Sustainability **2015**, *7*, 3244-3268; doi:10.3390/su7033244

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Using Urban-Carrying Capacity as a Benchmark for Sustainable Urban Development: An Empirical Study of Beijing

Yigang Wei [1], Cui Huang [1,*], Patrick T. I. Lam [2], Yong Sha [3] and Yong Feng [2]

[1] School of Public Policy and Management, Tsinghua University, Beijing 100084, China; E-Mail: weiyigang@mail.tsinghua.edu.cn

[2] Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Hum, Hong Kong; E-Mails: bsplam@polyu.edu.hk (P.T.I.L.); jmarty.feng@connect.polyu.hk (Y.F.)

[3] Institute of Population Research, Nanjing University of Posts and Telecommunications, Nanjing 210023, China; E-Mail: sy@njupt.edu.cn

* Author to whom correspondence should be addressed; E-Mail: hcui@mail.tsinghua.edu.cn; Tel.: +86-10-6278-1584.

Academic Editor: Weidong Huang

Received: 15 November 2014 / Accepted: 27 February 2015 / Published: 17 March 2015

Abstract: Sustainable urban development has been receiving growing concerns from both city managers and urban residents across the world. As a yardstick of sustainability, urban carrying capacity (UCC) is an important conceptual underpinning that guides local governments in promoting sustainable urban development. However, existing studies still lack consensus not only on the theoretical aspects, but also on the methodological issues for UCC monitoring and evaluation. A knowledge gap exists, which this paper fills. This study aims to develop a practical UCC assessment framework to guide urban development towards achieving sustainability. The quantitative-based assessment framework provides a set of measurable indicators and benchmarks for city managers to conduct routine monitoring on progress toward urban sustainability, and helps identify deficient areas, which urgently need resource allocation to improve UCC. Focusing on a case study of Beijing, this study demonstrates that the framework is useful in promoting urban sustainability. This framework provides rich implications for other city prototypes in China as the nation marches into the next phase of development.

Keywords: sustainable urban development; urban carrying capacity (UCC); assessment framework; Beijing

1. Introduction

The term "urbanization" is officially defined by the United Nations as "the movement of people from rural to urban areas" at the beginning of the 21st century [1] (p. 17). Global population has been growing rapidly in recent decades, particularly in developing countries, and urbanization is recognized as the best solution to deal with the world's massive population growth [2,3]. Therefore, an inexorable trend exists, following which the world is becoming more urbanized [4,5]. Alongside the fast urbanization process, a rapidly increasing number of people are becoming urbanites, and human beings are relying more heavily on the artificial as well as natural systems of a city to live there [3,6].

With rapid urbanization across the world, many megacities have become showcases for a host of concomitant diverse urban problems. The "urban diseases" frequently besetting these cities include traffic congestion, housing shortage, lack of amenity, environmental pollution, and others, which has posed actual challenges and impediments for sustainable development. As argued by Onishi (1994) [7] and Saveriades (2000) [8], if the urban population and human activities expand infinitely and exceed the "limit of urban capacity", local urbanites would no longer perceive prosperity, but be troubled by the overall deteriorations in social-economic and ecological aspects. The immediate cause for these problems is the overdevelopment or overconcentration of population and socio-economic activities in urban areas, which has greatly exceeded the inherent UCC of cities [9–11]. The issue of excessively overladen UCC has spawned various city typologies across the world. It also bring to city managers' attention that urban indicators need to be well-maintained and their accuracy improved to attain sustainability. The necessity for UCC evaluations and improvements has drawn increasing attention at the international level.

The achievement of sustainable development has been a centrally important aim for urban planners and city managers [12]. However, city managers and planners often fail to undertake timely and appropriate assessments on the conditions of urban sustainable development, particularly in developing countries. In China, permeating official policies and plans, such as *China's 12th Five-Year Plan Report* [13], have highlighted the importance of UCC improvements in the government agenda. For progressing towards achievement of sustainable urban development, UCC merits systematic and scholarly studies.

With reference to the UCC concept, this research is aimed at developing a systematic and pragmatic UCC assessment framework. Specifically, an array of UCC measurable indicators and their associated thresholds are identified in this study. The indicators can serve as benchmarks for evaluating urban sustainability, leading through a set of scientific UCC assessment procedures to assess quantitatively the conditions of UCC, highlighting either surplus or deficiencies across various sectors. Development of a set of UCC measurable indicators and standards has become an important and practical tool for policy modeling and assessment [12]. Measures of UCC conditions in light of related sustainable standards are useful for identifying the relative importance and investment requirements for capacity improvements. This study is a response to a predecessor's call for such a practical UCC assessment framework, such as Joardar (1998) [14]. The latter developed a set of measurable indicators for UCC in India, and he appealed for future studies to identify the necessary standards to enable the application of the assessment framework in real-life cases in India. In this study, the assessment framework is used in a real-life case in Beijing to demonstrate its applicability. This framework comprises a series of generic and specific parameters and standards. It is sufficiently flexible to encompass new indicators, which facilitates application of the framework in a broad sense. Another feature of this assessment framework is that it accommodates a perspective over "dynamic time frames". Both sustainability and UCC should be viewed as "a continuing process rather than a single event" [15] (p. 1043). It means that the conditions of sustainability or UCC at one moment do not ensure the same status in various circumstances. Both of them should be continuously and iteratively monitored, measured, and improved to maximize the socioeconomic and environmental welfare. Consequently, this assessment framework begins with some basic preconditions concerning the pre-existing status. Users can input more specific data on an ongoing basis during the course of framework implementation. This framework is flexible enough to enable individual assessment of the UCC conditions over various time frames.

This research has rich academic and practical significance. The research findings provide a "nested" framework for a better understanding of the meaning, relationship, and implication of UCC. The framework is a powerful tool for planners and city managers for their rational decision-making when allocating investment and resources across different sectors to achieve urban sustainability. More importantly, if urban development can be objectively evaluated with reference to an array of widely recognized indicators and benchmarks, the policy-making process for sustainable urban planning and management will be more objective and become less affected by the whims and personal ideas of local elites.

2. An Overview of the Carrying Capacity Concept

The Carrying Capacity Concept is an evolving tool for monitoring sustainable development. The concept originates from animal ecology, based on the logistic growth curve theory by Verhulst in 1838 [16–19]. Kozlowski (1990) argued on the existence of certain thresholds, beyond which the natural environment will be irreversibly impaired [20]. According to the logistic growth model, the animal population growth can be constrained to an upper asymptote, *i.e.*, the carrying capability, because the population increase leads to negative effects during interaction among the members, which is often manifested as a high density and the associated crowding effects. Another reason for the control of population growth is the limited world energy sources. For example, the unregulated growth of given animal populations, exceeding the carrying capability, will damage their habitats, deplete available energy supply, and eventually result in a reduced population density. By contrast, if a certain animal population density is controlled by predators, keeping it below the carrying capability, the available food for that species of animal becomes more sufficient and their capability to resist environmental fluctuations increases [21] (for details, see [22]). Ecological carrying capacity forms the basis for derivative concepts, such as human carrying capacity, tourism carrying capacity, UCC, and others.

The human carrying capability, as proposed by Thomas Malthus, a demographer and political economist, can be defined as the size of population that the world can support without damaging the "natural, cultural, and social environment" and, therefore degrade future carrying capabilities [23] (p. 9). This idea was derived from the simplified assumptions that food productivity is the only constraining element of population growth [24,25]. Kozlowski (1990) and Wackernagel *et al*. (2002) also argued that there exists certain thresholds for human development beyond which the natural environment will be irreversibly impaired [20,26].

The carrying capacity of a region should not be exceeded [27]. Human carrying capacity is largely determined by the resilience of a region, *i.e.*, the capacity to absorb intervening influences without causing structural changes on the condition and functioning of the environment. Fearnside (1986) contended that, "in addition to its system orientation, modeling carrying capacity focuses attention on the reality of limits dispelling the illusion that infinite resources and agricultural potential exist" [28] (p. 155). The negative impacts of global overpopulation combined with the intense exploitation of environmental resources have altered the ability of humans to dwell within the limit of carrying capability according to its natural resource endowment.

However, UCC, as the focus of this study, has largely different meanings and implications from the aforementioned ecological and human carrying capacities because the concept of UCC should fully address the complex urban setting. The conceptual elusiveness of UCC is mainly underlined by the integrative attributes associated with urban planning and management. To address the conceptual elusiveness, existing studies have attempted to define explicitly the meaning of UCC and its determining components. For example, urban planners vaguely define UCC as the ability of an urban area to accommodate the population growth or physical development without causing substantial damages or apparent degradation [29]. By adopting a social perspective, the Seoul Development Institute (1999) define UCC as the maximum economic scale that a region's natural base can support [30]. By focusing on the physical aspects, Liu (2012) simplified the concept of UCC into four determining factors, namely, land, water, transportation, and environment [31]. Oh *et al.* (2005) define UCC as "the level of human activities, population growth, land use, and physical development, which can be sustained by the urban environment without causing serious degradation and irreversible damage" [6] (p. 3). They enumerated seven primary determinative factors of UCC components, which include energy, roads, water supply, sewage treatment, waste treatment, and subway systems. It is evident that the current definitions remain incomplete and unsound, since they are mainly focused on the environmental and man-made physical factors, leaving other soft factors out of scope.

