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Analyzing sustainability of Chinese mining cities using an association rule mining approach

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ABSTRACT

Mining cities are of vital importance to the global development, but they are facing great challenges to achieve sustainability goals. Understanding the characteristics and patterns of the environmental, economic, and social conditions of mining cities is critical to promoting their sustainability. After developing an Indicator System for Mining City Sustainability, we collected data from 110 prefecture-level cities and analyzed environmental, economic, and social characteristics of these mining cities using a data-mining method – Association rule mining. Our analysis revealed some novel, implicit, and previously unknown characteristics and patterns of mining city sustainability in China. We found that education investment, economic development, and some aspects of society were substantially unbalanced in most Chinese mining cities. Most coal-mining cites had a larger proportion of mining population, and usually faced severe challenges in reducing industrial dust emission. The unsustainable characteristics of Chinese mining cities exhibited distinctive regional patterns and should be considered explicitly in policy making to promote the sustainability of these urban areas.

1. Introduction

Mining cities have played an important role in socioeconomic development around the world. In China, mining cities provide primary raw materials and make great global contributions. Since 1949, Chinese mining cities have provided 52.9 billion tons of raw coal, 5.5 billion tons of crude oil, and 5.8 billion tons of iron ore for the whole country. However, these mining cities face great challenges in socioeconomic development and ecological environment protection because of their slow undertakings of social development, imbalanced economic structure, and seriously damaged ecological environment. To promote the sustainable development of mining cities, the first and most important step is to identify clearly the patterns and characteristics of mining city sustainability.

Several research efforts have been made in mining sustainability following the rising importance of sustainability. On one hand, mining activities have much in common with industry activities worldwide. Consequently, several researchers have contributed to the evaluation of mining sustainability from a mining industry perspective, mainly including evaluation indicator systems and evaluation methods. Among the burgeoning evaluation indicator systems, the Global Reporting Initiative (GRI) framework and its mining and metals sector supplement (MMSS) is arguably the most widely adopted evaluation system in the mining industry (GRI, 2000, 2012). Based on the second generation of GRI, Adisa Azapagic developed an evaluation framework for the mining industry, which has been cited widely (Azapagic, 2004). In addition, many industrial associations and organizations, such as the Mining Association of Canada (MAC), Mining, Minerals, and Sustainable Development project, and several researchers including Yu (2005, 2008) and Giurco (2012) also proposed evaluation indicator systems for mining industry sustainability (Yu et al., 2005, 2008; Giurco and Cooper, 2012). Moreover, Worrall discussed an evaluation system for legacy mine land while Solomon studied the social dimension of mining sustainability (Solomon et al., 2008; Worrall et al., 2009). With respect to evaluation method, Yu (2005, 2008) applied the fuzzy integrated judgment model and factor analysis (Yu et al., 2005, 2008), Kommadath (2012) discussed a fuzzy logic-based approach, and Valdivia (2011) utilized a life-cycle inventory method (Kommadath et al., 2012; Valdivia and Ugaya, 2011).

On the other hand, mining sustainability is closely related to the condition of the special geographical space where mining activities are carried out. Different geographical spaces have different ecological environmental, economic, and societal conditions; therefore, the patterns, characteristics, strategies, and policies for

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mining sustainability may vary greatly in different locations. As a result, a number of special researches and case studies were conducted on different mining locations using different scales, such as mining site, mining city, country, and region. Bebbington et al. (2009) studied the institutional challenges for mining and sustainability in Peru. They found that mining expansion has placed pressures on water resources, livelihood assets, and social relationships, and these pressures are because of the institutional conditions that separate the governance of mineral expansion, water resources, and local development, and of asymmetries of power that prioritize large-scale investment over livelihood and environment (Bebbington and Bury, 2009). Mudd (2007) examined the long-term trends of almost all sectors of the Australian mining industry by illustrating the principal issues concerning mining and sustainability: increasing production, declining ore grades, increased open-cut mining and associated waste rock or overburden and remaining economic resources. The author concluded that the sustainability of the mining industry in Australia continues to hang in the balance (Mudd, 2007). Hajkowicz et al. (2011) examined the relationship between mining and socio-economic wellbeing in Australia and found that mining activity has a positive impact on incomes, housing affordability, communication access, education and employment across regional and remote Australia. Sorensen (2012) studied the sustainable development of mining companies in South Africa and pointed out their inconsistent understanding of the idea of sustainability.

In addition, mining activities are usually organized in the form of projects, and a number of studies were from the perspective of mining projects and sustainability. McLellan et al. (2009, 2012, 2013) wrote a series of papers on integrating sustainability into design and management of mining projects (McLellan et al., 2009; Corder et al., 2012; Tuazon et al., 2012; McLellan and Corder, 2013). Phillips (2012) applied a mathematical model of sustainability to the environmental impact assessment of a proposed bauxite-mining project in Indian and indicated the potential of this model in problem resolutions of sustainability of local mining projects.

