 The compact city

A compact city, supported by the Commission of European Communities, is a city that limits urban sprawl, protects open space, and reduces energy use. A compact city focuses on high-density development, mixed land use and transport development. The compact city has already succeeded in some industrial countries such as Europe, Australia and the U.S.A. The characteristics of compact cities are:

- High residential density
- Multifunctional land uses
- Promotion of social and economic interaction
- Continuous development
- High level of accessibility
- Highly developed transportation

Those in favor of the compact city include Nairn (1955), Jacobs (1962), CEC (1990), de Wofle (1970), Dantzig and Saaty(1975), Newman and Kenworthy(1989), Elkin et al. (1991), Sherlock (1991), Enwicht (1992), McLaren (1992), Owens and Rickaby (1992) and other organizations and scholars argue that the compact city benefits the environment and society in urban areas (Frey, 1999, pp. 24-25 reorganized from Hillman, 1996, pp.36-44; Thomas and Cousins, 1996, p.56) in the following ways:

- A high degree of containment of urban development; as a result of containment and high population densities, a compact city forms and leads to better conservation of the countryside;
- Affordable public transport which meets the daily needs of those without a car; as a result, increased overall accessibility and mobility for the majority of the urban population;
- Increased public transport means reduced vehicular traffic volumes, related pollution and risk of death and injury in traffic; lower transport volumes lead to less pollution and congestion for shorter periods of time;
- The viability of mixed uses of transport as a result of overall higher population densities; reduced travel distances as a result of mixed uses and overall higher population densities; cycling and walking as the most energy-efficient way of accessing local facilities; less car dependency;
- A better environment- due to overall reduced emissions and greenhouse gases and lower consumption of fossil fuel- and consequently better health;
- Lower heating costs as a result of a denser urban fabric, with less energy consumption and less pollution;
- The potential of social mix as a result of higher population densities specifically when supported by a wide range of dwelling and tenure types in the neighborhoods;
- A concentration of local activities in communities and neighborhoods; as a result a higher-quality life, greater safety and a more vibrant environment as well as support for businessmen and services, i.e. a milieu for enhanced business and trading activities.

In general, a compact city is a kind of city that utilizes the least amount of energy and raw materials to deal with environmental problems and improve the living conditions in urban areas.

5.1.3 The compromised city

However, there are some scholars who have discovered disadvantages of compact cities, and the reasons are as follows (Breheny, 1996):

- The possibilities that environmental and social benefits will not be realized through the compact city model. Evidence showed that unpleasant feelings along with rigorous policies weighted higher than the expectation of decreasing energy utilization
- The probability of stopping urbanization from sprawling is impossible. In reality, even in European countries, such as the UK, which supported compaction policies, urban sprawling still emerged;
- Even under compaction policies green field development never stopped. Like urban sprawling, even though the policies strictly limited the development of green field land, green field development is inescapable;
- The higher density of population in urban areas will probably not improve living conditions. Data from the UK showed that people were satisfied more with low density because of the limitation of resources. In fact, people tend to move to suburban areas, which will lead to new problems. If the policies urge people to move back to urban areas, the living situation of urban dwellers will be sacrificed for the protection of the quality of rural dwellers' lives.

Breheny (1996) also posited the arguments against extreme urban sprawl (Breheny, 1996, p.31):

- Decentralization will lead to land loss, especially when the case is in an extreme situation;
- It is uncertain that the telecommunications will be available in every remote town or village;
- If the cities sprawl without limitation, they will lose their vitality.

Therefore, both centralists and decentralists are reasonable to some extent in arguing the advantages and disadvantages of a centralized and decentralized urban area. Another group of scholars raised a new idea of compromised urbanization, which stands at the middle point of the above two patterns. The scholars Blowers (1993), Berheney and Rookwood (1993), Hooper (1994) and Lock (1991， 1995) are the supporters of a compromised urbanization view. As the name suggests, comprised urbanization integrates urban and town areas and derives the benefits of both centralized and decentralized urbanization. All in all, urban areas could not escape sprawl, but such sprawling should be managed appropriately or it will accelerate the demise of urbanization.