3. Literature Review

The concept of urban carrying capacity is subject to hot debate but lacks scientific investigation. Currently, most relevant literature is dedicated to human or ecological carrying capacity. UCC studies, focusing on the urban setting, is a largely different research theme because of the different emphasis, meanings, principles, and implications. For example, UCC investigates the urban system, considering not only the natural elements but also the man-made attributes, such as economic, cultural, infrastructural aspects, *etc*. There is still a paucity of studies focusing on the important theme of UCC, and existing studies frequently raise questions of fragmented and incomplete understanding, a lack of credible assessment methods, and limited applications. For example, Onishi (1994) analyzed the carrying capacity conditions of Tokyo inner city [7]. The empirical study is mainly conducted by comparing the supply-demand relationship of physical man-made resources, such as road, water, sewerage, waste disposal, *etc*. The research findings reveal the areas of infrastructure that needs improvements as a matter of priority. Joardar (1998) developed a conceptual model for UCC evaluations in India [14]. An array of UCC indicators is established, through which carrying capacity conditions in terms of infrastructural and financial aspects can be measured in either quantitative or qualitative terms. As suggested by the author, the research provides an important basis for future studies to develop a set of minimum standards to facilitate UCC measures in actual cases. However, this conceptual framework lacks applicability in real-life cases. Another limitation is that the model mainly focuses on a small number of infrastructural and financial indicators, neglecting other important dimensions. Oh *et al*. (2005) developed an UCC evaluation framework to determine population density mainly based on infrastructure and land use [6]. This study integrates seven determining factors for evaluation, including energy, green areas, roads, subway systems, water supply, sewage treatment, and waste treatment. The use of Geographic Information System (GIS) technique enables measures on UCC conditions in spatial setting to be taken. However, due to data limitation, this study fails to include the economic, institutional, public perceptional dimensions into UCC evaluations. Based on the concept of supply-demand balance, Liu (2012) developed an UCC evaluation model to assess the UCC conditions of 16 cities in China's Yangtze River Delta [31]. The 12 measurable indicators focus on the physical factors, such as land, water, transportation, environment. As stated by the author [31] (p. 469), "it doesn't take the soft factors of science, technology, culture and humanity into account". It is evident that existing UCC models are confined to physical variables, which seems incomplete and fragmented. To fill the gap, this study enables a holistic integration of essential UCC indicators into UCC evaluations and city management.

The strength of UCC is that it can be recognized as a "sustainable threshold" to measure the state and condition of urban sustainability [10,32]. If population and human activities exceed the threshold limit of carrying capacity, adverse impacts would occur and deteriorate, undermining the integrity, function, and resilience of a specified urban region [25,27]. UCC serves as a gauge to determine the optimal population size and activity scale [6]. The weakness of UCC is also obvious. Despite plenty of discussions and explanations, UCC still lacks a widely accepted definition and standardized assessment method [10,33], which hampers its effective use in urban planning and management. Current UCC assessments mainly focus on single factor analysis and little progress has been achieved on a comprehensive UCC study. In addition, spatial analysis and dynamic comparisons have rarely been applied [31]. A wider application of the UCC concept requires these limitations to be addressed.

4. The Definition and Components of UCC

Given these initial efforts, several scholars argue that UCC concepts lack well-rounded and adequate definitions [10,33,34]. Zhu *et al*. (2010) argue that non-harmonious and imbalanced relations among resources, ecology, population growth, and socio-economic activities may significantly hamper sustainable development [35]. UCC is not only related to the study of ecology or physical infrastructure, but also comprises analysis on economic, social, environmental, and institutional aspects and other science [31,36].

In this study, UCC refers to the limit of population growth, urban physical development, and socio-economic activities that can be perpetually supported by the urban supporting systems and they will not incur apparent degradation and irrevocable damage. Key indicators that determine the UCC of an urban area are grouped into five main UCC components, *i.e.*, environmental impacts and natural resources; infrastructure and urban services, public perception; institution setting; and society supporting capacity by Wei *et al*. (2015) [37] (See Table 1). These five UCC components appropriately cover and subdivide the key determinative parts of UCC and urban sustainability, *i.e.*, the natural elements and man-made system [37]. They generally subsume the primary demands and development goals of various stakeholders of any given city. There are direct interactions and feedback between various components. For example, economic growth often generates negative impacts on ecological environment, whilst economic growth also ensures fiscal capacity for environment conservations. Therefore, it is important to adopt a dialectical view to understand their interrelationships, since both the negative and positive effects are often present.

Table 1. Determinative components of UCC.

Components	**Meaning and Definition**
Environmental impacts and natural resources	It refers to the size of population and human activity of a region, where waste and pollution can be adequately assimilated and sufficient resources can be provided by the environment without scarifying urban residents' living quality and the environment's endurance. This concept consists of two key components, namely, assimilative capacity and resources production capacity of the environment.
Infrastructure and urban services	It refers to the size of human activity that the infrastructure and urban services of a specified area can satisfactorily sustain without incurring living quality degradation. The efficiency and intensity of infrastructure and urban services should be accurately assessed, such as healthcare, housing, amenity, transport, pipeline, *etc*.
Public perception	It refers to the degree of visual or psychological changes that can be perceived by the public with apparent betterments than previously observed.
Institution setting	It refers to the political, regulatory, administrative, and sociological conditions of a city toward achieving its goal of sustainable development. Social equity, governance transparency, and cultural diversity are the primary components of institutional setting.
Society supporting capacity	It refers to the economic, technological, and fiscal capacity of a city to proactively promote carrying capacity. It is the most manageable and proactive parameter for UCC building. The associated indicators can be roughly represented by fiscal income of the local government, GDP, employment rates, portion of investment on environment protection to GDP, *etc*.

Adopted from [37].

5. The Urban Carrying Capacity Assessment Framework

5.1. Study Area

A case study of Beijing, which has a significant socio-economic importance in China and faces tremendous pressures on urban sustainable development, is presented in the following to validate the application of the framework. Beijing is China's capital city and the political, economic, and cultural center of China. Beijing consists of 16 administrative subdivisions (see Figure 1). After 30 years of rapid development since the opening-up initiated in 1979, Beijing has become one of the largest cities in the world, with an area of 16,410.54 km^2, a GDP of RMB 178,794 billion, and a residential population of 20.693 million by 2012. According to "2013 Beijing Domestic Economic and Social Development Consensus" [38], Beijing has attained many remarkable economic and social achievements. For example, GDP per capita reached USD 13,857/person in 2012; the tertiary industry contributed 76.5% of total GDP; and the total length of subways reached 442 kilometers.

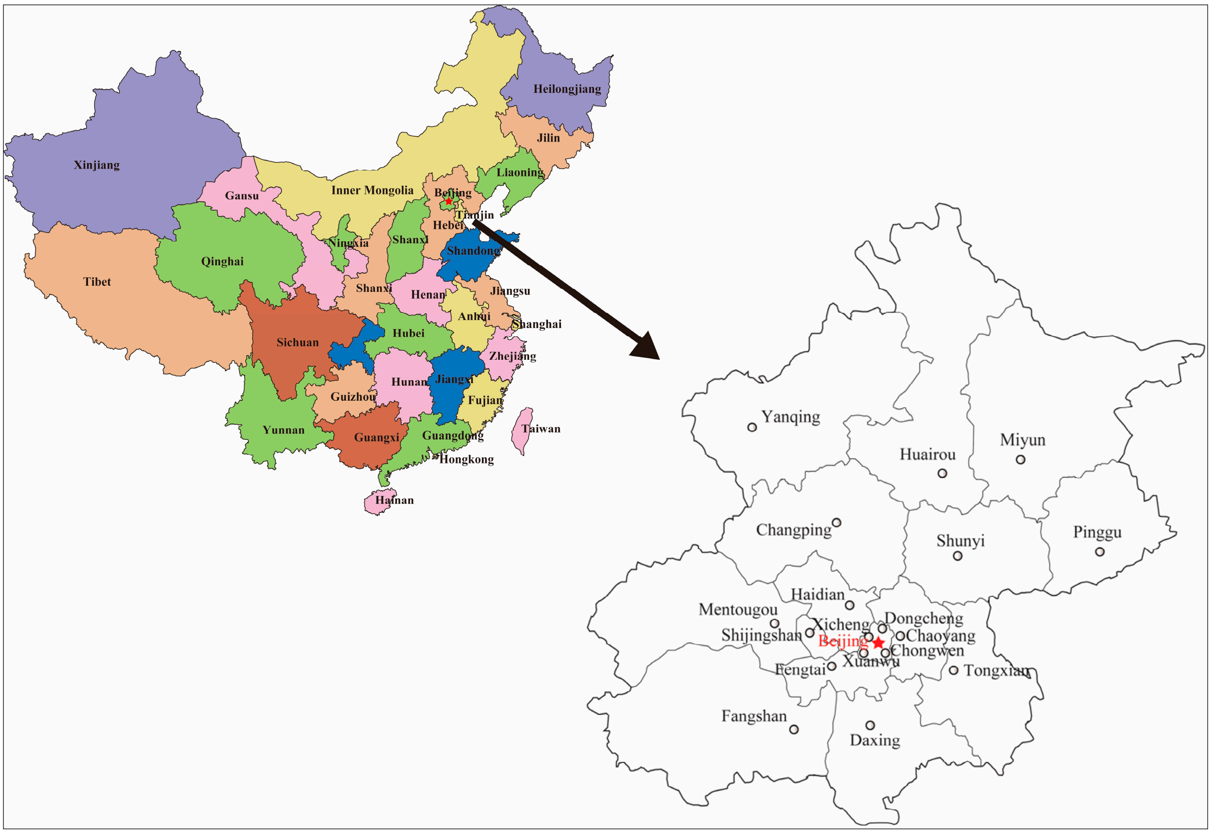

Figure 1. Location of the investigated area.

