Assessing industrial ecosystem vulnerability in the coal mining area under economic fluctuations

Delu Wang a, *, Jianping Zheng a, Xuefeng Song b, Gang Ma a, Yun Liu c

a School of Management, China University of Mining and Technology, Xuzhou, Jiangsu, 221116, PR China
b School of Management Science and Industrial Engineering, Nanjing University of Finance and Economics, Nanjing, Jiangsu, 210003, PR China
1 Management School, Lancaster University, Lancaster, LA2 0PJ, United Kingdom

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A B S T R A C T
In the context of the depth adjustment of the global economy and wild fluctuations in energy prices, the
vulnerability issue of the coal mining industrial ecosystem (CMIES) has seriously affected the sustainable
development of the regional economy. Comparisons of CMIES health status at a regional level are worthy
of being conducted. This not only contributes to understanding a particular coal mining area’s situation
in regards to CMIES vulnerability, but also helps to discover a meaningful benchmark to learn the ex-
periences in terms of action programmes formulation. In this study, based on the analysis of the
vulnerability response mechanism of CMIES to economic fluctuations, an initial indicator system for
vulnerability assessment of CMIES was constructed. Ultimately, 14 vulnerability-evaluating indicators
and their weights were obtained using rough set attribute reduction. Based on a composite CMIES
Vulnerability Index (CVI), the Rough Set-Technique for Order Preference by Similarity to Ideal Solution-
Rank-sum Ratio (RS-TOPSIS-RSR) methodology is proposed to conduct the CMIES vulnerability assess-
ment process from an overall perspective. Using this methodology, 33 coal mining areas in China are
ranked as well as grouped into three specific groups based on the CVI score. The results demonstrate the
feasibility of the proposed method as a valuable tool for decision making and performance evaluation
with multiple alternatives and criteria.

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1. Introduction

For a long time, the coal industry has caused an increasingly serious ecological crisis as well as numerous inevitable social problems under the one-way linear production model of ‘resources-products-waste’ (Kuai et al., 2015), despite the fact that it contributed significantly to economic development (Moran et al., 2014). Under the background of ecological civilization construction, the industrial metabolism model of ‘resources-products-regenerated resources’ has become the basic pattern for the green and intensive development of coal mining areas (Li and Wang, 2015; Ren, 2011). In fact, industrial enterprises mostly focused on their core business, and could not ensure that the secondary activities of value chain, such as pollution prevention and control, receive adequate attention. However, integrating resources through an industrial symbiosis network could relieve the finiteness of the resources and ability of environment governance, which also provides the most suitable way for intensive industry development (Korhonen et al., 2004; Yu et al., 2015). Recently, the United Nations Industrial Development Organization has advocated and promoted a regional ecological development strategy in the world. The Chinese government has focused on ecological modernization, green growth, and low-carbon development and made the circular economy development as a part of the national ecological security strategy, (Geng et al., 2013). Under the guidance, intervention, and even dominance of government bodies at all levels, more than 40 large-scale mining areas in China have constructed coal mining industrial ecosystem (CMIES) by building circular economy parks.

CMIES is formed by optimizing industrial chains vertically and horizontally according to the principle of material cycling and harmonious symbiosis between biology and industry in a coal mining area (Zhang et al., 2013). CMIES is an open and complex giant system. In such a complex system, a minor change in
economic or environmental factors can trigger enormous changes in the mining areas’ economic development (Martin and Sunley, 2015). CMIES vulnerability has restrained the sustainable development of coal mining areas. According to the theory of vulnerability, CMIES does not always demonstrate vulnerability under any kind of disturbance. It displays different characteristics of vulnerability in facing different types of disturbance. Therefore, CMIES vulnerability is always closely related to certain disturbances imposed on the system. The major industries of CMIES (e.g., coal, electronics, and coal chemical industry) are all the fundamental industries of the national economy. According to the Morgan Stanley Capital International Index, these industries are more sensitive to economic fluctuations and are relatively more affected by fluctuations compared with general light industries. Thus, economic fluctuations play an important role in many disturbance factors which affect the healthy development of CMIES. For example, as coal prices have been falling since 2012, many coal mining areas such as Changzhi, Hainan, Panzhihua, Qitahei, and Jincheng have suffered an economic slowdown and even fell into serious crisis, with unemployment rates of more than 800, 000.