5.2 The relationship between urban sustainability and urban morphologies in China

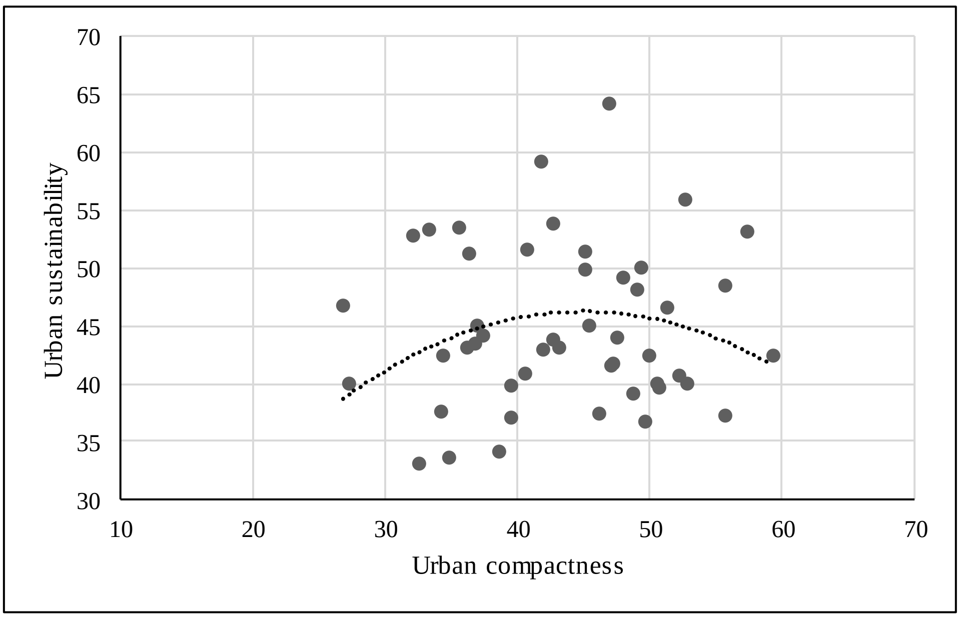
5.2.1 Urban compactness and urban sustainability

Figure 5-1 illustrates the relationship between urban compactness and urban sustainability. Urban compactness, according to the definition, includes the indicators of density, concentration, mixed use of land, and public transportation. Here, all indicators are given equal weight and the urban compactness is the average score of these four indicators. In this chapter, the urban sustainability indicator is transformed into the range of 1 to 100 by multiplying by 100:

Urban compactness= (Den+MU+Tran+Con)/4 (5-1)

As shown in Figure 5-1, there is an inverted-U shape relationship between urban compactness and urban sustainability. To be specific, as urban compactness increases the urban sustainability will increase to a certain level; however, with the continued increase of urban compactness the sustainability level shows a trend of decrease. From this figure, the average score of urban sustainability is the highest at the level of compactness between 40 to 45.