The rapid development of Beijing has led to a number of "city diseases", such as traffic congestion, ambient air pollution, meager provisions of public facility, and others. Average inhabitants are afflicted with these urban problems, which significantly degrade their life quality and the competitiveness of Beijing. The Beijing government has recognized these issues and has been actively searching solutions for UCC improvements. This study depicts the current UCC conditions of Beijing. The latest data used in this study is compiled from several sources, including China Statistical Yearbook 2013 [39], China Statistical Yearbook for Regional Economy 2013 [40], China Urban Construction Statistical Yearbook 2013 [41], and Beijing Statistical Yearbook 2013 [42].

5.2. Research Method

To develop the UCC assessment framework, Figure 2 describes the procedures for determining the extent of sustainability of urban development. This framework establishment process generally consists of two steps and is conceptually straightforward. Based on the selection principles, the first step is to determine the UCC indicators and their associated thresholds through literature review. This step is followed by organizing the indicators into appropriate subcategories. The next step is to enable comparisons between indicators and their related thresholds, which lead to credible measures on the UCC conditions of the investigated areas.

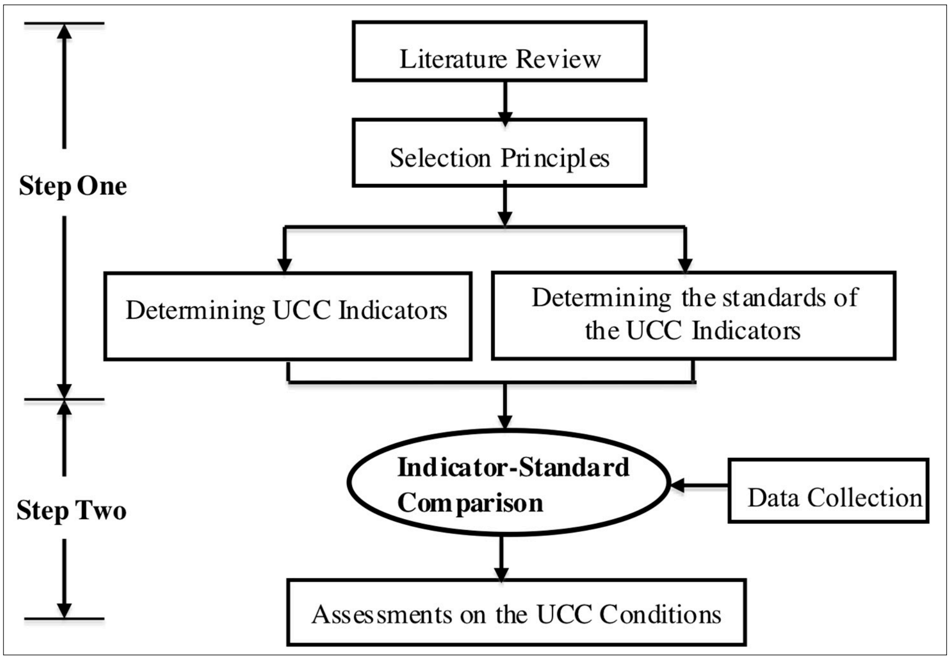

Figure 2. The flowchart of the UCC assessment process.

5.3. Indicator Selection

Through an extensive literature review, several key principles for the appropriate selection of UCC indicators are summarized in Table 2. It serves as the rules for indicator selection. For example, one important principle is that the inclusion of more indicators does not necessarily lead to a higher quality assessment [37,43]. Conversely, it may lead to repetitive information, which causes confusion and ambiguous signals to policymakers [18,27,44]. With a thorough understanding on UCC, Table 3 is a compilation of the main areas and factors for UCC assessments that UCC indicators should reflect. Indicators regarding perceptual and institutional factors are limited in this research due to difficulties in acquiring data. Because most of these factors involve common sense, attitudes, and behaviors of the public, data should be obtained by means of a social survey [45]. The goal of urban sustainability is to promote a stronger synthesis of environmental, economic, and social components [46]. Therefore, this study treats each UCC indicator as equally important. Practical measures can be taken to improve the overall capacities of the indicators.

Table 2. Criteria for indicator selection.

	Criteria
a.	"Scientific accuracy, operability, hierarchy, completeness, and dynamic" [18] (p. 181).
b.	Rich implications to the state of present conditions and link ultimate impacts with human activities [44].
c.	Providing policy implications with a forecasting function as to trend and proactive measures [44].
d.	Providing a testing ground for validating related theories with underlying factors.
e.	A small and manageable set of indicators is desirable for an effective assessment framework [18,27,44].
f.	A high degree of sensitivity to the underlying conditions where they exist [44].
g.	Easy to quantify and reliably measurable [32].
h.	Uniformity and consistency of indicators across cities [44].
i.	Good data availability [6,11,27].

Table 3. Evaluative areas and factors for UCC.

Components	Evaluation Areas and Factors	Ref.
Environmental impacts and natural resources	• Green areas: (a) Coverage of city green areas (b) Per capita public green areas	[1,2,4,6,31,37]
	• Water resources	[1,4,6,7,14,31,47]
	• Land resources: (a) Per capita urban land (b) Constructive Land per capita (c) Plowland areas	[1,2,6,31,36,46,47]
	• Biodiversity	[1,6,14,26,46]
	• Ambient air quality: (a) Air quality index (b) Air pollutants concentration	[1,6,7,46,47]
	• Energy resources and consumption: (a) Energy use intensity	[6,14,36,46,47]
	• Waste treatment and waste recycle system: (a) The disposal and recycling rate of Solid waste (b) The disposal and recycling rate of Sewage (c) Noise compliance area coverage rate	[1,6,7,13,14,46]
Infrastructure and urban services	• Basic municipal facilities such as water, electricity, and gas supply and communication links: (a) Length of water pipe, gas pipeline, drainage and cable (b) Access rate for the public (c) Breakdown frequency	[1,6,7,46,48]
	• Cultural and recreational facilities: (a) Number of public library/museum/park per capita (b) Coverage rate of these recreational facilities that households can get accessed within walking distance	[1,46,48]
	• Sports facilities	[46,48]
	• The local government educational facilities	[1,46,48]
	• Housing conditions: (a) Housing construction quality (b) Floor space per capita	[1,7,47]
	• Healthcare facilities: (a) Population life expectancy (b) Number of ward bed/medical personal per capita (c) Community health service coverage rate	[1,7,12,37]
	• Public traffic: (a) Length and area of roads per capita (b) Public transportation ridership rate (c) Average commuting time (d) Social parking rate	[1,6,7,31,46]

Table 3. *Cont.*

Components	Evaluation Areas and Factors	Ref.
Institutional carrying capacity	• The disparity between the rich and the poor: (a) Gini Coefficient	[1,46,48]
	• Affordable housing: (a) The housing price-to-income ratio (RIP) (b) The rate of median rent to household income for public housing (c) The rate of households with an average housing area of 10 m^2 per capita (d) The percentage of ordinary commodity housing, low-rent housing, and economically affordable housing to the total housing stock	[7,46,48]
	• Public order: (a) Low criminal rate (b) Detection rate of criminal cases	[1,46,48]
	• The food and drug safety: (a) Pass rate of spot check for key food safety monitoring (b) Pass rate of Drug spot check	[48]
	• Social security system: (a) The coverage rate of social security (b) The low-income fatalities and special social class including the elderly and the disabled can get access to living subsidies by government.	[1,46,48]
	• Cultural diversity: (a) Number of cultural events (b) Number of historical and cultural sites.	[1,37]
	• The involvement of all urban stakeholders, such as the public and private sector and NGO, in policy decision-making.	[1,37,48]
	• The provision of conflict coordination system	[48]
	• Policy communication and information disclosure to the public	[48]
Society supporting capacity	• Economic growth: (a) GDP (b) GDP Per Capita (c) End consumption rate	[1,7,18,23,32,46,48]
	• Household disposable income growth rate	[1,18,46,48]
	• Financing capacity of the local government to complete scheduled plans and projects: (a) Government expenditure on health, education, environment protection.	[1,37,46,48]
	• The public fiscal income: (a) Fiscal income growth rate (b) Fiscal surplus	[1,37,46]
	• Technical capacity of the local government to complete scheduled plans and projects.	[12,18,37,48]

