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CASE REPORT

# Measuring sustainable urbanization in China: a case study of the coastal Liaoning area

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**Abstract** The global urbanization process poses a serious challenge to achieving sustainable development. The significance of sustainable urbanization has been increasingly appreciated, yet, very little empirical evidence has been provided for this prospect. In this paper, we use the Human Development Index and the ecological footprint to measure the sustainability of the coastal Liaoning area. We then use the quadrant map approach to determine the relationship between sustainability and urbanization. The results show that the coastal area has made progress in sustainable urbanization in the social dimension. Improvement in the environmental dimension has been dynamic. Our results indicate that sustainable urbanization is a dynamic, multi-dimensional progress that requires regular monitoring and reevaluation. This paper also highlights the importance of choosing more complete indicators for measuring the sustainability of urbanization, as no single model or measurement is sufficient for quantifying the different dimensions of sustainability.

**Keywords** Sustainable urbanization · Urbanization velocity · Sustainability velocity · Ecological footprint · Human Development Index · Northeast China

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## Introduction

Since the industrial revolution in the late 18th century, humanity has experienced a remarkable shift to urban living. In 1900, only 10 % of the global population lived in urban areas, and that percentage now exceeds 50 % and will rise to 69 % by 2050 (United Nations 2010). Cities have become the hot spots of production, consumption, and waste generation. Covering <3 % of the world's surface, cities are responsible for 75 % of global energy consumption, 80 % of greenhouse gas emissions (United Nations 2010), 60 % of residential water use, and 76 % of wood use for industrial purposes (Grimm et al. 2008). On the one hand, urbanization has brought improvement to economic development, healthcare, education, and social welfare. On the other hand, urbanization results in irreversible land-use and land-cover changes, disturbance of biogeochemical cycles, modification of urban climate and hydrological systems, and reduction in global biodiversity (Grimm et al. 2008; Seto et al. 2011). Besides, poorly planned urbanization can lead to unemployment, poverty, violence, inequality, congestion, and poor quality of life (Bloom et al. 2008). Without careful investment and planning, these problems will become barriers to sustainable development. It is in this context that the significance of sustainable urbanization has been increasingly appreciated by policymakers, experts, and the public.

"Sustainable urbanization" is a dynamic and multidimensional process with environmental, social, economic, and political-institutional dimensions (United Nations Human Settlements Programme/Department for International Development; UN-Habitat/DFID 2002) and is an indispensable part of sustainable urban development. As a rational, practicable, and scientific urbanization model, sustainable urbanization is becoming an increasingly important policy toolbox to tackle climate change, loss of biodiversity, and overconsumption of materials and energy (Shmelev and Rodríguez-Labajos 2009; Roy 2009). Sustainable urbanization requires a combination of strategic policy-making and a system that combines personal opinion with scientific knowledge to reach a balance between economic, environmental, sociopolitical, and technological concerns (Jepson 2001). Pivo (1996) argued that sustainable urbanization occurs when the urbanization process is compatible with the principles of sustainable development. He theorized that planners aiming to make cities more sustainable should follow six basic principles: compactness, completeness, conservation, comfort, coordination, and collaboration. However, there are six main challenges to the achievement of sustainable urbanization: conflicts between economic growth and environmental sustainability; economic sustainability and poverty reduction; inequity and exclusion; infrastructure deficient; inadequate governance capabilities of the agencies; and realization of the benefits of interdependence between rural and urban areas (UN-Habitat/DFID 2002).

As a fast-growing developing country, China is confronting an unprecedented urbanization challenge (Chen 2007; Enserink and Koppenjan 2007; Weng 2009; Ma and Xu 2010). The Chinese government has introduced a variety of policies to protect the environment and produce a more sustainable growth, including family planning, enforcement of environmental laws, development of "eco-cities", application of strategic environmental assessment (SEA) and environmental impact assessment (EIA), and so on. Scholars have introduced a variety of models and methods to guide sustainable urbanization (Lu et al. 2008; Fan et al. 2010; Wu and Tan 2012). However, little empirical evidence has been provided to assess the sustainability of a particular practice or mode of urbanization. To address this knowledge gap, we took the coastal Liaoning area as a case study and analyzed the sustainability of the urbanization progress. Our analysis consisted of three main steps: (1) measuring the velocity of urbanization; (2) measuring the velocity of sustainability; and (3) evaluating the sustainability of the urbanization process with quadrant maps.

## Study area and data sources

### Study area

The coastal Liaoning area is located in the southeast of northeast China and includes 6 prefecture-level cities[1]: Dalian, Dandong, Yingkou, Panjin, Jinzhou, and Huludao. Nestled between the Bohai Sea and the Huanghai Sea, the strategically important area is located in the center of the northeast Asia economic circle and the Ring-Bohai economic circle (Fig. 1). In 2009, there were 17.84 million people living in the area, which accounted for 42 % of the population in Liaoning province. The area was responsible for 50 % of the provincial economic growth, with a gross regional production of $7.61 \times 10^{11}$ RMB (1 RMB = 0.1585 USD in 2012). Per capita GDP grew to 42,656 RMB in 2009 and the level of welfare was higher than other areas in Liaoning province. Since the implementation of the "reform and opening up" policies, the area has become one of the most rapidly developing and urbanizing regions in China. This, however, has put ever-greater pressure on resources, ecosystem, and public services (Fan 2010). The area has outstanding problems of repeated construction and blind competition, problems that are typical of the northeast old industrial area. Overall, the primary industry in Yingkou, Dandong, and Jinzhou and the secondary industry in Dalian and Yingkou are comparatively competitive. Moreover, the tertiary industry in Jinzhou and Yingkou is developing rapidly (Guan and Yu 2011). Table 1 lists the selected statistics of the 6 coastal prefecture-level cities in 2009, including area, population, density, and GDP.