Figure 5- 1 The relationship between urban compactness and urban sustainability



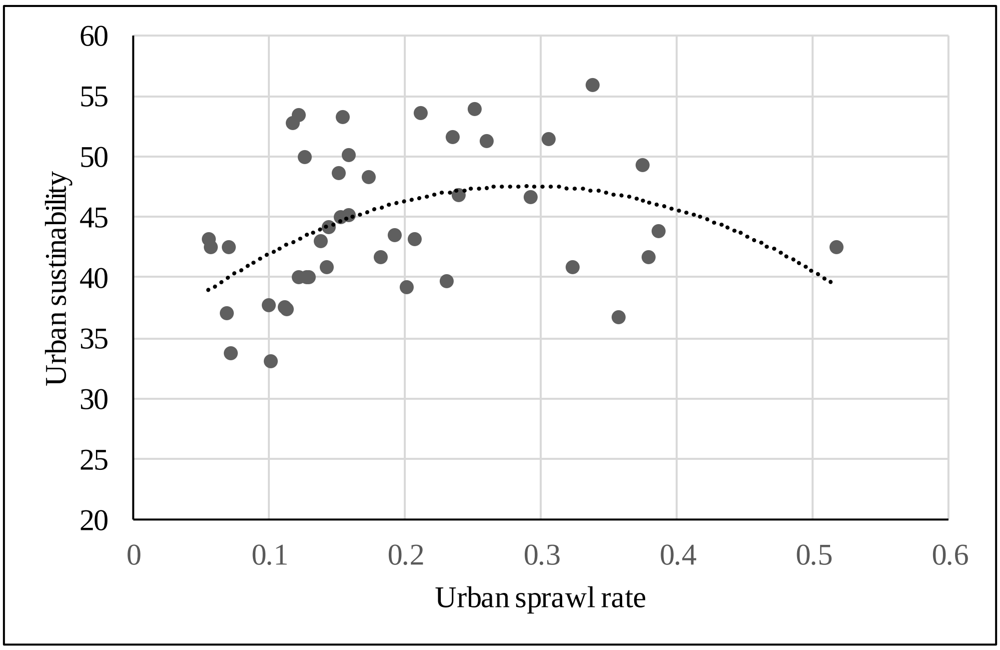
Source: Author

Figure 5-2 shows the relationship between urban sprawl and urban sustainability. Here, I utilize the ratio between land concentration (the proportion of built-up area to total urban area) and population concentration:

Urban sprawl= Land concentration/ Population concentration (5-2)

As shown in Figure 5-2, the relationship between urban sprawl and urban sustainability also verifies an inverted-U relationship. Specifically, the majority of the selected cities at a low sprawl level, meaning that the development of land is lower than the concentration of population. With the increase of sprawl level, the urban sustainability increases; however, when urban sprawl continues, urban sustainability begins to decrease. From the figure, it can be seen that the urban sustainability starts to decrease when urban sprawl level surpasses 0.25.

Figure 5- 2 The relationship between urban sprawl and urban sustainability



Source: Author

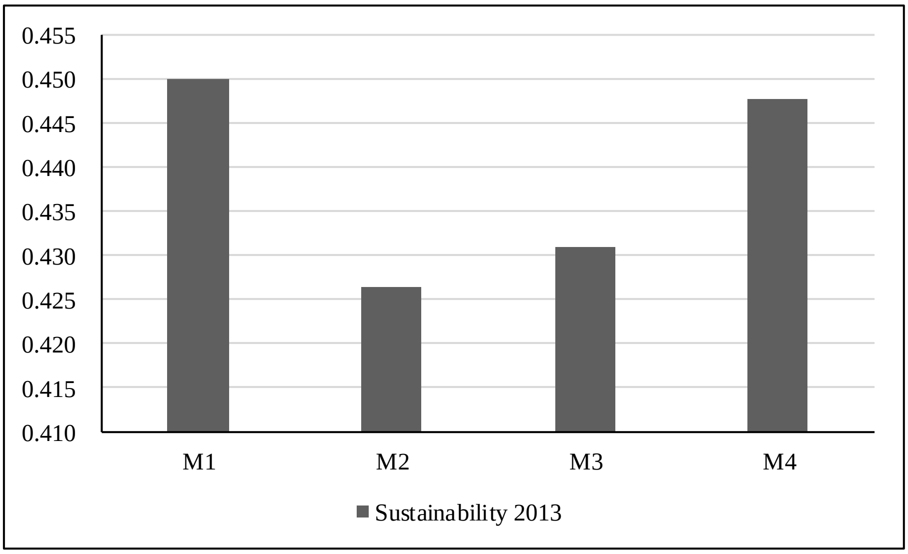
In terms of specific indicators of urban compactness, a balanced development among all aspects is more desirable. The cities with higher population density always reflect a higher level of built-up area development, such as in Shenzhen, Guangzhou and Shanghai. However, the residential density of these areas is not high due to the development urban built-up areas. These cities show a high level of economic and social development and high level of sustainable development driven by economic growth. In addition, some of the cities are at a low level of sprawl and population density, such as Baotou and Tangshan. In these cities population is highly condensed in built-up areas, which results in a low level of urban sustainability. Moreover, public transport can help increase urban sustainability, but in some low-density cities such as Baotou, the high level of public transport may result in a low use ratio. In the respect to mixed use, some of the cities are at a high level of mixed use but low level of public transport. In these cities, the high mixed use of land cannot increase urban sustainability due to high dependence on automobiles.

