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An emergy accounting based regional sustainability evaluation: A case of Qinghai in China

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ABSTRACT

Featured with a unique geographic position and climate conditions, Qinghai is abundant with natural resources, making significant contribution to China's or even the world's ecological security. In order to evaluate its current sustainability and provide useful policy suggestions to improve its sustainable development, a systematic study on Qinghai's socio-economic system was conducted by applying emergy synthesis. Results show that the total emergy use for supporting Qinghai's economy was 5.13×10^{24} sej in 2015. The values of emergy to money, emergy density, and emergy used per person are 2.12×10^{13} sej/RMB, 7.11×10^{12} sej/m^2, and 8.72×10^{17} sej/person, respectively. The holistic picture of Qinghai's socio-economic system is also uncovered based on the temporal analysis of emergy-based indicators. Results show that emergy yield ratio increased from 52.21 in 2002 to 164.10 in 2015. Similarly, the environmental loading ratio increased from 4.64 in 2002 to 57.99 in 2015. Correspondingly, the value of emergy-based sustainability index decreased from 11.25 in 2002 to 2.83 in 2015. These results indicate that Qinghai was highly dependent on local resources and its sustainability experienced a declining trend. In addition, the high absolute value of emergy to money ratio indicates that Qinghai was a net loser for its domestic and international trade. Sensitivity analysis was also conducted to test the reliability of these results. Finally, policy recommendations based on such a systematic evaluation and local realities were proposed to improve its sustainable development.

1. Introduction

Rapid industrialization and urbanization has resulted in significant environmental problems, with not only environmental emissions but also biodiversity loss and ecological degradation. In response to these increasing environmental issues, the Chinese government has enacted many policies and regulations aiming to achieve sustainable development (Zhu and Geng, 2013; Zhu et al., 2014). For example, the Chinese government has paid a great attention on promoting circular economy (Geng et al., 2013a; Geng et al., 2016), which is considered an effective approach to achieve long-term sustainable development. Particularly, the first National Security Commission of the Communist Party of China listed ecological security as one key national security mission in 2014 (The State Council of China, 2014), which highlights the significance of environment protection.

Known as China's water tower (also Asian water tower), Qinghai has rich endemic species and natural resources (Li et al., 2012) and plays a significant role in keeping the ecological balance of China and the rest of the world (Wang et al., 2015). However, under the policies of China Western Development, the West-to-East Gas Transmission, and the Qinghai-Tibet Railway, Qinghai has been facing increasing ecological problems, such as overgrazing, grassland degradation, and ecological deterioration (Han et al., 2016). Under this circumstance, the Chinese central government has decided to implement the comprehensive environmental protection policies in Qinghai and actively promote circular economy so that the overall resource efficiency and environmental quality can be improved. Therefore, it is crucial to identify its resource utilization structure, current sustainability level, and uncover key factors hindering its sustainable development, so that valuable policy implications on promoting sustainable development in Qinghai

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can be raised.

The sustainability evaluation of one socio-economic system has been widely conducted by applying various methods, such as material flow analysis, eco-footprint method, and emergy accounting (EMA) method. However, both material flow analysis and eco-footprint methods can hardly reveal the characterization of environmental integrity and resource use for a socio-economic system (Viglia et al., 2017). Also, both methods cannot fairly judge the true contribution of local ecosystem to local economic development. In this study, EMA method based on biophysical and thermal dynamic theory is adopted to evaluate the sustainability of Qinghai's socio-economic system from the perspective of donor side. The unique advantage of EMA is that the diversity of energy and material flows related to the investigated system can be converted into a unified dimension, addressing both their quantity and quality (Brown and Ulgiati, 2016; Brown et al., 2016). By integrating ecological hierarchy and resource quality, EMA has been proven to be an appropriate method for evaluating the sustainability of socio-economic systems (Geng et al., 2013a; Lou and Ulgiati, 2013). Specially, EMA has been extensively applied for regional sustainability evaluation in recent years. For example, Chen et al. (2017b) applied EMA to evaluate the sustainability of Yunnan Province in China and provided useful suggestions for Yunnan's long-term sustainable development. Similar studies were also performed to evaluate the sustainability at different levels, such as the whole China (Yang et al., 2010; Lou and Ulgiati, 2013), Beijing-Tianjin-Hebei region (Fang and Ren, 2017), Yellow River Delta region (Wang et al., 2016), Shenyang city (Sun et al., 2016), Beijing city (Jiang et al., 2009; Qi et al., 2017), Mongolia (Li and Brown, 2017), Montreal in Canada (Vega-Azamar et al., 2013), as well as Roma, Napoli, Vico Equense, Massa Lubrense and Ischia in Italy (Viglia et al., 2017). Chen and Chen (2011) also evaluated the global solar emergy use associated with economy activities. However, a literature review did not find any special EMA studies on Qinghai's socio-economic system, except three papers published in Chinese (Zhuo et al., 2008a,b,c), which are not easily available for international academia. The aforementioned three studies on Qinghai (Zhuo et al., 2008a,b,c) also have several limitations, such as the lack of data integrity and transparency. Furthermore, the emergy baseline and emergy-based conversion factors (i.e. Unit Emergy Value, UEV) have been modified and improved in the recent years (Brown et al., 2016; Brown, et al., 2011; Lou and Ulgiati, 2013), leading to a request to update evaluation results. In order to address these problems, this paper aims to evaluate Qinghai's socio-economic system based on updated data so that its resource utilization structure and sustainability level can be uncovered. Temporal analysis is also performed so that the historical evolution of Qinghai's social-economic system can be presented. Finally, sensitivity analysis is conducted so that results obtained in this study could be more accurate and reliable for policy-making. The whole paper is organized as below. After this introduction section, Section 2 introduces research methods and data sources. Then, Section 3 presents research results and Section 4 discusses policy implications. Finally, research conclusions are drawn in Section 5.