Table 3. *Cont.*

Components	Evaluation Areas and Factors	Ref.
Society supporting capacity	• Employment conditions: (a) Employment rate (b) Registered unemployment rate	[7,46,48]
	• Economic structure: (a) Outputs of service industry as % of GDP (b) R&D expenditures as % of GDP (c) The percentage of employment in tertiary industries to total employment population	[1,18,46,48]
	• Consumption and living costs for average households: (a) Engle coefficient	[1,18,48]

5.4. Benchmarks for Assessing UCC Indicators

A set of benchmarks, norms, and standards is necessary for either qualitative or quantitative assessments of UCC conditions [49]. The next step is to determine the benchmarks for assessments on the evaluative indicators. Thus, determining the benchmarks is a key procedure to enable the monitoring, measurement, and adjustment of UCC by matching urban development objectives and available resource distributions. The selection of benchmarks seems subjective and largely affects the presentation and accuracy of estimating results [50]. The recommended/acceptable/optimal thresholds for UCC vary greatly across different countries [14]. With a special focus on the cities in China, a set of thresholds in "livable, conformable, or sustainable" levels is compiled through an extensive review on government documents and previous literature. The current research prefers per capita norms over aggregate ones because human activity outputs are closely linked with the population size [14]. The use of per capita dimension will avoid data contamination by different city scales. The standards used in this study are carefully collected through an extensive policy checking and literature review. There are three sources for identifying the standards. The first is *The 12th Five-Year Plan of Beijing* [51]. Acting as a blueprint for Beijing's development, it officially proclaims the goals, strategies, overall emphasis and development paths for 2010–2015. The formulation process involves an open and procedural process for public decision-making. A series of consultations and narrations among various entities was conducted, including the local authority, departmental offices, urban residents, authoritative third parties, experts, *etc*. It leads to a consensus of the society for overall development goals and a coordinated plan. The second is "The Study on the Indicator Systems of Livable City Scientific Evaluation" [52]. This research was conducted by the Chinese Society for Urban Studies (CSUS), a well-known NGO in the field of urban planning and management [52]. The research provides an evaluation system for measuring livable city development in China, consisting of a set of indicators and standards. The research is approved by the Ministry of Construction (MOC) in 2007, and MOC encourages the wide application of this indicator system for livable city development in China. The third is through reviews on academic studies, which involve the benchmarks applicable for China's cities. Therefore, through these three sources, the joint concerns and cooperation between government, NGO, and academia are systematically addressed in the benchmarks. To avoid the potential different thresholds among stakeholder groups, this study makes it a priority for adopting the thresholds from *The 12th Five-Year Plan of Beijing* [51] due to its authority. The rest thresholds are compiled primarily from the NGO report, which balances the practical feasibility, and then from academic papers which mainly address scientific rigor.

6. Evaluation Analysis and Policy Recommendation

The framework consists of 54 indicators and associated thresholds, including generic and topic-specific parameters and standards (Table 4). In the table, the sources of benchmarks are presented in the column entitled as "Ref."; the data source of each indicator is included in the "Result" column; the estimating results are presented in the "Result" column, within which "No" shows the indicators overrunning the UCC limit and needing urgent improvements. Due to a lack of suitable statistics, only some important indicators and their thresholds marked by (i) are presented in Table 4. The data is mainly based on experience and site inspection. However, these parameters, accompanied by ongoing improvement of data quality in China, are indispensable and useful for future studies. Perceptual dimension is out of the scope of this research, due to the absence of related data for quantifying the assessment. The indicators and associated standards can be classified into four evaluative dimensions, namely, environmental impacts and natural resources, infrastructure and urban services, institutional setting, and society supporting capacity. In general, the evaluative target for each analytic dimension is sustainable environment and resource utilization, adequate and well-maintained infrastructure and urban service, institutional viability, and economic affluence, respectively. The evaluation results in Table 4 are elaborated and discussed below. Treatment measures are also recommended.

Table 4. Evaluation of Beijing's UCC.

	Indicators	Thresholds	Ref.	Results
Environmental impacts and natural resources	Coverage of city green areas (%)	≥35%	a	Yes, 46.2% (c)
	Coverage of city forest (%)	≥57% (obligatory target)	b	No, 55.5% (c)
	Plowland areas (km^2)	≥2205 km^2 (obligatory target)	b	Yes, 2316.88 (c)
	Constructive Land per capita (m^2)	• ≥80 m^2 for large cities • ≥100 m^2 for small-medium cities	b	No, 163 (c)
	Per capita water resources (m^3)	• ≥1000 m^3/person • ≤500 m^3/person is severe deficiency	a	No, 193 (c)
	Per capita urban land (km^2)	• ≤80 m^2 for large cities • ≤100 m^2 for small-medium cities	a	No, 163 (c)
	The ratio of reusable water reused (%)	≥75% obligatory target	b	No, 49.34% (c)
	The recycling rate of industrial water (%)	=100%	a	No, (i)
	The ratio of days with air quality better than or equal to Grade-2 standard per year (%)	≥80%	b	No, 78.4% (c)
	Decrease of energy consumption per 10,000 RMB GDP	≥17% (obligatory target)	b	No, 4.75% (c)
	Decrease of water consumption per 10,000 RMB GDP	≥15% (obligatory target)	b	No, 7.38% (c)
	Urban industrial wastewater treatment rate (%)	=100%	a	No, 83% (c)

Table 4. *Cont.*

	Indicators	Thresholds	Ref.	Results
Environmental impacts and natural resources	Rate of harmless disposal of domestic garbage (%)	=100%	a	No, 99.1% (c)
	Noise compliance area coverage rate (%)	=100%	a	No, (i)
	The utilization rate of industrial solid waste disposal (%)	=100%	a	No, (i)
	Per capita public green area (m^2)	≥10 m^2	a	Yes, 15.5 (c)
Infrastructure and urban services	Urban gas connection rate (%)	=100%	a	No, (i)
	Access rate of Cable TV (%)	=100%	a	No, (i)
	Internet cable connection rate (%)	=100%	a	No, 572/10,000 subscribers (c)
	The normal supply of tap water (days/year)	=365 days/year	a	Yes, (i)
	The number of libraries per 10 thousand people	≥0.3	a	No, 0.012 (c)
	The number of museum per 10 thousand people	≥0.3	a	No, 0.0096 (c)
	The coverage rate of free open sports facilities within 1000 meters of residential areas (%)	=100%	a	No, (i)
	Public satisfaction rates for sports, education and culture facilities (%)	=100%	a	No, (i)
	Per Capita floor space of houses in urban areas (m^2)	≥26 m^2	a	Yes, 29.26 (c)
	Number of hospital bed per thousand persons (%)	≥90	j	No, 4.48 (c)
	The community health service coverage rate (%)	=100%	a	No, (i)
	Population life expectancy (%)	≥75 years old	a	Yes, 80.2 (c)
	Public satisfaction of urban traffic (%)	=100%	a	No, (i)
	Per capita road areas (m^2)	≥15 m^2	a	No, 4.46 (c)
	Public transportation ridership rate (%)	≥35% for large and medium-sized cities	a	Yes, 44%, (j)
	Resident's average commuting time (One-way) (%)	≤30 minutes	a	No, (i)
	Social parking rate (%)	• ≤150% for large cities; • ≤100% for small-medium cities (a higher rate indicates a higher utilization rate of the parking place).	a	No, (i)
Institution setting	Gini coefficient	0.3–0.4	a	No, 0.72 in 2010 (d)
	The housing price-to-income ratio (RIP) (%)	≤6	g	No, 12.08 (h)
	The rate of households with an average housing area of 10 m^2 per capita (%)	=0%	a	No, (i)
	The rate of ordinary commodity housing, low-rent housing, and economically affordable housing to the total housing stock (%)	≥70%	a	No, (i)
	Detection rate of criminal cases (%)	=100%	a	No, 69.8% (d)
	Pass rate of spot check for key food safety monitoring (%)	≥98% (obligatory target)	b	No, 95.29% (c)
	Pass rate of Drug spot check (%)	≥98% (obligatory target)	b	No, 99.71% (c)
	Social security coverage (%)	=100% (This study uses the coverage of New Cooperative Medical System to approximate)	a	No, 98% (e)