5.2.2 Urban morphologies and urban sustainability

Figure 5-3 shows the sustainability development of the sample cities of each morphology. Since urban morphology five is a special urban form that is limited by the landform and natural resources, in this chapter only four morphologies are compared. Among all urban morphologies, morphology one and morphology two perform the best in urban sustainability level, while urban morphology two performs the worst among all morphologies. Figure 5-4 illustrates the relationship between urban morphologies and the urban environmental state. According to Figure 5-4, urban morphology four performs best among all cities and urban morphology two ranks at the bottom of all morphologies. Figure 5-5 explains the relationship between urban morphologies and the social state. Based on

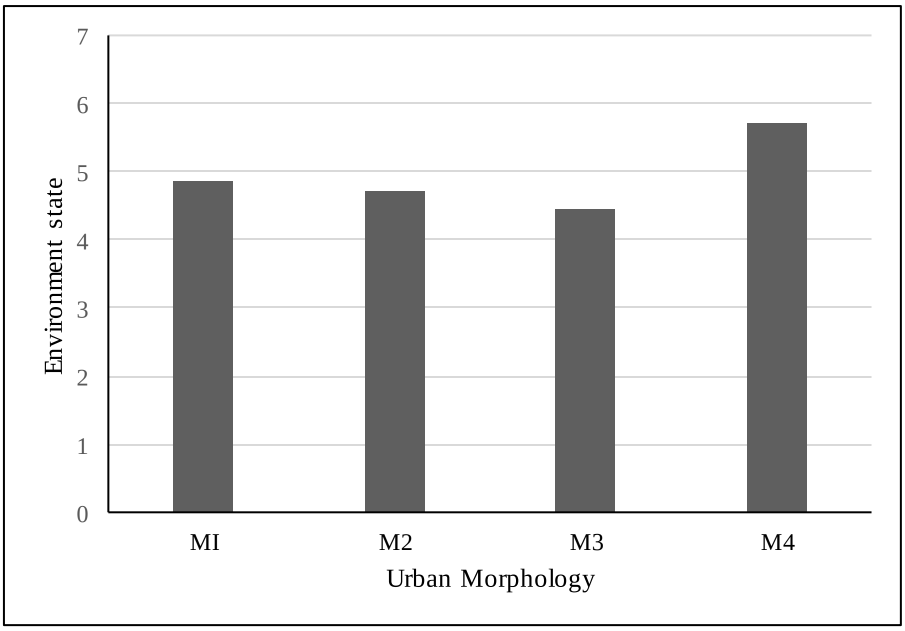
Figure 5-5, urban morphology three performs the best due to high availability of education and doctors as a result of the high compactness of central urban areas.

