Resources, Conservation & Recycling 134 (2018) 196–205

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Constraint-adaptation challenges and resilience transitions of the industry–environmental system in a resource-dependent city

Dewei Yang[a,*], Xueli Gao[a,b], Lingxing Xu[a,c], Qinghai Guo[a]

[a] Key Lab of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021, China
[b] College of Geography and Environmental Science, Northwest Normal University, Lanzhou 730070, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Keywords:
Adaptive capacity
Environmental constraints
Industrial transitions
Resource depletion
Resilience management
Baiyin City

ABSTRACT

Resource-dependent cities face the significant challenge of industrial transition under resource and environmental constraints. However, the interplay between industrial and environmental variables and their resilience trajectories have received insufficient attention to date. A constraint–adaptation framework was established to quantify the constraint–adaptation trajectory and resilience transitions of the industry–environmental system in the transition pilot of Baiyin City, western China. In this framework, an environmental performance index (EPI) was employed to reveal constraints of seven resource and environmental variables on local industrial development, combining with industrial indicators (i.e., industrial structure entropy and the shift-share method) to reflect the industrial structure adaptation. The resilience trajectories of seven resource and environmental variables were simulated to depict the industry–environmental system resilience dynamics using the four-phase adaptive cycle theory. Results from 1990 to 2016 in Baiyin City demonstrate that: (1) heavy dependence on mineral and energy resources, and resulting solid waste and atmospheric pollution, undermined local industrial competitiveness; (2) The competitiveness of secondary industry experienced a descending trend since 2011, while the total increase fell dramatically with total deviation of −30.64%; (3) the system underwent a vulnerable resilience transition to great adaptive capacity, with most resilience values greater than 0.5 (ascending adaptive capacity with resilience values from 0 to 1) in the past five years; (4) aggressive transition measures must be adopted to enhance adaptive capacity in the local industry–environmental system and foster co-benefits. This study provides a model to explore the transitions of resource-dependent cities in and beyond China.

1. Introduction

In the current Anthropocene era, industrial activities are directly reshaping environmental systems and triggering far-reaching resource depletion and undesirable environmental consequences (Erkman, 1997; Cmtzen, 2002). This inversely challenges industrial resilience transitions and the pursuit of sustainable goals (Li and Shi, 2015; Jia et al., 2017). Since the Industrial Revolution, rapid industrial growth has not only consumed abundant natural resources, but also exerted negative impact on the quality of the environment system. A series of worldwide events and actions have occurred, e.g., “Eight Social Pollution Nuisance” in the 1950s, and the Rio Declaration on Environment and Development of UNECD in 1992. Since the middle of the 20th century, the traditional resource-based cities have attempted to globally explore pathways of industrial transitions. These events have triggered considerable concern about mitigating the intensive use of resources and accompanying negative environmental effects around the world (Pyka, 2013; Swart and Dewulf, 2013; Fang and Côté, 2005; Li et al., 2016a; Li et al., 2016b; Peng et al., 2017a; Yang et al., 2017).

The first stream of research on the industry–environmental relationship has focused on potential impact during resource exploitation and the related constraint theories. Resource depletion and potential environmental damage are inevitable during industrial development. Thus, the estimate of influencing levels, scales, and directions remains an issue. Many theories, including the resilience theory, resource curse theory, inverted U-shape environmental Kuznets curve, and planet boundary, are introduced to understand these problems (Hollings, 1973); Auty, 1993; Bridge, 2008; Swart and Dewulf, 2013; Whitmee et al., 2015). These tools could depict the relationships of environmental welfares and economic pursuits by means of loss minimization and value maximization.

The second stream of literature has focused on the industrial transition and competitiveness under resource and environmental constraints. Viable means to enhance industrial competitiveness and urban

* Corresponding author.
E-mail addresses: dwyang@iue.ac.cn, davecas@163.com (D. Yang).

https://doi.org/10.1016/j.resconrec.2018.03.016
Received 21 November 2017; Received in revised form 17 March 2018; Accepted 19 March 2018

transition, such as structural adjustment (Chen et al., 2011), technological innovation (Wallace and Kalleberg, 1982), layout optimization (Rodwin and Sazanami, 2017), mode improvement (Yang et al., 2013), development stage enhancement (Bryan et al., 2013), and industrial symbiosis (Jensen, 2016; Jia et al., 2017; Sun et al., 2017), have been explored to relieve the constraints of resources and the environment. Industrial reorganization and optimization depend on resources supplies and technology available, but vary in their speed, scale, and policy. This research stream provided an extensive thinking on reconciling physical limits with socio-economic aspirations for activating industrial vitality.

The third stream has focused on green and sustainable means of industrial transition. Coping with global climate change and environmental appeals requires exploring clean production, low-carbon technologies, and circular economies. These extensive research topics cover green and low-carbon economies (Fang and Côté, 2005; Kuai et al., 2015; Liu et al., 2016; Yang et al., 2017; Yang et al., 2018), green utilization of natural resources (Miao et al., 2017), environmental health appeals (Zhang et al., 2008), sustainable transformation (Lebel et al., 2002; Luken and Castellanos-Silveria, 2011), resilience transitions (Agudelo-Vera et al., 2012; Jabareen 2013; Pyka 2013; Zhu and Ruth, 2013; Li and Shi, 2015; Jensen 2016; Tan et al., 2017), and so on. The methods involved include index evaluation, economic network analysis, life cycle analysis, and model simulation. Among these studies, the concept of resilience evaluation was gradually borrowed to account for the adaptive capacity of the coupled industry–environmental systems.

