Energy Policy 67 (2014) 508–516

Contents lists available at ScienceDirect

Energy Policy

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

Emergy evaluation of agricultural sustainability of Northwest China before and after the grain-for-green policy

Xiuhong Wang [a,*], Jianxiu Shen [a,b], Wei Zhang [c]

[a] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[b] University of Chinese Academy of Science, Beijing 100049, China
[c] Institute of Remote Sensing and Earth Sciences, Hangzhou Normal University, Hangzhou 311121, China

HIGHLIGHTS

- The total emergy input and energy output of the study system increased from 1991 to 2008.
- The change of each emergy index was more evident after the GFGP launched in 2001.
- The increase in input of non-renewable purchased resources will gradually reduce the function of the GFGP in West China.
- Agricultural development in West China should be based on organic agriculture.

ARTICLE INFO

Article history:
Received 13 May 2013
Received in revised form
18 November 2013
Accepted 28 December 2013
Available online 16 January 2014

Keywords:
Emergy
Agricultural sustainability
Northwest China

ABSTRACT

China's grain-for-green policy (GFGP) was implemented with the goal of improving ecological security. Consequently, agricultural energy and agrochemical inputs have been significantly increased to improve food security and to increase the income of farmers in the regions where the GFGP was implemented. In analysis of the sustainability of the agricultural system affected by the GFGP, it is essential to consider both economic profitability and environmental sustainability. Using Yanchi County as a case study area, this study used an emergy synthesis to examine the sustainability of the agricultural system before and after the GFGP in Northwest China. We found that the total emergy input and energy output of the agricultural system in the study area increased from 1991 to 2008; however, the sustainability of the system declined, and this decline was especially evident after the GFGP was launched in 2001. Increasing inputs of non-renewable purchased resources will not only reduce the effectiveness of the GFGP in Northwest China, but also hinder the implementation of the energy-saving and emission-reduction policy that China launched in 2005. We suggest that sustainable agricultural development in Northwest China should be based on effective use of renewable resources and development of a low-carbon agricultural economy.

1. Introduction

With the rapid social changes and population growth that occurred in China under the planned economy from 1953 to 1978, food security became a primary goal of the central government, and this led to increased land reclamation. Although the central government was aware of the adverse effects caused by agricultural land expansion, ecological goals had to be set aside under pressure from the growing population and increasing food demand (Qin and Chen, 2005). Since the start of economic reforms in China in 1978, it has become evident that the single-minded pursuit of economic efficiency has resulted in growing ecological problems, especially in the ecologically vulnerable western regions, and serious ecological problems have been affecting the quality of life and even the survival of local people (Wang et al., 2007).

In 1999, the intensifying ecological degradation led the central government to implement the grain-for-green policy (GFGP), an important initiative promoting ecological restoration of the country's ecologically vulnerable regions (Qin and Chen, 2005; Wang and Chen, 2006). China's GFGP involved the conversion of marginal cropland to forests or grasslands (Feng et al., 2005). Local farmers were required to quit agricultural production on marginal croplands, and were compensated with grain and cash, depending on the size of the land they converted (Yang, 2004). The GFGP was gradually implemented in 25 provinces (regions and cities) and involved 3.20 million households and 124 million farmers. The

* Correspondence to: Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, P.O. Box: 9717 or 9719, 11A Datun Road, Anwai, Beijing 100101, China. Tel.: +86 10 64888206; fax: +86 10 64851844.
E-mail addresses: wangxh@igsnrr.ac.cn, wangxh567@163.com (X. Wang).

0301-4215/$ - see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2013.12.060

policy has made great strides in slowing ecological degradation in the ecologically vulnerable regions, particularly in Northwest China, which has been impacted by desertification. It has also contributed to the improvement of ecological conditions in the downwind and downstream eastern and southern regions (Wang and Chen, 2006).

After the GFGP was implemented, a number of new problems arose, which affected the quality of life of local communities and even food security in China: small landholdings per household, low quality of croplands, insufficient cropland reserve resources, and an alarming rate of reduction in overall cropland (Chen et al., 2003; Song et al., 2012; Feng et al., 2005). Therefore, improvement of the production capacity of cropland and the entire agricultural system has become essential to food security and is complementary to the GFGP goals. In Northwest China, improvement in production capacity and the economic efficiency of the local agricultural systems is also essential to the basic living conditions of the local people, who are the primary driving force behind ecological restoration (Wang et al., 2007). To address the problems listed above, local people commonly increase agricultural energy and agrochemical inputs in order to maintain and enhance land productivity for food security. However, greenhouse gas emissions and potential agricultural non-point source pollution from these types of agricultural operations have increased, which, in turn, has affected the quality of local land, groundwater, surface waters, and agricultural products. For example, the use of plastic film mulch in West China has exceeded that of East China (Gao et al., 2003). This type of agricultural input not only affects regional agricultural sustainability, but also poses a potential threat to the ecological and environmental stability of the entire country (Wang, 2013), which will ultimately reduce or offset the role of the GFGP.