Figure 5- 3 Urban morphologies and urban sustainability



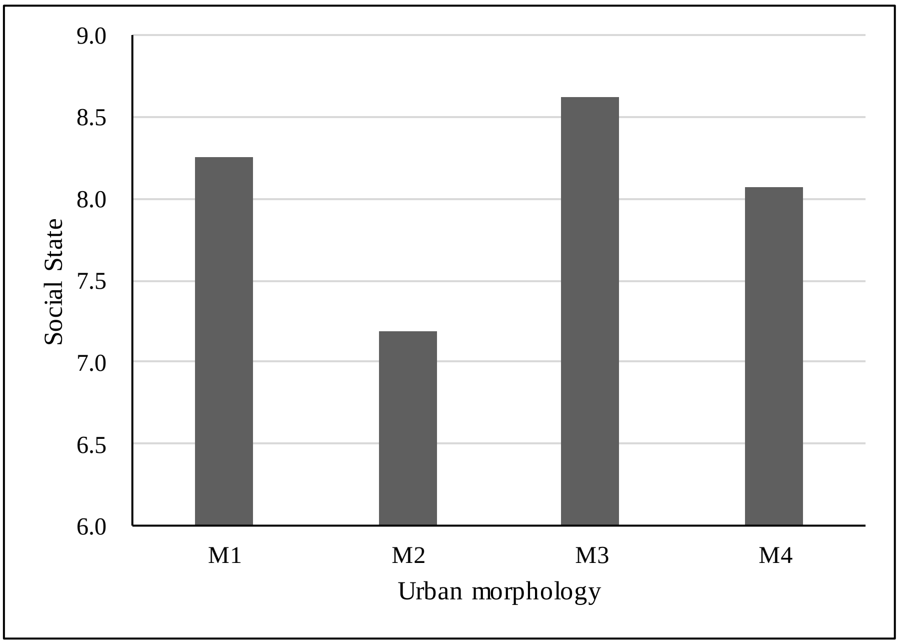
Source: Author

Figure 5- 4 Urban morphologies and the environmental state



Source: Author

Figure 5- 5 Urban morphologies and social state



Source: Author

On the whole, as discussed in Chapter IV, urban morphology one includes most of the capital cities and municipalities. The overall density of these cities is high while the residential density is at a medium level. These cities reach balanced compact city development with moderate development of residential areas, medium level of mixed use of land, high development of public transportation systems, and high concentration of population in built-up areas. The majority of central and western cities belongs to urban morphology four and the development level of these cities is behind the eastern cities. However, due to the low contamination rate of these urban areas, the quality of the environment is much higher than other areas. Urban morphology two contains resource-based cities, which reflects the lowest level of urban sustainability. Low levels of mixed land use and single-use development result in a lower level of sustainability. Urban morphology three includes the cities with both low levels of urban sprawl and public transport but high levels of density. Therefore, the low development level of the public transportation system results in a high utilization rate of cars, which decreases the sustainability level of these areas.

5.3 Conclusions

This chapter discussed the relationship between urban development patterns and urban sustainable development. Frankly speaking, this research simply analyzes the sustainability of 49 Chinese cities and is limited by the sample size. The inverted-U shape relationship is not significant in statistics; therefore, the results of this chapter can only show a trend of the sustainable development level with the change of urban development patterns. However, through the analyses of representative cities of each development pattern, the findings can also make sense. The results show that there is an inverted-U shape relationship between urban compactness and urban sustainability and the relationship between urban sprawl and sustainable urban development shows the same trend as well. At low levels of urban sprawl, the population concentrates into built-up areas, which therefore results in the high compactness of urban areas. In contrast, if the cities sprawl at a high level, the compactness will necessarily decrease and therefore result in low density in the built-up areas. Based on the analysis, compared with finding the proper level of compactness or sprawl, the balanced development of each aspect of urban forms is more crucial.

In addition, different urban morphologies show different levels of sustainable development. The sustainability of urban morphology one is driven by the economic development level while the environmental state contributes significantly to the sustainable development level of urban morphology four. In terms of social development, morphology three performs best due to the high availability of doctors and education results, since both hospitals and schools are highly compact in built-up areas. Urban morphology five performs the worst in the metric of sustainable development level because of high dependence on natural resources and the monotonous industrial structure. Limited by the scarcity of natural resources and disadvantages of location

Chapter 6 Conclusions and policy implications

6.1 Review of the study

As the largest developing nation in the world, China has experienced unprecedented economic growth since 1970s. With such rapid economic development, during the 1995-2014 period, China's urbanization rate increased from 29.04% to 54.77%, with an average increase of 1.2% annually. However, this urbanization rate is still far behind the average urbanization level of developed countries, where approximately 70%-90% of people are living in urban areas (World Bank, 2015). The rural-urban transformation has become a dominant feature of socio-economic change in China, and urban areas are flooded by large numbers of rural migrants on an annual basis. However, these developments have been accompanied by a tremendous increase in resource and energy consumption, pollutant emissions, and social stratification in urban areas. Triggered by accelerated urbanization, increase in income level, promotion of living standards, and increases in private transportation, the environmental problems have attracted increasing attention from the public. According to the United Nations (2014), by 2050, approximately 80% of China's population will live in urban areas, thus the environmental and social pressures will be increased. Therefore, finding the relationship between urban development patterns and urban sustainability improvement is a crucial aspect of sustainable urban development in China. Previous studies have well documented the significance of urban development patterns and the relationship between urban forms and sustainable city development, but evidence from developing countries is scarce. Hence, this research has tried to further discuss the sustainable urban development pattern with the evidence of 49 Chinese cities using an assessment of urban forms and urban sustainability.