### Data sources

In this study, we analyzed the ecological footprint, Human Development Index (HDI), and urbanization rate at the regional scale. The CD-ROM of the "Statistical yearbook of Liaoning 2001–2009" from Liaoning Statistics Bureau (2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009) was the primary source. We also used the "Liaoning statistical survey yearbook" in various printed and CD-ROM editions (Liaoning Survey Team of the National Bureau of Statistics 2005, 2006, 2007, 2008, 2009, 2010). Finally, areas of land use were collected from the "Second national

[1] In China, there are three types of cities: a municipality is a provincial-level division (e.g., Shanghai or Beijing); a prefecture-level city is governed by provinces or autonomous regions; and a county-level city is a sub-unit of a prefecture-level administrative division. Prefecture-level cities, the unit of analysis in this study, usually comprise an urban core surrounded by large stretches of rural areas. See Chan (2007) for an insightful discussion on the definition of cities in China and its implication on urbanization statistics.

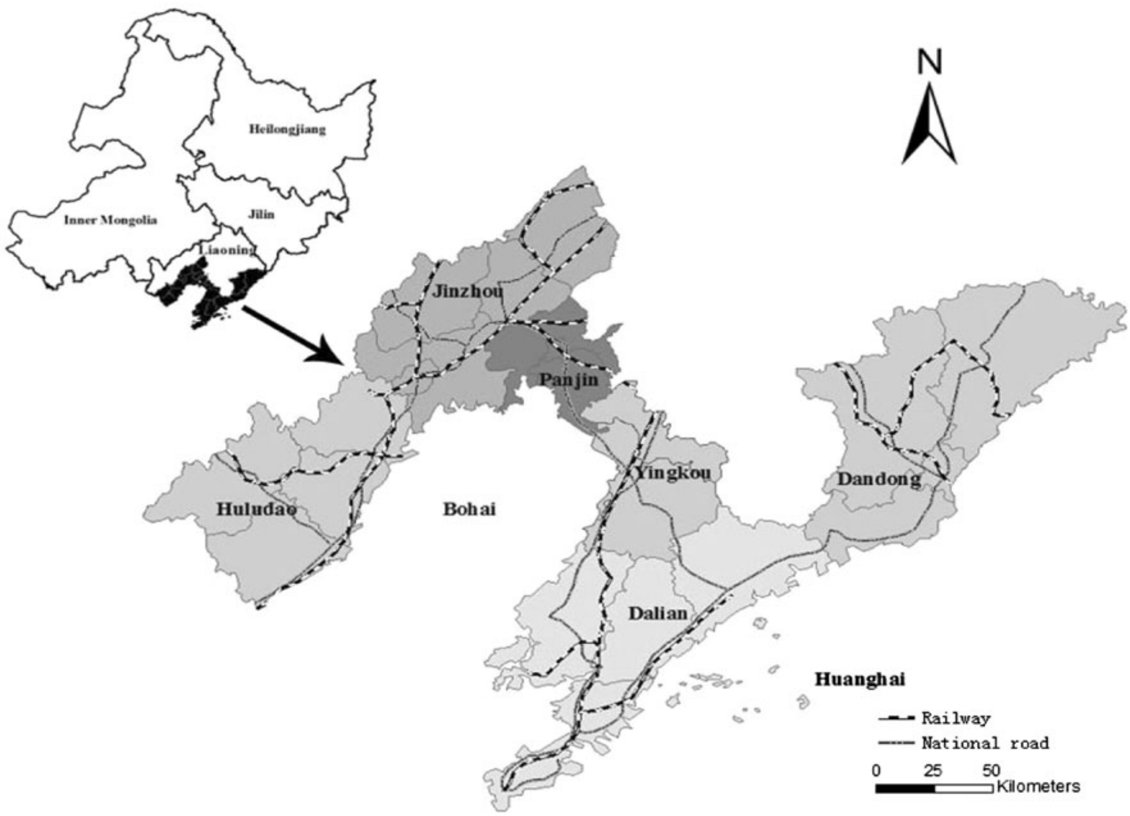


**Fig. 1** Location of the study area in northeast China

**Table 1** Area, population, population density, and GDP of coastal Liaoning prefecture-level cities in 2009

| Cities | Area ($km^2$) | Population (millions) | Density (persons/$km^2$) | GDP (billions) |
|---|---|---|---|---|
| Dalian | 12574 | 5.85 | 465.09 | 434.95 |
| Dandong | 15222 | 2.42 | 159.37 | 60.75 |
| Jinzhou | 9891 | 3.1 | 313.62 | 72.73 |
| Yingkou | 5402 | 2.35 | 435.02 | 80.7 |
| Panjin | 4071 | 1.3 | 319.33 | 67.69 |
| Huludao | 10415 | 2.82 | 271.05 | 44.56 |
| Coastal Liaoning | 57575 | 17.84 | 310.01 | 761.37 |

land survey" results obtained from the Liaoning Construction and Planning Agency.