Considering the complexity and systematic nature of mining sustainability, all these research perspectives are necessary and significant. Research from a sustainable mining industry perspective can promote information exchange and comparisons between mining corporations to contribute to mining sustainability. Research from a sustainable mining projects perspective can help implement sustainable mining activities according to particular circumstances, while research from a mining region perspective can comprehensively and profoundly identify the sustainability of the mining region and the relationships between mining and local sustainability. Considering that mining activities have fundamental influences on the local environment, economy and society, the mining region perspective is ideal and greater attention needs to be paid to this perspective. Regarding the scale of the mining location, a national scale may be too large to understand the local effects of mining on sustainability, whereas a site scale may be too small to include all the important effects of mining. Thus, we consider a mining city to be a key scale for studying mining sustainability. Overall, the study of mining city sustainability is still in its infancy and needs further research.

The main purpose of this study was to investigate the environmental, economic and social characteristics of mining cities in China using association rules mining, which is a novel method in this field. Following the Tipple Bottom Line model of sustainability, we developed an Indicator System for Mining City Sustainability (ISMCS), collected data from 110 prefecture-level mining cities, and applied Association rule mining to the collected dataset. The mined association rules and frequent patterns were analyzed to identify the patterns and characteristics of mining city sustainability in China, so as to provide a scientific basis for policy making.

2. Methods

2.1. Indicator system for mining city sustainability

We propose the ISMCS based on the triple bottom line model (Fig. 1). As we can see from the triple bottom line model, apart from the three fundamental dimensions, environment, society and economy, there are three intersections of two dimensions and one intersection of three dimensions. Here the four intersections are differentiated from the three fundamental dimensions and treated as separate dimensions. That is, in addition to the three fundamental dimensions (environment, economy, and society), there are three integrated two-dimensional domains (economy-society, economy-environment, society-environment), and one integrated three-dimensional domain (economy-society-environment). This structure will be helpful not only to represent and understand the sustainability status of mining cities in China, but also to analyze and interpret the mined association rules. Furthermore, for mining city in China, four type indicators is vital to both the description of mining city status and discovery of characteristics and patterns of mining city sustainability. Among the four indicators, Province and Region describes each mining city's geographical location, Stage represents each mining city's development stage, and Resource shows the mineral resources each mining city reserves and produces. As a result, mining city type dimension is needed. Consequently, there are eight dimensions in the ISMCS altogether.

Furthermore, since association rule mining is an unsupervised learning method, there is no clear measure of success, which can be used to judge adequacy in indicator selection (Hastie et al., 2009). Therefore, to effectively discover the novel, implicit association rules of mining city sustainability, we select relatively larger number of indicators than previous research (Yu et al., 2005; Yu et al., 2008), so as to collect adequate data on mining city sustainability. In consequence, we constructed the ISMCS using eight dimensions and 52 indicators (Table 1).

2.2. Sample selection and data collection

Considering comprehensiveness and comparability for our research sample, we chose all prefecture-level mining cities

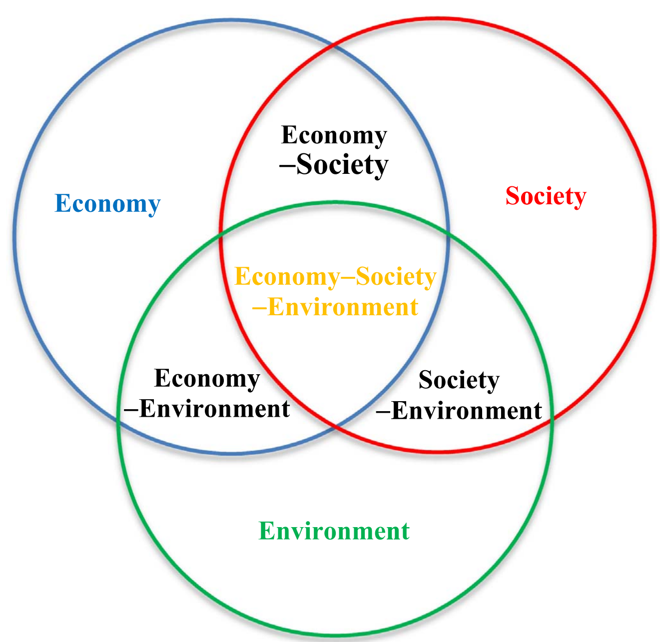

Fig. 1. Improved Triple Bottom Line Model.