Accordingly, this dissertation has tried to address potential urban development policies to promote sustainable development encompassing economic, social and environmental development. To be specific, four goals were established in this research. The first was to provide a composite index for sustainable city development based on a casual-relation framework of urbanization to track the sustainable development trend of Chinese cities for decision makers to monitor urban sustainability. Secondly, it identified the principal development patterns of major Chinese cities and described the main characteristics of each urban form. Moreover, the study attempted to link the urban forms and urban sustainability to provide empirical evidence of the significant role of urban design in realizing sustainable city development. Finally, this research has tried to stress the importance of cooperation among government, institutions and the public in achieving a sustainable urban future.

The dissertation was organized into two parts. The first part consisted of one chapter that conducted an indicator approach to learn the sustainable development condition of Chinese cities. Generally, economic development is the driving force of sustainable development; however, the high speed of economic development is based on the increasing pressures on the environment and the deteriorating environmental state. Therefore, high dependence on resources and industry will challenge the long-term development of cities. The majority of the eastern cities enjoyed earlier economic opening and kept a rapid rate of economic development for the past 30 years, while some of the eastern cities are facing the challenge of scarcity of resources, such as the cities of Hebei and North-East China. These cities are praised as the “eldest sons of the republic”, with a huge contribution to the development of the new China. However, currently these cities are suffering from the problems of unsuccessful industrial transformation, resource scarcity, and serious environmental problems.

The second part consisted of two chapters. This part addressed the main development pattern of Chinese cities and found the relationship between sustainable urbanization and urban forms. In brief, an Inverted-U shape relationship between urban compactness and urban sustainability was found. To be specific, as urban compactness increases urban sustainability will increase to a certain level, but with the continued increase of urban compactness the sustainability level decreases. Currently, the urban compactness of Chinese cities is already high. In face of the future 100 million urbanized population, the urban population will keep rising, and this will result in more rapid urban sprawl, especially in western cities. The cities will be more and more crowded and environmental pollution, social inequality, and security problems will be deepened. Therefore, the living environment will necessarily decline as a result of overcrowding.

This chapter is organized as follows. First, I will elaborate on the main findings of this research. In addition, the policy implications will be listed according to the findings. Moreover, the limitation of this study is explained. Finally, paths for future study are recommended in the last part.

6.2 Main findings

6.2.1 Chapter III: monitoring the sustainability of Chinese cities

This chapter clarified the sustainable development of 49 important Chinese cities utilizing an indicator approach on the basis of the casual relation framework called Driving forces- Pressures- State- Impacts- Response (DPSIR). A composite index of urban sustainability was then calculated based on the entropy method.

6.2.1.1 The four development trends of urban sustainability

Two kinds of indexes calculated urban sustainability and sustainability improvement, and based on this the cities were divided into four groups. The majority of inland and resource-based cities were classified at a low sustainability level and sustainability growth. For the inland cities, sustainable development is limited by the economic development level, while for the resource-based cities sustainability is restricted by serious environmental degradation as a result of over exploitation of natural resources. The coastal cities show a level of high sustainability but with a slow growth rate of sustainability. These cities benefit profoundly from the early opening up, therefore economic growth and social development are the engines of sustainable development. However, the increasing environmental and social pressures as a result of population agglomeration limited the future sustainable development of these areas. With the support of the local government, some cities with low sustainability levels show a trend of rapid sustainable development, and four cities (Guangzhou, Zhuhai, Hangzhou, and Ningbo) have both high levels of sustainability and sustainable growth.

6.2.1.2 Weak sustainable development in China

The urban development of Chinese cities is still weak sustainable development that is highly reliant on resources and heavy industry. Even though many of the coastal cities show a high level of sustainability, it is at the expense of the unsustainable development of other cities. Therefore, the western cities should not follow the traditional development mode of eastern cities, and realizing a strong sustainable development is still one of the difficult tasks in China. Sustainable development indicators are necessary for policy makers to trace the whole influence of human activities on the environment and ecosystem. More responses are required, including technology innovation, environmentally friendly resource exploration, and investment in technology and environmental protection. Finally, it is also important to enhance the cooperation among local governments, NGOs, and research institutions to share advanced technology, successful experiences and research achievements to reduce the unbalanced development among regions.