## Measuring the velocity of urbanization

### Methodology for measuring the velocity of urbanization

The velocity of urbanization measures the rate and direction of change in urbanization. It can be measured by the urbanization rate ($u_R$), which is calculated according to the ratio of urban population to the total population. Almost all countries distinguish between urban and rural population, but the definition of urban varies among countries and, in some cases, even within a single country (Moore et al. 2003; Cohen 2006). China's actual urbanization rate has often been subjected to intense debate among researchers (Chan 2007; Zhou and Ma 2003; Sun 2003; Shen 2005; Shi et al. 2010; Cohen 2006). We computed $u_R$ by the ratio of non-agricultural population living in urban districts to the overall population. Compared to using the total non-agricultural population, our method yields a lower urbanization rate, which we believe is closer to the reality (Xie and Deng 1996). $V_{u_R}$ is the urbanization velocity that can be calculated by the following formula:

$$V_{u_R} = \frac{u_{Rt_1} - u_{Rt_2}}{t_2 - t_1} = \frac{\Delta u_R}{\Delta t} \quad (1)$$

where $u_{Rt_1}$ and $u_{Rt_2}$ are the urbanization rates at time $t_1$ and $t_2$, respectively.

### Results of the velocity of urbanization analysis in the coastal Liaoning area

Figure 2 shows the urbanization rate and the total population over the period 2000–2008. Both indicators

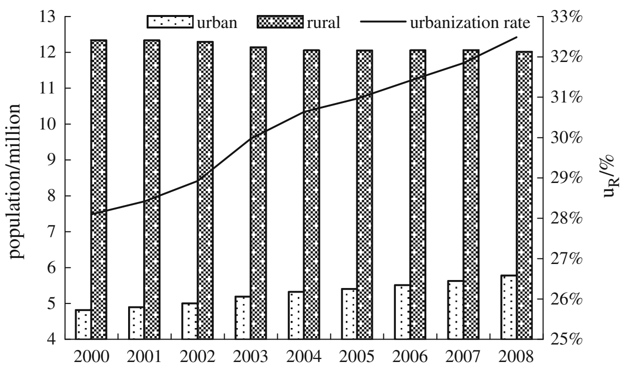


**Fig. 2** Changes of population and urbanization rate from 2000 to 2008 in the coastal Liaoning area

**Table 2** The urbanization velocity ($V_{u_R}$) of the coastal Liaoning area from 2000 to 2008

| Cities | 2000–2002 | 2002–2005 | 2005–2008 | 2000–2008 |
|---|---|---|---|---|
| Dalian | 0.0072 | 0.0116 | 0.0095 | 0.0097 |
| Dandong | −0.0003 | −0.0009 | 0.0003 | −0.0003 |
| Jinzhou | 0.0037 | 0.0017 | 0.0026 | 0.0026 |
| Yingkou | 0.0031 | 0.0170 | 0.0047 | 0.0089 |
| Panjin | 0.0017 | 0.0042 | 0.0035 | 0.0033 |
| Huludao | 0.0035 | 0.0015 | 0.0022 | 0.0023 |
| Coastal Liaoning | 0.0041 | 0.0068 | 0.0051 | 0.0055 |

increased during the period. This reflects a sustained increase in the urban population, combined with a slight decrease in the rural population. The rural population had decreased to 12.01 million, resulting in a decline from 71.9 % of the total population in 2000 to 67.5 % in 2008. During the same time period, the urban population increased by 16.7 %. In other words, urbanization was the main engine of population growth in the costal Liaoning area.

There was significant diversity in the level of urbanization in different regions. Dalian and Panjin had reached a higher level of urbanization, owing to their early start in the progress. In 2008, 45.4 and 42.3 % of the inhabitants were urban. The figures for Dandong, Jinzhou, Yingkou, and Huludao were 25, 24, 30, and 20 %, respectively. However, the urbanization rate can be expected to rise rapidly in these less-developed cities because they had reached the acceleration urbanization stage according to Northam's theory of urbanization (Northam 1975).

Table 2 shows the urbanization velocity of the coastal areas. Dalian, Yingkou, and Panjin experienced a "rise-down" process, like an inverse "U" curve, whereas Jinzhou and Huludao experienced the opposite (i.e., "down-rise"). Dandong has apparently undergone a counter-urbanization process. This is, however, highly unlikely, considering both China and Liaoning province have been in the accelerated phase of urbanization. According to the Liaoning Statistical Survey Yearbook 2009, the delineation of urban area in Dandong has changed from 2000 to 2008. This may be the main reason for the apparent counter-urbanization of Dandong.