Table 4. *Cont.*

	Indicators	**Thresholds**	**Ref.**	**Results**
Society supporting capacity	Annual growth rate of GDP of Beijing (%)	≥8%	b	No, 7.7% (c)
	GDP Per Capita (RMB/person)	• ≥40,000 for large cities • ≥25,000 small-medium cities (deflated by treating CPI in 2005 as 100)	a	Yes, 87,475
	Annual growth rate of per-capita disposable income of urban residents (%)	≥8%	b	No, 7.3% (c)
	Annual growth rate of per-capita disposable income of rural residents (%)	≥8%	b	Yes, 8.2% (c)
	The per-capita disposable income of urban residents (RMB/person)	• ≥25,000 for large cities; • ≥20,000 for small-medium cities (deflated by treating CPI in 2005 as 100)	a	Yes, 40,321 (e)
	The per capita fiscal income (RMB/person)	• ≥4000 for large cities • ≥2000 for small-medium cities (deflated by treating CPI in 2005 as 100)	a	Yes, 21,808.6 (c)
	Annual growth rate of local government general budgetary financial revenue (%)	≥9%	b	Yes, 10.3% (c)
	End consumption rate (%)	≥60%	b	No, 59.6% (c)
	Urban registered unemployment rate	≤3.5	b	Yes, 1.27 (c)
	Service as % of GDP	≥78%	b	No, 76.5% (c)
	R&D expenditures as % of GDP	≥5.5%	b	Yes, 5.95 (c)
	The employment population of tertiary industries accounted for the proportion of the total population of employment (%)	≥70%	a	Yes,75.6% (c)
	Engel coefficient of Urban Households (%)	United Nations Food Agricultural Organization defined as follows: • Above 59% is poverty; • 50% to 59% is mere subsistence; • 40% to 50% is fairly well-off life; • 30% to 40% is a wealth living; • Below 30% is a very affluent living.	f	Yes, 31.3% (c)

Note: Obligatory targets refer to the development goals with binding effects, which were promulgated by "*The 12th Five-Year Plan of Beijing*"; a refers to information from the Chinese Society for Urban Studies (CSUS) (2007) [52]; b refers to information from *The 12th Five-Year Plan of Beijing* [51]; c refers to information from 2013 Beijing Domestic Economic and Social Development Consensus [38]; d refers to [53]; e refers to Statistical Communiqué of Beijing on the 2013 National Economic and Social Development [54]; f refers to Zhang (2008) [55]; g refers to Liu *et al*., (2008) [56]; h refers to per capita total income is RMB 41,103, according to Beijing Statistical Yearbook 2013 [42]; pre-specified gross floor area per housing unit is 90 sqm; average number of persons in each household is 3; average housing selling price is RMB 16,553/sqm in 2012, according to China statistical Yearbook 2013 [39]; i indicates that information is not available in the official statistical report and judgments are made by the authors' experience and site inspection; j refers to Xu, Kang, and Wei (2010) [57]; j refers to information from Beijing Transport Annual Report 2013 [58]; CPI refers to consumer price index.

6.1. Environmental Impacts and Natural Resources

Sufficient resource reserves and a high environmental assimilative capacity are important preconditions for a high level of UCC. This section analyzes the challenging factors of Beijing's natural resources and assimilative capacity. In general, Beijing performs well in two areas, *i.e.*, urban greening and plowland conservation. A high greening rate is vitally important to improve the ecological environment and the perceptual satisfaction of the public. Beijing has a desirably high forest and city green coverage, reaching 55.5% and 46.3%, respectively. The per capita public green area has reached 15.5 m^2, which is substantially higher than the standard level of 10 m^2. The obligatory target of plowland areas conservation has been satisfactorily achieved, with 2316.88 km^2 in 2012, which is larger than the obligatory goal of 2205 km^2. Adequate plowland areas are essential to ensure the agricultural safety for urban residents.

Notwithstanding its achievements, Beijing continues to face serious environmental challenges. First, urban ambient air quality is poor and improvement remains slow and unsatisfactory. In 2012, the ratio of days with air quality better than or equal to Grade 2 standard per year was only 78.4%, which does not fulfill the government goal of 80%. If measured by the new air quality standard GB3095-2012, which has established higher criteria, this passing ratio would lag behind the regulated target. Currently, the main pollutants include sulfur dioxide (SO_2) and nitrogen oxides (NO_X) from industrial emissions and particulate matter (PM) from vehicle exhausts. To solve this problem, the government should improve the use of clean and renewable energy to substitute fossil-based fuel; related treatment technology, such as flue gas desulfurization and denitration devices, should be expanded [59]; cross-boundary cooperation among local governments are needed to monitor and control industrial emissions in Beijing and the adjacent regions; the number of private vehicles should be controlled and the public should be encouraged to use urban mass transport.

Second, two obligatory targets on energy and water saving have not been achieved. Beijing suffers from a desperate water shortage. In 2012, Beijing's per capita water resources was only 193.3 m^3, which significantly lagged behind the sufficient level of 1000 m^3/person and the severe deficiency level of 500 m^3/person. The reduction of water consumption per RMB 10,000 GDP was only 7.38% in 2013, which failed to achieve the obligatory target of 15%. Evidently, water is the centrally important resource for the long-term development of Beijing. Beijing heavily relies on external water resources diverted from nearby water abundant regions. For instance, the central government plans "the South-to-North water diversion project" to relieve Beijing's water shortage. The reusable water utilization rate is only 49.34%, which is significantly lower than the obligatory target of 75%. Industrial water has not yet been adequately recycled as regulated target of 100% and only 83% is being treated. The government and the public should make considerable commitments to save water. The water shortage problem can be mitigated by several measures, such as an improved utilization of water resources, preventions of pollution on surface water and groundwater, a higher percentage of waste water being treated and reused to meet national standards. In terms of energy saving, energy consumption per RMB 10,000 GDP in 2012 was reduced by 4.75%, whereas the obligatory goal is 17%. The heavy and inefficient use of energy is detrimental not only to energy security, but also to environmental stability and integrity. Energy use efficiency should be improved by means of investment in energy-saving technologies. Besides, heightened public awareness and a transition to low-energy lifestyle are centrally important for achieving energy saving goals.

Third, the treatment and reutilization of garbage and industrial waste should be further improved to meet the targets. According to official statistics [60], Beijing generates 18,000 tons of garbage every day. The total volume increases by 8% each year, but the treatment capacity is only 10,410 ton/day. Hence, the capacity gap is 8000 ton/day. Currently, Beijing is suffering from the problem of *Garbage Surrounding City*. The utilization of industrial solid waste remains low, which adds to the treatment gap. In addition, although 99.1% of domestic garbage has been treated through harmless disposal, the biggest portion of the garbage is processed by landfill, *i.e.*, 94.1% by sanitary landfill, 3.9% by compost method, and only 2% by garbage cremation. However, sanitary landfill encroaches upon a large quantity of land, and this method is unsustainable. In the future, the recycling of garbage, either industrial or domestic, should be significantly promoted. Furthermore, waste composting facilities and incineration plants should be expanded and widely used, which are superior to landfilling in terms of land-saving and treatment capacity.

Fourth, constructive land resources are limited in Beijing. According to governmental standards, the per capita constructive land should be controlled within 80 m^2 for large cities. However, in Beijing, this number has reached 163 m^2/person, which results in inefficient or even wasteful use of land resources. The concept of "compact city" is an effective solution to improve land use efficiency. To promote sustainable urban development, Beijing should avoid the traditional development pattern of urban sprawling and should enhance the plot ratio and population density. More restrictive buildable land use policy should be implemented.

6.2. Infrastructure and Urban Services

The basic urban services and infrastructure provided by the local government are necessary demands by urban residents for a comfortable living [6]. Some infrastructural facilities and services are indispensably needed, such as water supply, power, gas, sports, cultural, and amenity facilities. The rapid urban-industrial development resulting from economic growth may add tremendous pressures and tensions on those already fragile conditions, particularly in urban centers [14]. In general, urban services in Beijing are well developed and maintained because they benefited from the country's strong economic performance. Beijing has developed a high quality infrastructure and urban services network. However, relevant information is absent in statistical reports. Access to gas, cable TV, and Internet are readily provided to average households in Beijing. However, some aspects, such as cultural facilities, including public libraries and museums, healthcare services, and transport systems, are not yet adequate. For example, the number of public libraries and museums per 10,000 people is limited to 0.012 and 0.0096, respectively, which are significantly below the recognized level. The total number of hospital beds in Beijing in 2012 reached 92,610. However, when the average is taken, only 4.48 beds are available per 1000 people, which is significantly lower than the threshold of 90. This situation leads to tensions and difficulty for patients to secure healthcare. To improve the level of urban service, the local officials should give a high priority to substantially upgrade the cultural and healthcare facilities.