6.2.2 Chapter IV: Exploring the urban development patterns of Chinese cities

In this chapter, five indicators were selected based on the definitions and characteristics of urban forms. To be specific, the five indicators are public transportation, density, green area, concentration and mixed-use of lands, representing the different aspects of urban morphology, and based on these the cities were clustered into five groups through the SOM clustering method.

Specifically, urban morphology one represents cities with developed public transportation systems, high concentrations of population and high levels of mixed use. Many capital cities are typical of this group, with high levels of economic and social development, good quality of infrastructure, and rapid residential area development inside cities. Urban morphology two is characterized as having a low level of mixed use land. In this group, the majority of the cities are resource-based cities and tourism cities, therefore the urban construction and development of these cities depends on the distribution of natural resources. As a result, the industry of these cities are monotonous. Urban morphology three are those cities with high density in the central urban areas while the sub urban areas are sprawling in a rapid speed. The concentration of these areas is lower than urban morphology one and two meaning that in the future increasing non-urban lands will be transformed into urban areas in the near future. Finally, urban morphology four and five explain the typical characteristics of medium central and western cities. In these areas, pursuing rapid economic development is the driving force of urban contamination. The development of these urban areas is still at the primary stage and in the face of large amount of future urban population according to the 13th five-year plan, the high rate of urban sprawling could not be avoided. Urban morphology five shows some different characteristics from urban morphology four that the scarcity of natural resources and disadvantage of location limited the speed of development of these areas.

6.2.3 Chapter VI: Examining the relationship between urban morphologies and urban sustainable development

This chapter further discusses the relationship between urban forms and urban sustainability with the evidence of 49 Chinese cities. The existed researches on urban sustainable development can be divided into two approaches: one is through finding balance among three pillars (environment, economy and society) or four pillars (environment, economy, society and institution) and the other is through exploring sustainable urban design. The discussion of sustainable urban design has been well documented with the evidence of developed countries, while in developing countries this topic is just developed in recent decades. In addition, majority of the discussions on sustainable urban design focuses on qualitative analysis while quantitative analysis on this topic is few. Therefore, this chapter tries to analysis the relationship between urban forms and urban sustainability to find whether different urban design can influence the sustainable city development in China based on Chapter IV and Chapter V.

On the whole, the relationship between urban sustainability and urban compactness illustrates an inverted-U shape that with the promotion of urban compactness the sustainability will be promoted however when the urban compactness increases to a certain level the sustainability will shows a trend of decrease. The relationship between urban sustainability and urban sprawl rate tells the same story. Limited by the sample size, the relationship between urban forms and urban sustainability are not significant in statistical meaning however the results of the development trends of urban sustainability can make sense to some extent for policy makers.

To be specific, different urban forms of Chinese cities do reflect different levels of urban sustainability. Economic development is not the driving forces of sustainable development but also the development of urban areas. For the municipalities and capital cities, the infrastructure and public transportation system has been already highly developed

6.3 Policy recommendations

The analysis has concluded that high rate of economic development cannot guarantee sustainable development, and blindly pursuing GDP growth may result in a decrease in sustainability. In addition, urbanization helps a large number of people get out of poverty and improve their living standards; however, the disorderly development of urban areas and urban populations will lead to serious environmental problems which threaten the health of city residents. However, the results have shown that Chinese cities has huge potential to improve sustainability trough targeted policies and urban design.

6.3.1 Chinese cities should balance the development of economics, society, environment and institution.

As illustrated above, the development of Chinese cities are weak sustainable development that sacrificing the environment and natural resources to realize high rate of economic growth. Based on an in-depth study of DPSIR, the cities with balanced development on three pillars, economy, society and environment, will promise a better future.