## Measuring the velocity of sustainability

### Methodology for measuring the velocity of sustainability

The velocity of sustainability is the rate and direction of change in sustainability. Because sustainable urbanization is a multi-dimensional process covering environmental, social, economic, and political-institutional aspects (UN-Habitat/DFID 2002), we used two models to quantify sustainability. The fist model is the UN Human Development Index (HDI), which is widely used to measure the level of human development (Davies and Quinlivan 2006; Grimm 2008). The second model is the ecological footprint (ef), which is a standardized measure of demand for natural capital relative to the planet's ecological capacity to regenerate it. The model is widely used around the globe as an indicator of environmental sustainability (Castellani and Sala 2012; Wood and Garnett 2009). The two models complement each other and, together, they provide a good coverage of the various dimensions of sustainability. The following part will further elaborate how we adopted the models and will present the results using data between 2000 and 2008.

### *Ecological footprint*

The ecological footprint was formally introduced by Wackernagel and Rees in the 1990s (Rees 1992; Wackernagel 1994; Wackernagel and Rees 1996), and has gained much attention as a useful measure of ecological sustainability. Although there are a number of criticisms of the ecological footprint (Fiala 2008; Herendeen 2000; van den Bergh and Verbruggen 1999), the concept remains a leading biophysical accounting tool for comparing human demand on bioproductive land area with the earth's gross ecological capacity to sustain human life (Moran et al. 2008). The methods of calculating per capita ecological footprint (ef), per capita ecological capacity (ec), and ecological deficit (ed) can be found in the papers by Wackernagel et al. (1999) and Wang and Wang (2011). $u_{sef}$ denotes environmental sustainability. It is used to measure the stage of environmental sustainability in a region. Larger values indicate better sustainability. The rate of change of environmental sustainability can be examined by the velocity of environmental sustainability ($V_{u_{sef}}$), which is calculated by the following formulas:

$$u_{sef} = ec/ef \quad (2)$$

$$V_{u_{sef}} = \frac{u_{sef t_2} - u_{sef t_1}}{t_2 - t_1} = \frac{\Delta u_{sef}}{\Delta t} \quad (3)$$

where $V_{u_{sef}}$ is the velocity of environmental sustainability, $u_{sef t_1}$ and $u_{sef t_2}$ are $u_{sef}$ at time $t_1$ and $t_2$, respectively, and $\Delta u_{sef}$ is the increment of environmental sustainability in the specified time interval, while $t_1$ and $t_2$ are the observed points in time and $\Delta t$ represents the increment of the time interval.

*Human Development Index (HDI)*

The Human Development Index (HDI), created by the United Nations Development Program in 1990, is a well-known global measure of human development at the national and regional levels (Li and Zhao 2009; United Nations 2011; Gong et al. 2012). It is composed of three variables: GNI per capita, life expectancy at birth, and education level. In this paper, the HDI is used to quantify the social sustainability ($u_{sh}$) of a region (United Nations 2011). The rate of change of social sustainability can be examined by the velocity of social sustainability ($V_{u_{sh}}$), which is calculated by the following formula:

$$V_{u_{sh}} = \frac{u_{sh t_2} - u_{sh t_1}}{t_2 - t_1} = \frac{\Delta u_{sh}}{\Delta t} \quad (4)$$

where $V_{u_{sh}}$ is the velocity of social sustainability, $u_{sh t_1}$ and $u_{sh t_2}$ are $u_{sh}$ at time $t_1$ and $t_2$, respectively, and $\Delta u_{sh}$ is the increment of social sustainability in the specified time interval, while $t_1$ and $t_2$ are the observed points in time and $\Delta t$ represents the increment of the time interval.

## Results of sustainability velocity analysis in the coastal Liaoning area

*Environmental sustainability (ecological footprint and biocapacity)*

Figure 3 shows the per capita ecological footprint of different consumption categories. Energy consumption was the biggest contributor to the ecological footprint in the area, accounting for 34–53 % in 2000–2008. The second largest contributor was fishing ground (31–43 %). Other consumption categories accounted for 19–23 % of the ecological footprint. There are three main reasons to explain the costal Liaoning area's high energy consumption. First of all, the area is dominated by old industrial cities. Due to path dependency and institutional lock-in, the leading industries in these areas are limited to raw material processing, mechanical manufacturing, electric power, and other heavy industries (Wang and Li 2004; Jiang 2007). Second, the area is located in the frigid region with long and cold winters. Consequently, people consume huge amounts of energy and electricity for warming. The third reason is related to people's lifestyle. The high ecological footprint of fishing ground is mainly due to the fact that marine industry such as fish farms, marine tourism, marine traffic, and transportation developed quickly in recent years and the economic center of Liaoning province gradually moved to the coastal area (Ma and Han 2011). Overall, the rapid economic development has exerted much pressure on the marine ecological environment.

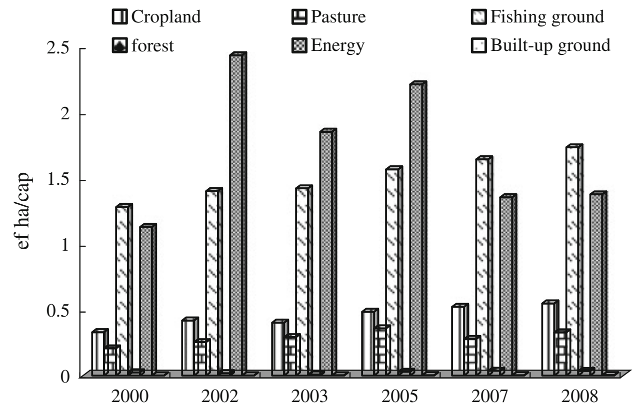


**Fig. 3** Per capita ecological footprints of the coastal Liaoning area by cropland, forest, pasture, fishing ground, built-up ground, and energy, 2000–2008