In recent years, many challenge-seeking researchers among both academia and industry have spent considerable efforts on the CMIES’ development strategy (Muduli et al., 2013), evolution mechanism (Van Beers et al., 2007), efficiency evaluation (Kulshreshtha and Parikh, 2002), and resource metabolism (Salmi, 2007). However, literature shows that studies on the composite index and method of CMIES vulnerability assessment are limited, despite the fact that they are the key processes affecting the success of comprehensive management of CMIES. Evaluating vulnerability is an interesting and challenging problem, and always an important concern for both managers and policymakers. Therefore, we attempt some exploratory research on the vulnerability assessment related to CMIES under economic fluctuations scenario. This study contributes to the literature in three ways. First, we propose a new RS-TOPSIS-RSR methodology to assess CMIES vulnerability. The integration of three isolated models can give full play to each other’s advantages as well as overcome their disadvantages. Second, we introduce a hierarchical structure of CMIES Vulnerability Index (CVI). The CVI captures a multitude of risk information in a comprehensive way instead of considering isolated indicators, and offers advantages in terms of benchmarking and decision making. Third, the 33 coal mining areas of China are ranked and classified into three groups, and the causes of high-vulnerability pattern are revealed. This is favorable for policymakers in drawing up targeted programmes.

The remainder of this paper is structured as follows. After the introduction, Section 2 reviews the related literature. Section 3 introduces a hierarchical structure of the composite CMIES Vulnerability Index (CVI) of coal mining areas as well as the study areas and data sources. Section 4 presents the integrated RS-TOPSIS-RSR methodology for CMIES vulnerability evaluation. Section 5 reports the application of the methodology and computational results. Section 6 discusses the corresponding results and implications. Finally, Section 7 summarizes the key conclusions and outlook.

2. Literature review

The concept of vulnerability originated from studies about natural disaster in 1960s (Janssen et al., 2006). As a new analysis tool in the area of sustainability science, the vulnerability research has been applied to disaster management (Zhang and Huang, 2013), ecology (Collin and Melloul, 2002), economics (Serwa and Bohl, 2005), etc. Among them, some natural science fields such as climate change and natural disaster always take up a dominant position. In recent years, as many research institutions (e.g. Inter-governmental Panel on Climate Change) increasing emphasis on the response and adaptation of human society to global change (Marshall et al., 2014), the researches on the vulnerability of human system and social-economic-natural complex ecosystem have become a new trend. From the point of view of research in different fields, natural sciences consider that the disturbance imposed on the system, the exposure degree and sensitivity of the system to disturbance are the determinants of system vulnerability. However, humanities take the vulnerability of human system as an intrinsic property originated from the internal of the system. And they focus on the discussion of the system, economic and culture factors that cause the human society to be easily damaged. The researches on the vulnerability of complex ecosystem explain emphatically the interaction among nature, society, and economic systems.

In order to better carry out vulnerability assessment, scholars have proposed many vulnerability analytical frameworks, such as risk-hazards (RH) model, Pressure–State–Response (PSR) model (Wolfslehner and Vacik, 2008), the Exposure–Sensitive–Adaptation (ESA) model (Polsky et al., 2007), and airline house vulnerability (AHV) (Turner et al., 2003). In terms of evaluating method, most of the extant studies adopt composite index method (Zhang and Huang, 2013). However, based on different analytical frameworks, the vulnerability assessment indexes built by the scholars are different from each other. For example, when assessing the impact of disasters or climate change based on RH model, the exposure and sensitivity of hazard-affected body to environment change are often emphasized. According to the models of PSR and ESA, the vulnerability depends on how the system can respond to disasters. Therefore, compared to RH model, these two models more emphasize that the resilience has the decisive significance for disaster vulnerability.

The extant studies suffer from a few limitations. The first issue is related to the assessment indicators of CMIES vulnerability. The existing studies tend to describe industrial ecosystem property from different points of view (Chopra and Khanna, 2014; Li and Shi, 2015). They doesn’t presents an overall perspective on the industrial ecosystem health by capturing a multitude of vulnerability information in one index score (Jiao and Boons, 2014; Wang et al., 2013). Comparing each indicator individually doesn’t account for the aggregation of indicators. This may then make coal mining areas have different evaluation results using different exposure information. It is unfavorable for policymakers in assessing their own relative CMIES vulnerability and drawing up targeted programmes. Consequently, it is attractive, desirable and necessary to create an overall CMIES vulnerability index. Further more, the combination of CMIES vulnerability indicators into an index is a methodologically intensive process. It includes assigning weights of indicators and aggregating these indicators. In this respect, new methods are worthwhile exploring and testing for the CMIES vulnerability case.

3. Indicators and data

3.1. Composition of CMIES

Coal mining areas are the economic geography areas which are formed during the process of coal mining and processing and have common features in economic characteristics, social functions, and environmental attributes. According to Mathews and Tan (2011) and Yao et al. (2015), CMIES consists of four subsystems (as shown in Fig. 1), namely, original industrial subsystem, extended industrial subsystem, resources and environment subsystem, and social service subsystem. The original industrial and extended
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