A convenient and efficient traffic system is an important element for high-quality living. Traffic congestion has been a key bottleneck in many megacities across the world. Considering its importance, this research has devoted some efforts to study public traffic conditions. Based on the limited statistics as published and site inspection, this research finds that traffic services, particularly mass transportation facilities, should be a priority to enable local governments to improve UCC. Urban residents are generally dissatisfied with the present inefficient traffic flow. The mobility of urban residents is an important target for city planners and managers. A residential location and the associated transportation that only allow access to a small portion of the job market within one-hour commuting time have afforded limited convenience to urban households [61]. For example, the South African government has been developing a million units of affordable housing in remote areas that demand a long time and expensive commuter traffic expense amounting to more than half of a worker's salary. Therefore, poor mobility directly leads to a high unemployment rate and poverty. The average one-way commuting time in Beijing is more than 30 min, which poses substantial inconvenience to jobs and other social-economic activities. Public transportation ridership rate is 44%, surpassing the goal of 35%. However, comparing to other cosmopolitan cities, this rate remains low in Beijing, mainly because of inconvenient mass transit facilities. The average resident often chooses driving as the primary transport means. As a solution, various low-carbon or efficient transportation means, such as mass transit, walking, and cycling, should be encouraged. Subway systems are primarily operated for transport in urban areas, and they have the highest passenger volume capacities among various public transport modes. Beijing's subway network is suggested to be further expanded, in terms of the route length and the number of stations. A high subway ridership would substantially ease the pressures on road traffic. The per capita road areas in Beijing are only 4.46 m^2, which is significantly lower than the recommended level of 15 m^2. Thus, the number of private vehicles should be strictly controlled. To this end, a market-based "driver pays" principle is expected to be implemented, and private car owners can be charged a high unit rate for license plates and gasoline. A higher social parking rate indicates a higher utilization level of parking facilities. Parking in many large cities has become an urgent problem for the local government. More parking facilities, such as the land-saving and efficient type of stereo garage, should be constructed to meet the parking demand brought about by the rapid increase in vehicles.

6.3. Institutional Setting

Harmony and equity among different social groups are of considerable significant importance for social stability and sustainable urban development. The achievements of rapid economic development should be widely and equally shared by different social groups; otherwise, a highly stratified society would bring many problems, such as high crime rates, discrimination, poor social integrity, *etc*. Statistics related to social harmony and equity in governmental reports are limited. Several findings are provided below based on information from official census, extant literature and site visits.

First, the polarization of rich and poor in Beijing is very serious. A reasonable Gini coefficient is between 0.3 and 0.4. A high Gini coefficient beyond 0.4 indicates the existence of severe income disparity, and a coefficient beyond 0.6 suggests that the wealth gap is highly serious. In 2013, China announced the national Gini coefficient from 2003 to 2012. The latest Gini coefficient was

0.474 in 2012. Beijing has yet to publish its Gini coefficient. As the economic center, the Gini coefficient of Beijing should be higher than the national average level. Zhu and Zheng (2014) [53] calculated that the Gini coefficient of Beijing reached an extremely high level of 0.72 in 2010, which is generally consistent with the reality that a large number of elites in China are keen to attain a registered permanent residence (Hukou) of Beijing. The inflow of elites from other cities inevitably leads to social division. Related measures, such as tax, subsidy, and regulatory approaches, are imperatively needed by the government to even out income disparities.

Second, housing prices are unaffordable for an average household, and economic housing is inadequately provided for the medium- and low-income groups. Housing represents basic shelters and the largest expenditure for urban residents [62–64]. According to the World Bank, the affordable level of housing price-to-income ratio (RIP) should not exceed six times the annual income of a household [56]. However, the ratio in Beijing was 12.8 in 2012, which indicates a serious housing affordability issue. In addition, the market shares of ordinary commodity housing, government subsidized housing, and cheap rental house remain low, which cannot meet the housing requirements for middle- and low-income families. These situations indicate severe deficiency of affordable housing for economically challenged families [62]. The local government should increase its investment on economical housing (ECH) and cheap rental housing (CRH) to meet the housing demand of middle- and low-income families.

Third, data regarding Beijing crime rate are not available. The detection rate of criminal case is around 70%, which represents an efficient legal system, albeit a large room for improvement exists. Fourth, food and drug safety has not met the obligatory targets set out in the governmental plan. On the other hand, Beijing has performed well in the areas of social security and welfare coverage. Around 2.543 million people in rural regions enrolled in the New Cooperative Medical System, which represents a coverage rate of 98%.

6.4. Society Supporting Capacity

Economic development is an essential pre-requisite for UCC improvements and sustainable urban development. Economic affluence, shown as rich employment opportunities, rapid economic growth, and high household income, are important factors for urban residents to achieve high living quality. In addition, the direct investment of the government on different sectors is the most manageable and proactive means to enhance the UCC of a specified urban area. Therefore, the fiscal, financing or technological capacities of a city are closely related to its potential UCC.

Beijing has performed fairly well in the last decade in terms of economic growth, particularly after the Olympic Games in 2008. Its GDP increased rapidly from RMB 811.78 billion in 2006 to RMB 1787.9 billion in 2012, which more than doubled in six years. In 2012, the high GDP growth rate was maintained at 7.7%, which was slightly lower than the goal of 8%. The per capita GDP increased from USD 6488 in 2006 to USD 13,857 in 2012, which exceeded the threshold of developed countries of USD 10,000/person. With rapid economic development, the per capita fiscal income increased rapidly to RMB 21,808.6, which was significantly higher than the target of RMB 4000/person. The Engel coefficient of urban households is 31.3%, which indicates that the average household in China enjoys a wealthy lifestyle, according to the standards of the United Nations.

Beijing has provided rich employment opportunities. Urban registered unemployment rate is maintained at a low 1.27%, which is below the governmental target of 3.5%. Beijing has established a well-balanced and sustainable economic structure, with 76.5% GDP and 75.6% employment rates from tertiary industries. In addition, the growth rates of household income in both urban and rural areas rapidly increased at around 8% per annum. The investments in R&D activities have contributed to 5.95% of the GDP, which is higher than the goal of 5.5%. This figure contributes to the technological advancement and economic advantages that support enhancement of the UCC of Beijing.

7. Policy Recommendations and Conclusions

UCC has important implications for China's cities, since various sustainability challenges are posed during the process of rapid and widespread urbanization. The over-development beyond UCC has brought much adverse impact to urban development, which significantly impairs sustainability and is perceived as degrading life quality by urban residents. This study investigates the use of urban-carrying capacity as a benchmark for Beijing's sustainable urban development.

The collected data of the UCC measures on Beijing depict a serious situation, particularly in the aspects of environmental impacts and natural resources, infrastructure and urban services, as well as institutional setting (as summarized in Table 4). The performance of these aspects is generally worse than recognized standards for sustainable urban development. A dynamic city policy for restructuring the carrying capacity is essential to ameliorate the conditions for urban development and resident's living quality. Thus, it is suggested that the Beijing city government considers the following strategic solutions to improve the carrying capacity:

(1). "Decentralization policy"—Decentralization policies are widely recognized as being effective for relieving congestions. The rapid influx of urban population is the immediate cause for the overdevelopment of Beijing. It generates substantial pressure on every aspect of urban development such as: urban facilities, public services, welfares, *etc*. It impairs sustainable development and life quality of urban residents. For example, according to "Beijing's Overall City Plan 2004–2020" [65], Beijing's population is planned to reach 18 million in 2020. Beijing's urban development schemes in various aspects were planned according to this demographic forecast. However, the rapid population influx is out of expectation of the local government. In 2010, the population reached 19.61 million, and the annual population growth is constantly maintained at 0.64 million [66]. It means that the predicted population of 2020 would be exceeded by 10 years in advance, and that Beijing will suffer from dramatic pressure of population concentration. The government should release growth management regulations to constrain the repaid influx of people and business activities. Besides, Beijing should no longer compete to be a municipality of "centers", such as creativity-industrial center, financial center, vehicle-production center, *etc*. Some industries should be reallocated outward through stimulatory subsidies under a decentralization policy. The coordinated development plan for "*The Beijing-Tianjin-Hebei Integration*" is essential to devolve parts of Beijing's functions to surrounding regions and to relieve the pressures on Beijing's heavily populated areas. However, the extent to which the urban population and industries should be decentralized needs careful discussion. If urban population and economic activities are reduced, the often-faced urban symptoms, e.g., meager urban services, environmental deterioration, resources shortage and social conflicts will be fundamentally improved.

(2). Investment and resource allocation are proactive means to improve UCC. The government is expected to increase the investment and emphasize key projects in the field of resources/waste reutilization, environmental preservation, infrastructure development and social welfare.

(3). The urban planning department should improve land use efficiency. The means are various. For example, the relocation of habitation and economic centers to the suburbs can alleviate the heavy use of urban facilities. According to the "compact city" theory, the government is expected to legally designate high floor area ratios for new construction.

(4). It is important to transform the current consumptive lifestyles to conserving and environment-friendly lifestyles.