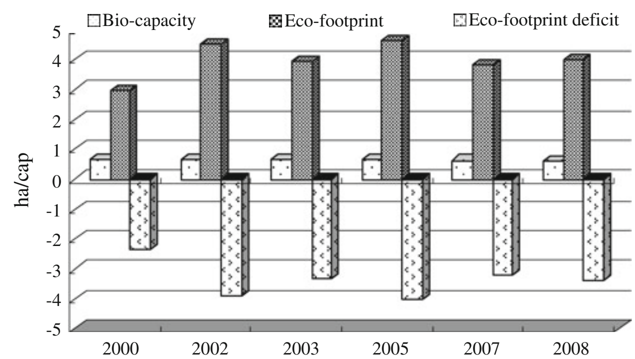


**Fig. 4** The ecological footprint, the ecological capacity, and the ecological deficit per capita in the coastal Liaoning area, 2000–2008

Figure 4 shows the trends of the ecological footprint, the ecological capacity, and the ecological deficit per capita between 2000 and 2008. As a whole, the per capita ecological footprint was always higher than the per capita ecological capacity. In other words, the carrying capacity of land in the coastal Liaoning had been exceeded, and the economic activity had not been sustainable. At the same time, the total ecological capacity was low and had been falling since 2000. It was 0.65 ha/per capita in 2000, but decreased to 0.63 ha/per capita in 2008. Moreover, the change in the ecological deficit fluctuated due to the variation of the ecological footprint. The variation was, in turn,

**Table 3** The urban environmental sustainability $u_{sef}$ of the coastal Liaoning area between 2000 and 2008

| Years | Dalian | Dandong | Jinzhou | Yingkou | Panjin | Huludao | Coastal Liaoning |
|---|---|---|---|---|---|---|---|
| 2000 | 0.161 | 0.463 | 0.366 | 0.294 | 0.146 | 0.162 | 0.220 |
| 2002 | 0.094 | 0.419 | 0.173 | 0.255 | 0.091 | 0.141 | 0.143 |
| 2003 | 0.156 | 0.387 | 0.165 | 0.159 | 0.086 | 0.131 | 0.162 |
| 2005 | 0.132 | 0.297 | 0.128 | 0.120 | 0.104 | 0.114 | 0.138 |
| 2007 | 0.123 | 0.318 | 0.227 | 0.132 | 0.108 | 0.191 | 0.165 |
| 2008 | 0.118 | 0.303 | 0.214 | 0.116 | 0.103 | 0.187 | 0.157 |

**Table 4** The environmental sustainability velocity $V_{u_{sef}}$ of the coastal Liaoning area between 2000 and 2008

| Cities | 2000–2002 | 2002–2005 | 2005–2008 | 2000–2008 |
|---|---|---|---|---|
| Dalian | −0.033 | 0.013 | −0.005 | −0.005 |
| Dandong | −0.022 | −0.041 | 0.002 | −0.020 |
| Jinzhou | −0.097 | −0.015 | 0.029 | −0.019 |
| Yingkou | −0.020 | −0.045 | −0.001 | −0.022 |
| Panjin | −0.028 | 0.004 | 0.000 | −0.005 |
| Huludao | −0.010 | −0.009 | 0.025 | 0.003 |
| Coastal Liaoning | −0.039 | −0.002 | 0.006 | −0.008 |

due to the dynamics of the energy footprint and the fishing ground footprint.

Table 3 depicts the dynamics of environmental sustainability for the areas from 2000 to 2008. The level of environmental sustainability in Dalian, Dandong, and Yingkou declined, while Panjing, Jinzhou, and Huludao experienced a "down-rise" development, like a "U" curve. Table 4 clearly shows that the velocity of environmental sustainability was negative in most of the coastal cities most of the time. The exception was Huludao, where environmental sustainability improved by 15.4 % from 2000 to 2008.

*Social sustainability (HDI)*

Table 5 shows the change in social sustainability of the areas between 2000 and 2008. The HDI index clearly shows a general positive trend between 2000 and 2008 (Table 6). People's livelihood improved along with economic development and improvement in public welfare. According to the human development report (United Nations 2011), the HDI can be classified into four groups: very high (average 0.889); high (average 0.741); medium (average 0.630); and low (average 0.456). Most of the coastal regions are in the medium category. Only Dalian and Panjin reached the high human development stage in 2007 and 2008.