Resilience depends on a system's adaptive capacity or its ability to reorganize and renew itself in the face of change (Carpenter and Folke, 2006). With its roots in a branch of ecology (Hollings, 1973), recent advances in the socio-ecological resilience evaluation include social learning, agent and actor groups, social networks, transformability and adaptive governance, and thresholds (Folke, 2006; Li et al., 2016a). Industrial activities are embedded in and confined by the environmental system and the resources it provides (Fazey et al., 2007). In this industry–environmental system, the characteristics of resilience dynamics can be conveyed by the four-phase adaptive cycle, namely exploitation, conservation, release, and reorganization (Carpenter et al., 2001; Li et al., 2016c). Industrial resilience focuses not only on the contradictory and adaptive feedback of the industry–environmental system, but also on the role of human agents. This fosters the knowledge-based adaptive capacity for achieving the positive interaction and desired resilience change. Unfortunately, contemporary studies have not devoted sufficient attention to the resilience evolution of the industry–environmental system.

Resource-dependent cities rely on the exploitation and processing of local natural resources, such as minerals, forest, and petroleum resources. Meanwhile, accompanying problems, e.g., resource wastage, accumulative pollution, and cross-boundary pollutant diffusion (Yang et al., 2014), often occur during the industrial development (Jia et al., 2017). In 2015, the annual disposal of the waste gas (8.40×10^{11} m^3), dust (4.10×10^5 t), wastewater (2.25×10^9 t) and solid waste (1.40×10^9 t) in the mining industry was estimated to cover 1.23%, 3.7%, 12% and 45% of those in China, respectively (NBS, 2016). These problems, which are often caused by excessive exploitation, disordered utilization, and unreasonable emissions, lead to regional ecosystem degradation and socio-economic problems. Thus, the industry-induced environmental issues and alternative transition pathways must be addressed in resource-based cities (Fang et al., 2007; Chen et al., 2011; Li et al., 2013; Yang et al., 2013; Li et al., 2016b; Yang et al., 2017; Fan et al., 2017). In 2008, 2009, and 2011, China established three groups of 69 resource-exhausted cities (counties and regions) and invested in a fund for industrial transitions with a total of approximately RMB 500 billion. In 2013, the State Council released the *Sustainable Development Plan for National Resource-based Cities*, which guided the economic transition to sustainable goals in resource-based cities.

This study chooses Baiyin City, one of the first industrial transition pilots for national resource-exhausted cities, as a case study to examine how resource and environmental constraints affects local industrial competitiveness and the resilience dynamics of the industry–environmental system, and if such constraint–adaptation relationships can promote sustainable transitions. The research objectives are as follows. (1) Seven resource and environmental variables are measured to reveal the constraints on local industrial development. These combine with industrial indicators to reflect the industrial structure and its competitiveness. (2) The resilience curves of seven resource and environmental variables are identified to depict the adaptive capacity of the local industry–environmental system from 1990 to 2016. (3) Resilience-oriented management is discussed for adaptive capacity and transitions in the coupled industry–environmental systems.

2. Methods

2.1. Case study

Baiyin City (35°33′N, 103°33′E) belongs to Gansu Province, Western China, and covers an area of approximately 21200 km^2. It lies in the eastern entrance of the Hexi Corridor (the ancient land-based Silk Road) and is located in the transition region of the Loess Plateau, the eastern Qilian Mountain, and the Tengger Desert. Baiyin City is the core of the Lanzhou–Baiyin economic circle in Gansu Province. The city had a population of 1.70 million in 2015.

Complex geographical features and harsh weather conditions result in intensive human–land relationships. Typically, Baiyin City suffered from a shortage of water resources; its per capita fresh water supply (136 m^3) accounted for only 6.2% of national level in 2014. As a mining and smelting base in China, Baiyin City was well known for its rich nonferrous metal resources. The reserves of 23 out of 45 categories of mineral resources in Baiyin City are top-ranked in Gansu Province. Baiyin City had been ranked first for 18 successive years in copper production, output value, taxation, and profits (Su, 2005). Given the heavy dependence of local industries on mineral resources and long-term, high-intensity exploitation, the main mineral resources in Baiyin City have been exhausted, accompanied by intensifying environmental pollution since 1990. As a result, the economic structure changed from a "primary–tertiary–secondary" mode to a "tertiary–secondary–primary" mode in 2016.

In this study, Baiyin City is chosen to analyze the constraint–adaptation characteristics and resilience dynamics of the industry–environment system. First, Baiyin City was listed among the first 12 industrial transition pilots for national resource-exhausted cities in 2008. Transition practices and the valuable "Baiyin Mode," that is, the combined mode of industrial transition and ecosystem restoration, are representative efforts that are worthy of generalization. Second, as a city dependent on mineral resources, Baiyin City is highly similar to most resource-based Chinese cities in its lifecycle evolution of the industry–environmental system. Baiyin City is the epitome of a resource-dependent city in China. Third, the location and regional characteristics of Baiyin City deserve to be studied because of the vulnerable environments in Western China and increased environmental issues.

2.2. Data acquisition

Baiyin City was compared with Gansu Province and the entire country in terms of environmental and industrial performance from 1990 to 2016. The industrial, environmental, and resource data utilized in this study are from the *Statistical Yearbook of Baiyin City, Yearbook of Baiyin City, National Economic and Social Development Statistics of Baiyin City, Development Yearbook of Gansu Province, Yearbook of Gansu Province, Statistical Yearbook of Gansu Province, City Yearbook of Gansu Province, National Economic and Social Development Statistical Bulletin of Baiyin City in 2016, China Statistical Yearbook,* and *National Economic*