In China, the inputs of non-renewable purchased resources of agriculture are growing; however, the contribution of agricultural production to gross domestic product (GDP) is gradually declining (Qi et al., 2010). Based on reports released by the Intergovernmental Panel on Climate Change (IPCC), agriculture produced about 14% of the world's total greenhouse gas emissions (Willey and Chameides, 2007; Wan et al., 2013). As the largest developing and agricultural country, China announced that carbon emissions per unit of GDP would be reduced 40–50% from 2005 levels by the year 2020 (Wan et al., 2013). Nevertheless, sufficient effort has not been extended to the control of the development of high carbon agriculture resulting from the increasing inputs of non-renewable purchased resources in the GFGP implemented regions. Consequently, these trends are harmful to the implementation of China's new energy-saving and emission-reduction policy launched in 2005.

Many studies have calculated the amount of converted marginal croplands and analyzed the improvement in economic efficiency of the remaining croplands associated with the GFGP (Deng et al., 2006; Feng et al., 2005; Xu et al., 2006; Lu et al., 2013; Dang and Liu, 2012); yet, few have discussed the potential environmental problems and the sustainability of the agricultural system caused by intensive agricultural development, especially in Northwest China, where most of the land conversion and agricultural intensification has occurred. Also, an integrated approach is needed to quantify the impact of free environmental resources and purchased resources on the sustainability of the agricultural system in the ecologically vulnerable regions with regard to local economic development and national ecological security (Zhang et al., 2007).

Emergy synthesis is an evaluation system designed to measure both environmental and economic values (Odum, 1996) and is a suitable tool for assessing the long-term sustainability of various systems (Brown and Ulgiati, 1999). Thus, emergy synthesis not only has been effectively used to evaluate agricultural systems at national scales, but also has been adopted to assess agricultural systems at smaller scales. It has also been used to evaluate management patterns with regard to their resource use, productivity, environmental impact, and overall sustainability (Dong et al., 2006; Zhang et al., 2007). For example, emergy synthesis was applied to assess: the environmental performance and the effects of land use on sustainability of a coffee farm located in Coromandel, Minas Gerais, in the Brazilian Cerrado (Giannetti et al., 2011); resource consumption in a Japanese agricultural system and the link between energy security and food security (Gasparatos, 2011); biomass resource exploitation by agriculture in China (Jiang et al., 2007); and the sustainability of a cropping-grazing system in the Inner Mongolia Autonomous Region in North China (Zhang et al., 2007).

Using Yanchi County in the Ningxia Hui Autonomous Region in Northwest China as a case study area, and adopting emergy synthesis as the main assessment tool, the objectives of this study were: (1) to probe the state of emergy input and energy output for the agricultural system before and after the intensification of agricultural land use and changes in resource use efficiency associated with the GFGP; (2) to reveal the potential environmental problems created during the agricultural production process characterized by high inputs of agricultural energy and agrochemicals, an issue which has attracted much attention in East China but has been neglected in Northwest China; and (3) to promote an ecological and organic agricultural system, which is closely related to the development of characteristic, low-carbon agriculture in Northwest China based on the analysis of emergy-based indices. This research can hopefully contribute to policies promoting ecological conservation and the development of a low-carbon agricultural economy in Northwest China.

2. Material and methods

2.1. Study area

Yanchi County is located at 37°35′–38°10′ latitude and 106°30′–107°39′ longitude in the transition zone between the Ordos Plateau and the Loess Plateau with an area of 8661 km^2 (Fig. 1). It has a relatively low annual average precipitation of 220 mm and a relatively high annual evaporation of 2897 mm. The annual average temperature is about 8.5 °C, and the annual average wind speed is about 2.7 m/s (Jiang, 2006).

Yanchi County (Salt Pond County) is the place of origin for Chinese Tan sheep, a branch of Mongolian sheep known for its fine, thick wool and delicious meat. The county was listed as a pilot

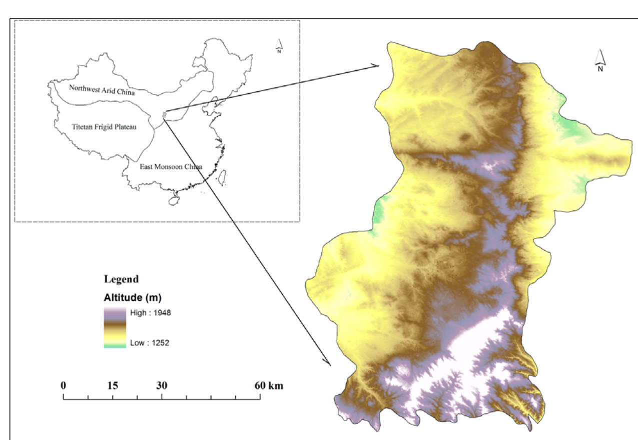

Fig. 1. Location of study area.