## Evaluating the performance of sustainable urbanization

### Methodology for evaluating sustainable urbanization

As discussed earlier in this paper, sustainable urbanization is a practicable and scientific urbanization model. The state of sustainable urbanization of a region can be clarified by the relationship between urbanization and sustainability. Following Shen et al. (2012), we used Cartesian coordinates to depict their relationship. Cartesian coordinates can be divided into four quadrants: in the first quadrant, $x > 0, y > 0$; in the second quadrant, $x < 0, y > 0$; in the third quadrant, $x < 0$, $y < 0$; in the fourth quadrant $x > 0$, $y < 0$. If we take urbanization velocity ($V_{u_R}$) as the $x$-axis and velocity of urban sustainability ($V_{u_s} V_{u_s}$) as the $y$-axis, we can easily evaluate whether a region is urbanized sustainably. As mentioned previously, we used the rate of urbanization to calculate $V_{u_R}$ and the HDI and the ecological footprint (ef) to calculate $V_{u_s}$ of coastal Liaoning areas. As Fig. 5 shows, there are four states of sustainable urbanization: in Quadrant I, $V_{u_R} > 0$ and $V_{u_s} > 0$. $V_{u_R} > 0$ indicates that urbanization progress is speeding up, while $V_{u_s} > 0$ suggests improvement of sustainability. This state denotes that, when urbanization accelerates, social sustainability improves accordingly. This is considered to be a sustainable urbanization practice. In Quadrant II, $V_{u_R} < 0$ and $V_{u_s} > 0$. $V_{u_R} < 0$ denotes that this region is in a counter-urbanization state, while $V_{u_s} > 0$ suggests improvement of sustainability. This denotes that sustainability improves in the region which is in the process of counter-urbanization. Counter-urbanization may solve some urban problems and improve sustainability. This is considered to be a sustainable counter-urbanization practice. Similarly, Quadrant III is unsustainable counter-urbanization and Quadrant IV is unsustainable urbanization.

### Results of sustainable urbanization analysis in the coastal Liaoning area

Using the data in Tables 2, 4, and 6 and the quadrant map presented in Fig. 5, we allocated $V_{u_R}$ and $V_{u_s}$ (studied in two dimensions $V_{u_{sef}}$ and $V_{u_{sh}}$) as shown in Figs. 6 and 7.

**Table 5** The social sustainability $u_{sh}$ of the coastal Liaoning area between 2000 and 2008

| Years | Dalian | Dandong | Jinzhou | Yingkou | Panjin | Huludao | Coastal Liaoning |
|---|---|---|---|---|---|---|---|
| 2000 | 0.644 | 0.570 | 0.562 | 0.579 | 0.659 | 0.559 | 0.612 |
| 2002 | 0.659 | 0.584 | 0.580 | 0.597 | 0.661 | 0.578 | 0.626 |
| 2003 | 0.675 | 0.601 | 0.597 | 0.612 | 0.672 | 0.594 | 0.642 |
| 2005 | 0.689 | 0.629 | 0.623 | 0.642 | 0.687 | 0.614 | 0.662 |
| 2007 | 0.714 | 0.656 | 0.652 | 0.672 | 0.705 | 0.638 | 0.688 |
| 2008 | 0.727 | 0.670 | 0.668 | 0.686 | 0.716 | 0.648 | 0.701 |

**Table 6** The social sustainability velocity $V_{u_{sh}}$ of the coastal Liaoning area between 2000 and 2008

| Cities | 2000–2002 | 2002–2005 | 2005–2008 | 2000–2008 |
|---|---|---|---|---|
| Dalian | 0.0075 | 0.0099 | 0.0127 | 0.0104 |
| Dandong | 0.0070 | 0.0149 | 0.0139 | 0.0126 |
| Jinzhou | 0.0091 | 0.0141 | 0.0150 | 0.0132 |
| Yingkou | 0.0087 | 0.0151 | 0.0147 | 0.0134 |
| Panjin | 0.0008 | 0.0089 | 0.0096 | 0.0071 |
| Huludao | 0.0094 | 0.0119 | 0.0113 | 0.0110 |
| Coastal Liaoning | 0.0071 | 0.0120 | 0.0129 | 0.0111 |

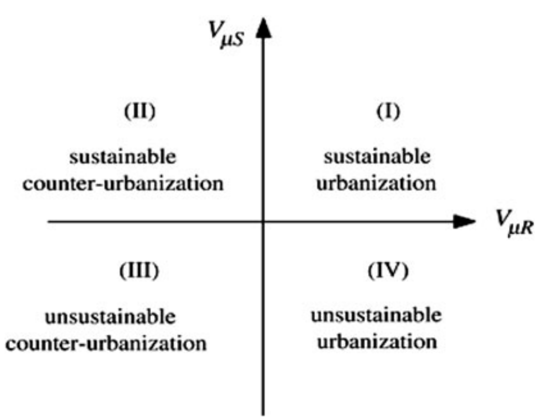


**Fig. 5** Quadrant map of urbanization and sustainability. Source: adapted from Shen et al. (2012)

Figure 6 shows the environmental sustainability quadrant map of the coastal Liaoning area in four time periods. First of all, the state of sustainability urbanization was different in different time periods. In 2000–2002, almost all prefecture-level cities were considered to be unsustainable, as they pursue economic development at the expense of the environment. The main difference was Dandong, which experienced a decrease in urban residents. But, as we discussed previously, this phenomenon was caused by a break in statistical continuity rather than actual counter-urbanization. This situation changed from 2002 to 2005. In particular, Dalian and Panjin experienced sustainable urbanization, because of the decrease in the ecological footprint driven mainly by the drop in energy consumption. However, the energy and fishing ground footprints in Huludao and Jinzhou were increased, making these places less sustainable. From 2005 to 2008, almost all of the coastal prefecture-level cities changed for the better. This is partly because the "Eleventh Five-Year Plan" imposed mandatory requirements on all local governments to cut emissions, conserve resources, and become more energy efficient. Nevertheless, from 2000 to 2008, urbanization of the costal area, with the exception of Huludao, had not been sustainable. These areas can become sustainable in the future only if they reduce their ecological footprint by slowing down the rate of resource consumption to fit within their biocapacity.