2. Methods and data

2.1. Research area

Located at 31°36′2″ ~ 39°12′45″ north latitude and 89°24′3″ ~ 103°4′10″ east longitude in northwest of China (Fig. 1), Qinghai province is on the northeast of Tibetan Plateau (known as the Roof of the World). It covers an area of 0.72 million square kilometers, with a total population of 5.94 million in 2016. The altitude evaluation of Qinghai stretches from 6.86 km to 1.65 km, with an average altitude of over 3 km above the sea level. Qinghai has a typical plateau continental climate, with features of cold, dry, windy weather, less precipitation, and a large diurnal temperature difference.

Qinghai is experiencing a rapid economic growth under the policy

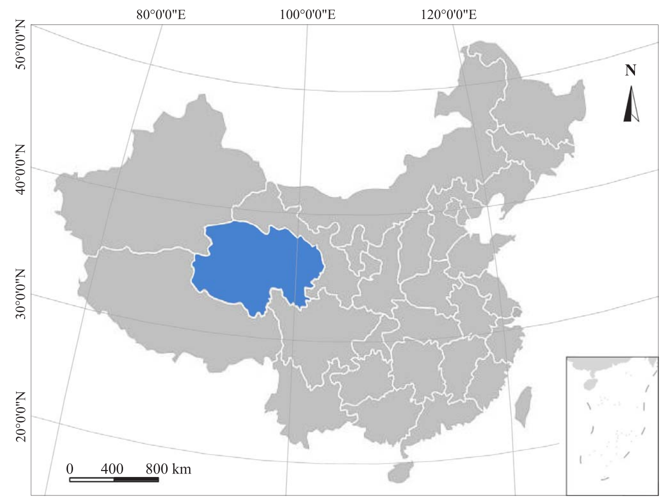

Fig. 1. The geographic location of Qinghai Province in China.

of China's Western Development. By the end of 2016, Qinghai's gross domestic product (GDP) reached 257.249 billion RMB, with an annual increase rate of 15% since 2000 (26.359 billion RMB). However, such a rapid economic development was based upon large scaled resource consumption, with less attention on environmental protection (Wang et al., 2017). In addition, Qinghai is ecologically fragile and particularly sensitive to environmental disturbance although it has a significant role to the global atmospheric and water circulation. Recognizing the important role in ecological security, Qinghai was listed as one national ecological civilization demonstration areas in 2014 (NDRC, 2014). Therefore, it is critical to promote sustainable development in Qinghai so that the overall environmental quality and resource security can be improved.

2.2. Emergy synthesis

2.2.1. Emergy accounting

Originated by Odum in the late 1980s, emergy theory can provide a biophysical perspective of one socio-economic system (Odum, 1996; Chen et al., 2017a). Emergy was defined as available energy previously used up directly and indirectly during the production process of a product or service (Odum, 1996; Viglia et al., 2017). It is measured in solar equivalent joules and expressed in solar emjoules (sej). Measuring all forms of energy, resources, and human services based on solar energy equivalent allows the direct comparison of input and output flows and thus makes it possible to analyze all aspects of a studied system in an integrated manner (Viglia et al., 2017). Emergy value of one individual flow (U_i) can be calculated according to Eq. (1):

$$U_i = UEV_i \times f_i \tag{1}$$

where f_i represents the amount of one individual flow, in the unit of grams (g), joule (J), or money ($); UEV_i represents the amount of emergy required to produce one unit of product or service, in the unit of sej/unit (i.e., sej/g, sej/J, and sej/$).

Based on Eq. (1), all the input materials, energy sources, and service flows could be calculated. According to Odum (1996), the sustainability evaluation of an integrated ecological-economic system could be conducted based on the following steps:

(1) Drawing a system diagram. Fig. 2 shows the emergy-based system diagram of Qinghai's ecological-economic system, in which main components, input and output flows are addressed.
(2) Identifying major flows (e.g., materials, energy, and monetary flow) which are used for sustaining the production and consumption processes within the studied system.