- In line with Twelfth Five-Year Plan and Thirteenth Five-Year Plan, Chinese cities should transform from blindly pursuing economic growth and urbanization to environmentally friendly urban development.
- In addition, currently the focus of sustainable development in China is always related to environmental aspects but ignoring social development. Social development should be given equal importance as economic development and environmental protection in realizing urban sustainability. The policy maker should guarantee the rights of equality such as education equality, gender equality and health equality.
- In addition, the cooperation between the government, urban designers, and research institutions is important in realizing sustainable development.

6.3.2 Chinese cities should enhance sustainable lifestyles.

For all Chinese cities, to realize a new type of urbanization and green development, sustainable lifestyles, in particular in central urban areas, should be one of the major strategies for realizing low-carbon and sustainable development during rapid urbanization with a high rate of economic development.

- It can be predicted that the rapid growth in private ownership is unavoidable. Therefore, policy makers should take actions to encourage low-emission and renewable energy vehicles through subsidies or other methods. Moreover, a moderate congestion tax and traffic restriction policy can be implemented in cities that suffer serious congestion problems due to high levels of vehicle ownership.

- In addition, modifying transport activities is also important to reduce energy consumption, for example by reducing travel distances and frequency. Urban designers should make efforts to build walkable cities that rely on convenient public transportation networks and mixed-use land.

6.3.3 Targeted policies should be formulated for different development level of cities.

DPSIR model helps us understand the casual relationship of urban development and the results showed that the formulation of policies should be based on the actual situation of each city.

- For central and western cities, policy makers should focus on improving resource efficiency and decreasing energy intensity as well as pollutant emission intensity in pursuing high rates of economic and social development.
- For eastern cities, the local governments should continue to control population growth rate, optimize urban design, improve the proportion of green energy and circular economy and increase investment in technology innovation.

6.3.4 Sustainable urban design is needed in Chinese cities

In the area of urban design, a balanced development of density, transportation system, mixed-land use and built-up area development is needed to achieve a more sustainable urban form. Targeted policy should be formulated on the basis of the different development patterns of cities.

- For highly developed cities, redevelopment of brown land is recommended. In addition, with the help of new technology, the popularization of green buildings and cars is important.

- For resource-based and tourism cities, the increase of diversified industries should be an important priority. In addition, the over-exploitation of natural resources should be avoided.

- For the cities that are highly compact, proper development of suburban areas can be acceptable.

- Moreover, for the western cities, scientific urban design should be given priority at the beginning stage of urbanization.

6.4 The limitation of the study

This dissertation mainly has four limitations:

- First of all, in this paper, only 49 Chinese cities were selected, and most the cities are key cities with policy support from the central government. These cities do not represent the development of 661 Chinese cities, and more research needs to be done regarding remote cities and little-known cities.

- In addition, limited by the availability of data, the assessment of framework is still at the primary stage that social indicators and institution indicators are few.

- Moreover, this research only explores the relationship between composite index while the relationship between urban forms and specific indicators such as energy consumption and air pollution was not discussed.

- Moreover, the research is focusing on the Chinese cities. Without the comparison with cities of developed countries, it is hard to simply concluded that the best performance cities in China are really sustainable cities.

6.5 Possible extensions

This dissertation has provided evidence of the relationship between urban development pattern and sustainable city development with the evidence of China. As limited by data availability, future research can incorporate more social and institutional indicators such as gender equality, social equality, education equality and good governance. In addition, the DPSIR that was utilized in this dissertation is still under the scope of four pillars of sustainable development, although the DPSIR model considered the casual relationship between urbanization and environmental as well as social impacts. Therefore, new indicators should be considered that can illustrate the influence mechanism between each sector. In addition, a comparative assessment between Chinese cities and developed international cities is needed in order to explore this gap and learn from the experiences of successful cities, especially the successful experience of other Asian cities such as Tokyo, Singapore and Seoul. However, limited by the weighting methods in this research, the weight could not be copied to other areas, therefore a new weighting method that can provide unified weight to each indicator is needed to make the performance of cities in different countries comparable. Therefore, more works are needed to enrich the research of sustainable city development in the future. In the aspects of urban morphologies. First of all, more tools such as remote sensing and GIS are needed to get more accuracy data of land utilization and urban development pattern. The surveys of traffic behavior including means of transportation, travel distance, travel frequency and fuel consumption per kilometer are needed.

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