Figure 7 shows the social sustainability quadrant map of the study areas in four time periods. The process of urbanization in all areas was socially sustainable. Life expectancy, literacy, education, and standards of living improved year by year, suggesting that the social sustainability had improved over time. There was a difference in velocity in different time periods. The improvement in social sustainability was, in no small part, due to the introduction of favorable policies and financial support to the region in 2003 under the "Northeast Area Revitalization Plan".

## Conclusions and discussion

Sustainable urbanization is about making sure that the urbanization process is compatible with the principles of sustainable development. To make urbanization sustainable, policy-makers and planners need to evaluate the impacts of urbanization on ecosystem conditions, ecological capacity, and the well being of humanity. The goal of the study is to systematically assess the degree of sustainability of the present urbanization process in the Liaoning coastal area. Our empirical results indicate that, in different time periods, the relationship between

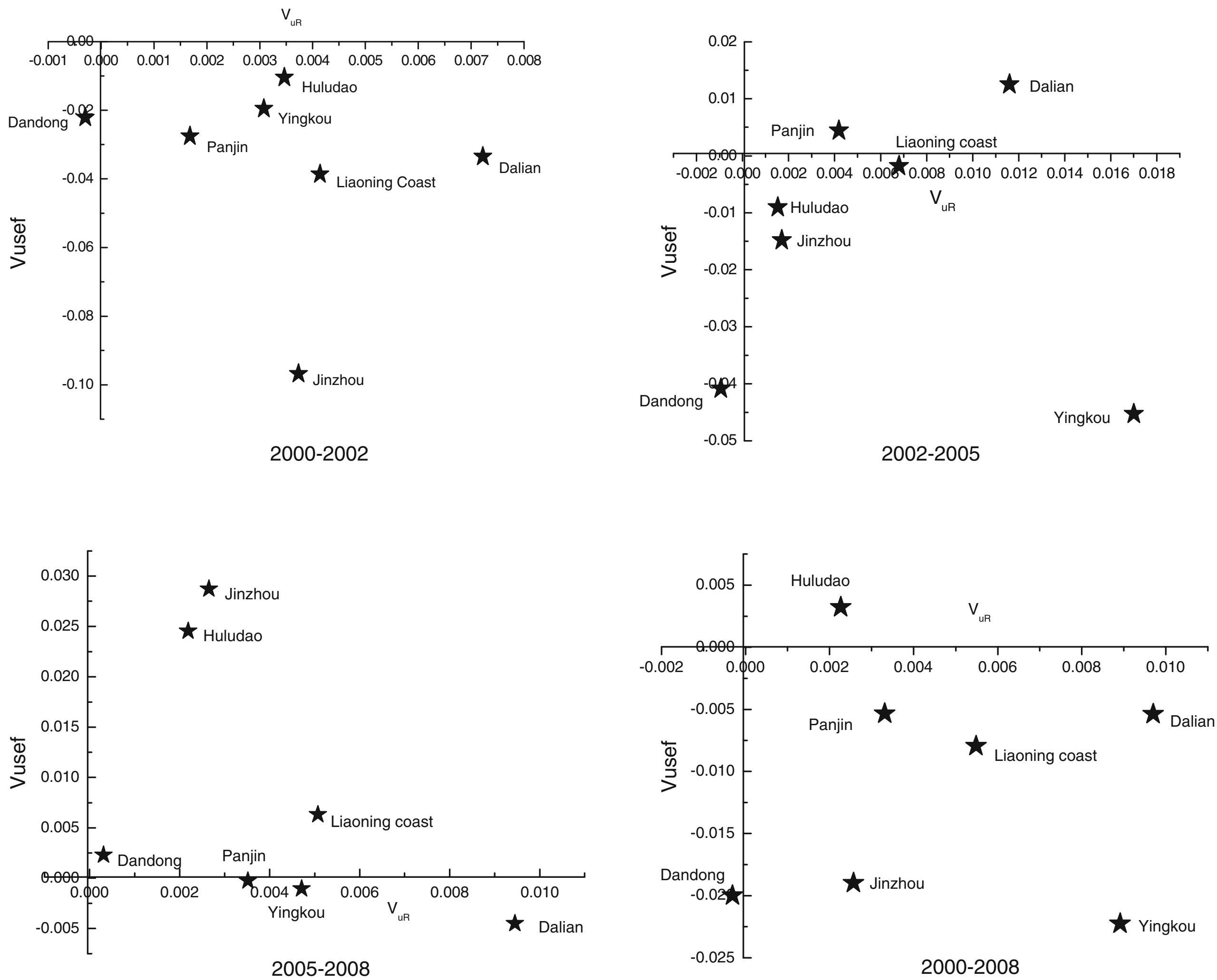


**Fig. 6** The environmental sustainability quadrant maps for the coastal Liaoning area between 2000 and 2008

environmental sustainability and urbanization is dynamic. Urbanization had been unsustainable environmentally in the early 2000s, but the situation had improved in recent years. Our results also indicate that urbanization had improved social sustainability between 2000 and 2008. Finally, our approach highlights the fact that sustainability is a multi-dimensional concept; no single model or measurement is capable of quantifying the different aspects of sustainability. Consequently, integrated methodology or new models are necessary in future studies.