In this study, an assessment framework with reference to the UCC concepts is developed to fill the gaps felt by urban planners and managers, who have not got the tool to monitor, assess, and improve urban sustainability. This research has developed the UCC concepts into an operationally workable framework for urban sustainability assessment. Urban planning and management authorities should compare these credible indicators with the thresholds. The applicability of this framework is demonstrated in the case study of Beijing. This study has identified the various "shortcomings", which should be improved to facilitate Beijing's sustainable development. Some suggestions are provided to link actions for UCC improvements in different sectors and achieve the goals of urban sustainability. There is an urgent need to identify the critical factors of urban sustainability, and this study has offered suggestions to benchmark the best sustainable practices. Therefore, both urban residents and city managers can reap the beneficial sustainability outcomes by detecting and improving the limiting factors. The purpose of the assessment is to facilitate urban planners and managers to evaluate current conditions of urban development performance and determine the sectoral limitations that need improvements. The research outcomes guide rational decision-making on the sectoral allocation of resource for capacity improvements and urban sustainability. The evaluation framework can be applied in various ways in different cities.

The study is limited in several aspects. First, the involvements of perceptual and institutional indicators are limited due to the difficulties of securing data, which is relevant to sense, attitudes and anticipations of the public. Such is difficult to measure and can only be assessed by social survey [45]. Future research efforts are expected to dedicate efforts in this field. Second, an appropriate determination of the spatial jurisdictions of the urban boundaries is a critical step in UCC assessments. The term of "appropriated carrying capacity" [67] formally refers to the circumstance that a specified urban area imports much of its carrying capacities (e.g., resources) from distant regions beyond its administrative or physical boundary. As cities are an open system, such dependencies of a city on distant locations' resources have been widely considered for capacity buildings by city managers, through interregional or global trade-off [14]. Some cities with a reputation for "sustainability" import much carrying capacity from other regions to support its consumptive lifestyle. From a holistic perspective, this practice virtually contradicts the core principle of sustainability. Therefore, this study recognized "self-sustenance" as the basic tenet for UCC assessment, which better reflect the sustainability concept. All indictors and measurements suggested in the paper are mainly based on a single city level. Further studies are needed to measure the trans-boundary effects of carrying capacity, which are largely ignored by current research. Third, there is a large variation in geographic, topographic and cultural contexts between Beijing and the rest of China. The benchmarks used in this Beijing may not be applicable to the situations of carrying capacity of another city in China. In any event, this study provides a nested framework for UCC measurement in China. The use of this framework should consider the variation and specific conditions of the city under investigation. Fourth, GIS techniques have been widely recognized as a powerful tool for assisting urban planners to evaluate urban development performance accurately [6]. The use of spatial analysis techniques in urban planning and management are superior in several aspects, such as "scientificity, intuition, and management" [11] (p. 28). From the perspective of UCC, this study has identified a number of indicators and criteria to enable urban planners and policymakers monitor and manage urban development more efficiently. The research outcomes provide a meaningful basis for the use of GIS in future studies. Related studies on spatial differentiation assessment at present are limited. With the use of GIS analysis, future researchers are expected to use these measurable indicators and standards to establish a spatial-based UCC evaluation framework to assist in sustainable urban development.

Acknowledgments

We gratefully acknowledge financial support from the National Natural Science Foundation of China (Grant Numbers 71173184, 71233005).

Author Contributions

Yigang Wei, Cui Huang, and Patrick T. I. Lam designed the research. Yigang Wei wrote the first draft of this article. Cui Huang and Patrick T. I. Lam reviewed and provided valuable comments and suggestions for paper revisions. Yong Sha and Yong Feng collected and compiled the data and literature. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Shen, L.Y.; Ochoa, J.J.; Shah, M.N.; Zhang, X.L. The Application of Urban Sustainability Indicators—A Comparison between Various Practices. *Habitat Int.* **2011**, *35*, 17–29.
2. Tzoulas, K.; Korpela, K.; Venn, S.; Yli-Pelkonen, V.; Kaźmierczak, A.; Niemela, J.; James, P. Promoting Ecosystem and Human Health in Urban Areas Using Green Infrastructure: A Literature Review. *Landsc. Urban Plan.* **2007**, *81*, 167–178.
3. Rengasamy, S. Understanding Urbanization and Urban Community Development. 2009. Available online: http://zh.scribd.com/doc/21976896/Understanding-Urbanization-Urban-Community-Development (accessed on 14 May 2014).

4. McKinsey Global Institute. Urban World: Mapping the Economic Power of Cities. 2011. Available online: www.mckinsey.com/~/media/McKinsey/dotcom/Insights%20and%20pubs/MGI/Research/Urbanization/Urban%20world%20mapping%20economic%20power%20of%20cities/MGI_urban_world_mapping_economic_power_of_cities_full_report.ashx (accessed on 14 May 2014).
5. Qi, Y.; Wu, T.; He, J.K.; King, D.A. China's Carbon Conundrum. *Nat. Geosci.* **2013**, *6*, 507–509.
6. Oh, K.; Jeong, Y.; Lee, D.K.; Lee, W.; Choi, J. Determining Development Density Using the Urban Carrying Capacity Assessment System. *Landsc. Urban Plan.* **2005**, *73*, 1–15.
7. Onishi, T. A Capacity Approach for Sustainable Urban Development: An Empirical Study. *Reg. Stud.* **1994**, *28*, 39–51.
8. Saveriades, A. Establishing the Social Tourism Carrying Capacity for the Tourist Resorts of the East Coast of the Republic of Cyprus. *Tour. Manag.* **2000**, *21*, 147–156.
9. Oh, K.Y.J.; Lee, D.; Lee,W. An Integrated Framework for the Assessment of Urban Carrying Capacity. *J. Korean Plan. Assoc.* **2002**, *37*, 7–26.
10. Sarma, A.K.; Mahanta, C.; Bhattacharya, R.; Dutta, S.; Kartha, S.; Kumar, B.; Sreeja, P. *Urban Carrying Capacity: Concept and Calculation*; Centre of Excellence: Assam, India, 2012.
11. Shi, Y.; Wang, H.; Yin, C. Evaluation Method of Urban Land Population Carrying Capacity Based on GIS—A Case of Shanghai, China. *Comput. Environ. Urban. Syst.* **2013**, *39*, 27–38.
12. Singh, R.K.; Murty, H.R.; Gupta, S.K.; Dikshit, A.K. An Overview of Sustainability Assessment Methodologies. *Ecol. Indic.* **2009**, *9*, 189–212.
13. The Eleventh Session of the National People's Congress. China's 12th Five-Year Plan Report. Available online: http://www.moa.gov.cn/fwllm/jjps/201103/t20110317_1949003.htm (accessed on 14 May 2014).
14. Joardar, S.D. Carrying Capacities and Standards as Bases towards Urban Infrastructure Planning in India : A Case of Urban Water Supply and Sanitation. *Habitat. Int.* **1998**, *22*, 327–337.
15. Lane, M. The Carrying Capacity Imperative: Assessing Regional Carrying Capacity Methodologies for Sustainable Land-Use Planning. *Land Use Policy* **2010**, *27*, 1038–1045.
16. Odum, E.P. *Fundamentals of Ecology*; Sanders: Philadelphia, PA, USA, 1971.
17. Kessler, J.J. Usefulness of the Human Carrying Capacity Concept in Assessing Ecological Sustainability of Land-Use in Semi-Arid Regions. *Appl. Soil. Ecol.* **1994**, *48*, 273–284.
18. Yu, D. L.; Mao, H.Y. Regional Carrying Capacity: Case Studies of Bohai Rim Area. *J. Geogr. Sci.* **2002**, *12*, 177–185.
19. Liu, R.Z.; Borthwick, A.G.L. Measurement and Assessment of Carrying Capacity of the Environment in Ningbo, China. *J. Environ. Manag.* **2011**, *92*, 2047–2053.
20. Godschalk, D.; Parker, F. Carrying Capacity: A Key to Environmental Planning. *J. Soil Water Conserv.* **1975**, *30*, 160–165.
21. Odum, E.P. *Ecology: A Bridge between Science and Society*; Sinauer Associates Inc.: Sunderland, MA, USA, 1997.
22. Pulliam, H.R.; Haddad, N.M. Human population growth and the carrying capacity concept. *Bull. Ecol. Soc. Am.* **1994**, *75*, 141–156.
23. Abernethy, V.D. Carrying capacity: The tradition and policy implications of limits. *Ethics Sci. Environ. Polit.* **2001**, *23*, 9–18.

24. Malthus, T.R. *An Essay on the Principle of Population*; Pickering: London, UK, 1789.
25. Yue, T.X.; Tian, Y.Z.; Liu, J. Y.; Fan, Z.M. Surface Modeling of Human Carrying Capacity of Terrestrial Ecosystems in China. *Ecol. Model.* **2008**, *214*, 168–180.
26. Wackernagel, M.; Schulz, N.B.; Deumling, D.; Linares, A.C.; Jenkins, M.; Kapos, V.; Monfreda, C.; Loh, J.; Mayer, N.; Norgarrd, R.; Rander, J. Tracking the Ecological Overshoot of the Human Economy. *Proc. Natl. Acad. Sci. USA* **2002**, *99*, 9266–9271.
27. Graymore, M.L.M.; Sipe, N.G.; Rickson, R.E. Sustaining human carrying capacity: A tool for regional sustainability assessment. *Ecol. Econ.* **2010**, *69*, 459–468.
28. Fearnside, P.M. Human carrying capacity estimation in Brazilian Amazonia as a basis for sustainable development. *Environ. Conserv.* **1997**, *24*, 271–282.
29. Schneider, D.M.; Godschalk, D.R.; Axler, N. The Carrying Capacity Concept as a Planning Tool. In *Planning Advisory Service Report 338*; American Planning Association: Chicago, IL, USA, 1978.
30. Seoul Development Institute. *A Study on the Environmental Capacity Assessment of Seoul (I)*; Seoul Development Institute: Seoul, Korea, 1999.
31. Liu, H.M. Comprehensive Carrying Capacity of the Urban Agglomeration in the Yangtze River Delta, China. *Habitat Int.* **2012**, *36*, 462–470.
32. Graymore, M.L.M.; Sipe, N.G.; Rickson, R.E. Regional Sustainability: How Useful Are Current Tools of Sustainability Assessment at the Regional Scale? *Ecol. Econ.* **2008**, *67*, 362–372.
33. Paul Summers Planning Strategies. Population Carrying Capacity in Noosa Shire. Available online: http://www.paulsummersplanning.com.au/Presentations&Publications_files/Documents/Population%20Carrying%20Capacity%20in%20Noosa%20Shire.pdf (accessed on 14 May 2014).
34. Tan, W.K.; Shi, Y.S.; Sun, L. Some Theoretical Issues on Urban Carrying Capacity. *China Popul. Resour. Environ.* **2008**, *18*, 40–44.
35. Zhu, Y.H.; Drake, S.; Lü, H.S.; Xia, J. Analysis of Temporal and Spatial Differences in Eco-Environmental Carrying Capacity Related to Water in the Haihe River Basins, China. *Water Resour. Manag.* **2010**, *24*, 1089–1105.
36. Downs, J.A.; Gates, R.J. ; Murray, A.T. Estimating Carrying Capacity for Sandhill Cranes Using Habitat Suitability and Spatial Optimization Models. *Ecol. Model.* **2008**, *214*, 284–292.
37. Wei, Y.G.; Huang, C.; Lam, P.T.I.; Yuan, Z.Y. Sustainable Urban Development: A Review on Urban Carrying Capacity Assessment. *Habitat Int.* **2015**, *46*, 64–71.
38. Beijing Statistic Bureau. 2013 Beijing Domestic Economic and Social Development Consensus. Available online: http://www.bjstats.gov.cn/xwgb/tjgb/ndgb/201402/t20140213_267744.htm (accessed on 14 May 2014).
39. National Bureau of Statistics of China. *China Statistical Yearbook 2013*; China Statistical Press: Beijing, China, 2014. (In Chinese)
40. Department of Comprehensive Statics and Development of Rural Survey of National Bureau of Statistics. *China Statistical Yearbook for Regional Economy 2013*; China Statistics Press: Beijing, China, 2014. (In Chinese)
41. Ministry of Housing and Urban-Rural Construction of the People's Republic of China. *China Urban Construction Statistical Yearbook 2013*; China Statistics Press: Beijing, China, 2014. (In Chinese)
42. Beijing Statistic Bureau. *Beijing Statistical Yearbook 2013*; China Statistics Press: Beijing, China, 2013. (In Chinese)

43. Gustavson, K.R.; Lonergan, S.C.; Ruitenbeek, H.J. Selection and Modeling of Sustainable Development Indicators: A Case Study of the Fraser River Basin, British Columbia. *Ecol. Econ.* **1999**, *28*, 117–132.
44. Button, K. City Management and Urban Environmental Indicators. *Ecol. Econ.* **2002**, *40*, 217–233.
45. Aspeslaugh, W. *Carrying Capacity and Its Application to the Portland Metropolitan Area*; Metro Future Vision Commission: Portland, OR, USA, 1994.
46. Li, F.; Liu, X.S.; Hu, D.; Wang, R.S.; Yang, W.R.; Li, D.; Zhao, D. Measurement Indicators and An Evaluation Approach for Assessing Urban Sustainable Development: A Case Study for China's Jining City. *Landsc. Urban Plan.* **2009**, *90*, 134–142.
47. Zhang, X.L.; Wu, Y.Z.; Shen, L.Y. An evaluation framework for the sustainability of urban land use: A study of capital cities and municipalities in China. *Habitat Int.* **2011**, *35*, 141–149.
48. Wong, S.W.; Tang, B.S.; Horen, B.V. Strategic Urban Management in China: A Case Study of Guangzhou Development District. *Habitat Int.* **2006**, *30*, 645–667.
49. Lee, Y.J. Sustainable Development Indicators for Taipei. In Proceedings of 12th Annual International Sustainable Development Research Conference, Hong Kong Convention & Exhibition Centre, Hong Kong, 6–8 April 2006.
50. Wood, R.; Garnett, S. Regional Sustainability in Northern Australia—A Quantitative Assessment of Social, Economic and Environmental Impacts. *Ecol. Econ.* **2010**, *69*, 1877–1882.
51. The 12th Five-Year Plan of Beijing. Available online: http://www.bjpc.gov.cn/fzgh_1/guihua/ (accessed on 14 May 2014).
52. Chinese Society for Urban Studies (CSUS). Study on the Indicator Systems of Livable City Scientific Evaluation. Available online: http://yjcs.city188.net/wjxzlist.asp (accessed on 14 May 2014).
53. Zhu, S.J.; Zheng, B.H. China's Regional Difference in City's Spitial Locations: The Gini Coefficient Perspective. *Stat. Decis.* **2014**, *3*, 127–129.
54. Beijing Statistic Bureau. Statistical Communiqué of Beijing on the 2013 National Economic and Social Development. Available online: http://www.bjstats.gov.cn/xwgb/tjgb/ndgb/201402/t20140213_267744.htm (accessed on 14 May 2014).
55. Zhang, Y.Z. China's Urban-Rural Economic Inequity: A Engel Coefficient Perspective. *Sci. Technol. Inf.* **2008**, *23*, 20–42.
56. Liu, M.J.; Reed, R.; Wu, H. Challenges Facing Housing Affordability in Beijing in the Twenty-First Century. *Int. J. Hous. Mark. Anal.* **2008**, *1*, 275–287.
57. Xu, L.Y.; Kang, P.; Wei, J.J. Evaluation of Urban Ecological Carrying Capacity: A Case Study of Beijing, China. *Procedia Environ. Sci.* **2010**, *2*, 1873–1880.
58. Beijing Transportation Research Center. Beijing Transport Annual Report 2013. Available online: http://www.bjtrc.org.cn/JGJS.aspx?id=5.2&Menu=GZCG (accessed on 24 May 2014).
59. Zhao, Z.J. The Solutions to PM 2.5 by Tsinghua University. 2014. Available Online: http://news.tsinghua.edu.cn/publish/news/4205/2014/20140419145852841229642/20140419145852841229642_.html (accessed on 24 May 2014).
60. Li, T.Y. Beijing Is Suffering the Issue of "Garbage Around City". *Cities Towns Constr. Guangxi* **2010**, *3*, 52–53.
61. Cox, W.; Hugh, P. *10th Annual Demographia International Housing Affordability Survey*; Demographia: Belleville, IL, USA, 2014.

62. Wei, Y.G.; Lam, P.T.I.; Chiang, Y.H.; Leung, B.Y.P. The Changing Real Estate Supply and Investment Patterns in China: An Institutional Perspective on Affordable Housing. In Proceedings of the 17th International Symposium on Advancement of Construction Management and Real Estate, Shenzhen, China, 17–18 November 2012; Wang, J.Y., Ding, Z.K., Zou, L., Zuo, J., Eds.; Springer-Verlag: Heidelberg, Germany, 2014; pp. 403–410.
63. Wei, Y.G.; Lam, P.T.I.; Chiang, Y.H.; Leung, B.Y.P. The Effects of Monetary Policy on Real Estate Investment in China : A Regional Perspective. *Int. J. Strateg. Prop. Manag.* **2014**, *18*, 368–379.
64. Wei, Y.G.; Lam, P.T.I.; Chiang,Y.H.; Leung, B.Y.P.; Seabrooke, W. An Exploratory Analysis of Impediments to China's Credit Control on the Real Estate Industry: An Institutional Perspective. *J. Contemp. China* **2014**, *23*, 44–67.
65. Beijing Municipal Commission of Urban Planning. Beijing's Overall City Plan 2004–2020. Available online: http://www.cityup.org/case/general/20070907/32261.shtml (accessed on 5 November 2014).
66. Jiang, Y.X. The newcomers of Beijing reach 7.04 million, accounting to 35.9% of total population. Available online: from http://www.bjnews.com.cn/news/2011/05/06/122271.html (accessed on 5 November 2014).
67. Rees, W.R. *Defining Sustainable Development*; CHS Research Bulletin; UBC Center for Human Settlements: Vancouver, BC, Canada, 1989.