Energy consumption was the biggest contributor to ecological deficit for the coastal Liaoning area. That means that the area discharged a large amount of greenhouse gases and other pollutants, which caused an urban heat island effect and air pollution. In order to combat global climate change and achieve regional sustainable development, it is time to change the urban energy structure and improve energy efficiency. There are opportunities for local administrations to influence citizens' ecological footprint, such as improving the energy efficiency of buildings, reducing heating consumption, encouraging low-carbon consumption, and so on.

Northeast China used to be a typical old industrial area. In 2003, the central government released a plan for rejuvenating the old industrial base, and, consequently, the coastal Liaoning area developed quickly. However, state-owned enterprises still account for half of the total production in the area. At present, the regional industrial structure is characterized by serious wasteful development and blind competition. To improve sustainability, the administrations which govern the territories need to plan the industrial structure scientifically and reasonably, alleviate the heavy social responsibility burden of the state-owned enterprises, modify existing development paths, and

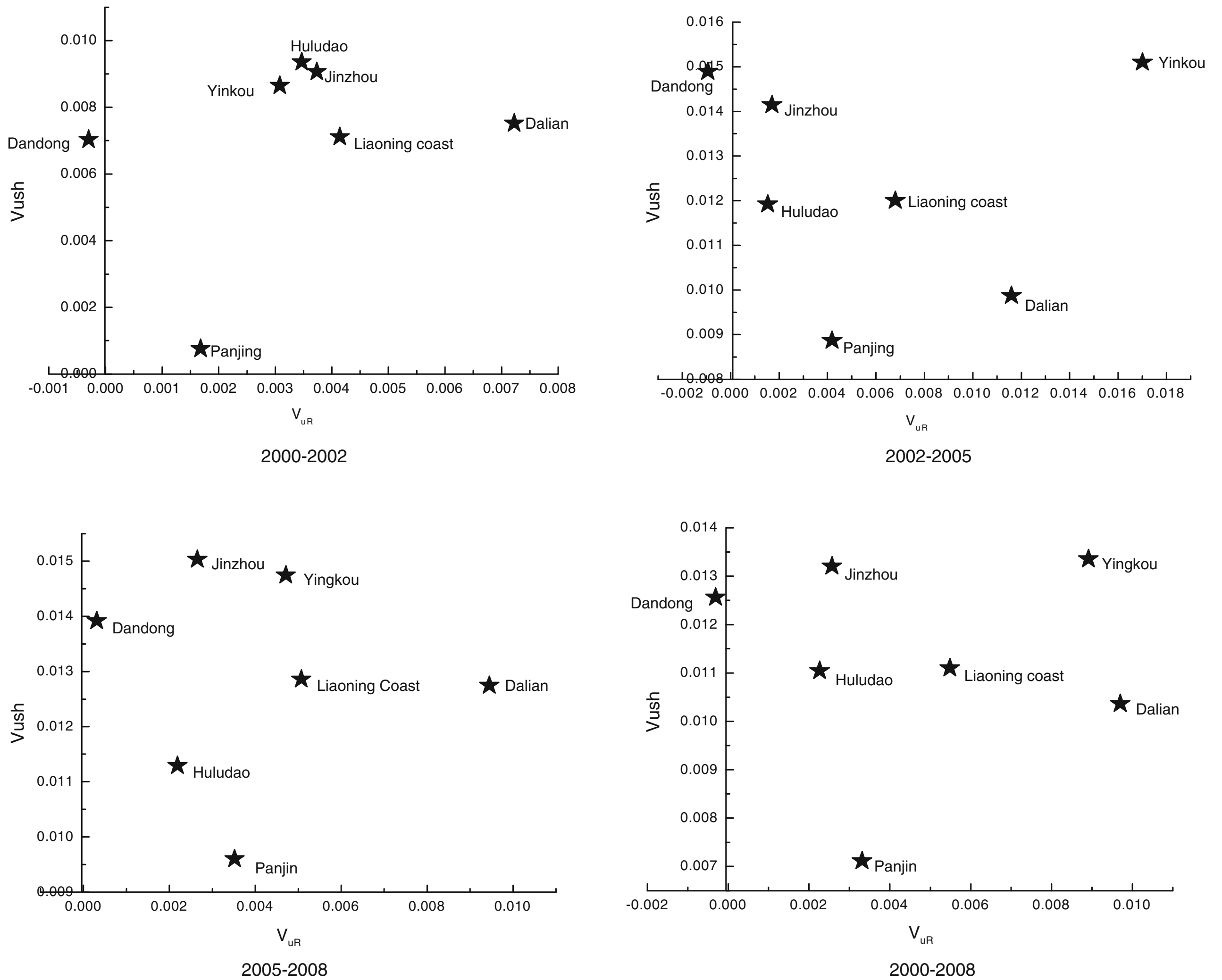


**Fig. 7** The social sustainability quadrant maps for the coastal Liaoning area between 2000 and 2008

introduce high-technology and knowledge-intensive industry.

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