ECOLOGICAL ECONOMICS 69 (2010) 1396–1404

available at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/ecolecon

Total embodied energy requirements and its decomposition in China's agricultural sector

Shuyan Cao[a,b,*], Gaodi Xie[b], Lin Zhen[b]

[a]Department of Public Management, Beijing Institute of Petrochemical Technology, 19 Qingyuan North Road, Daxing District, Beijing 102617, PR China

[b]Center for Resources Science, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 11A Datun Road, Chaoyang District, Beijing 100101, PR China

ARTICLE INFO

Article history:
Received 22 October 2007
Received in revised form 24 April 2008
Accepted 10 June 2008
Available online 16 September 2008

Keywords:
Energy use
Energy requirements
Input–output modeling
Decomposition analysis
Agricultural productivity
Energy efficiency

ABSTRACT

Humanity faces the important challenge of understanding and integrating human and natural processes, including agriculture. In China, the scarcity of arable land (0.09 ha per capita), increasing population, and migration of the workforce to cities pose a significant challenge for food security. Agricultural energy productivity has therefore become a key concern. In this study, we used input–output analysis to measure energy productivity at a national agro-ecosystem scale for China using the total embodied energy requirement (TEER) to reveal hidden energy flows. We introduced a structural decomposition technique that reveals how changes in TEER for the agricultural sector were driven by changes in energy-use technology and the inter-relationships among two agricultural sectors (farming and animal husbandry). The results will help both policymakers and farmers to improve the efficiency and environmental compatibility of agricultural production. Declining TEER for both sectors means that China's overall agro-ecosystem has increased its energy productivity since 1978 due to improved relationships between the agricultural sectors and increased use of biological energy. However, the net positive energy income decreased in the farming sector and an increasing proportion of fossil energy use, accompanied by increased energy income in the animal sector, provide incentives to increase yield and decrease labor by using more fossil energy, thus raising more animals in the animal husbandry sector. Overuse of fossil energy since 1990 has resulted in decreasing fossil energy efficiency, requiring immediate measures to improve the use of fossil-fuel-intensive materials such as fertilizers.

1. Introduction

For thousands of years, increasing population levels and a scarcity of land resources have driven humans to find ways to secure their food supply. Once fossil energy supplies became widely available about 200 years ago, the agricultural sector, like other sectors, became increasingly dependent upon fossil resources as energy inputs. The existing link between the growth of fossil energy consumption and increasing biophysical productivity of modern agriculture suggest that these technical changes did not provide any real "emancipation of production from the natural resources base" (Mayumi, 1991; Conforti and Giampietro, 1997). The implications of the growing dependency of food security on limited stocks of fossil energy has been widely recognized, and a large body of literature relates energy use to agricultural productivity

* *Corresponding author*. Department of Public Management, Beijing Institute of Petrochemical Technology, 19 Qingyuan North Road, Daxing District, Beijing 102617, PR China.
E-mail addresses: caoshuyan@bipt.edu.cn, cao_shuyan@263.net (S. Cao).

0921-8009/$ – see front matter © 2008 Published by Elsevier B.V.
doi:10.1016/j.ecolecon.2008.06.006

(Swanton et al., 1996; Thakur and Makan, 1997; Conforti and Giampietro, 1997; Uhlin, 1998; Pervanchon et al., 2002; Hatirli et al., 2005; Karkacier and Goktolga, 2005; Karkacier et al., 2006). Despite the importance of fossil energy, the biological energy embodied in seeds, human and animal labor, manure and crop residues, and other aspects of agriculture remains an important form of energy input, and is increasingly being recognized in the field of sustainable agriculture.

China is a large agricultural country with about 800 million of its citizens living in rural areas, and approximately 350 million workers employed in the agricultural sector. A scarcity of arable land (currently about 0.09 ha per capita), an excessive population, and migration of workers to cities to take advantage of China's recent economic boom and improve their livelihoods are now posing significant challenges to China's food security. A transition towards increasing use of fossil energy, both directly and indirectly, has occurred over a long period of time to overcome the ecological constraints on food output. Thus, the energy productivity of China's agro-ecosystem has been a key concern. As a result, many studies of agricultural energy use have been performed (Wen and Pimentel, 1984a,b; Wen and Qian, 1990; Li, 1993; Yin et al., 1998; Lu, 2006), most of which accounted for energy efficiency (the energy use per unit of crop produced; Bonny, 1993) at the site, village, or county level. There are two obvious drawbacks to this approach: one is that studying only the energy embodied in direct inputs of materials and services neglects hidden flows in intermediate industrial usage; the other is that there is no data on the energy linkages among different agricultural subsystems beyond the county level even though all industrial sectors of a modern economy are highly interdependent and this interdependence proceeds upstream through the economy like the branches of an infinite tree (Lenzen and Murray, 2003). Attempts to promote food security and to develop environmentally sound agriculture requires a clearer perspective of overall agricultural energy productivity, and given China's increasing dependence on sources of fossil energy, there is an urgent need to quantify the energy linkages among the various agricultural sectors and energy productivity on the final-use side or at the agro-ecosystem scale.

In the present study, we introduce a novel way of calculating the total energy requirements per unit of final use produced by two agricultural sectors in China using input–output analysis, a useful mathematical model that traces the monetary, material, and energy linkages within an economy. we also introduce a structural decomposition technique that reveals how energy-use technology and the inter-relationships among sectors contributed to changing the total energy requirements of China's agro-ecosystem over a given time period. we chose six individual years (1978, 1985, 1990, 1995, 2000, and 2004) as representative times in China's modern development. The results of our analysis will help both policymakers and farmers to make improvements that will increase the efficiency and environmental compatibility of China's agricultural production system.

2. System Boundary, Calculation Methods, and Data Sources

2.1. *Identification of the System Boundary*

In this study, we divided China's agro-ecosystem into three subsectors (Fig. 1): farming, animal husbandry, and "virtual

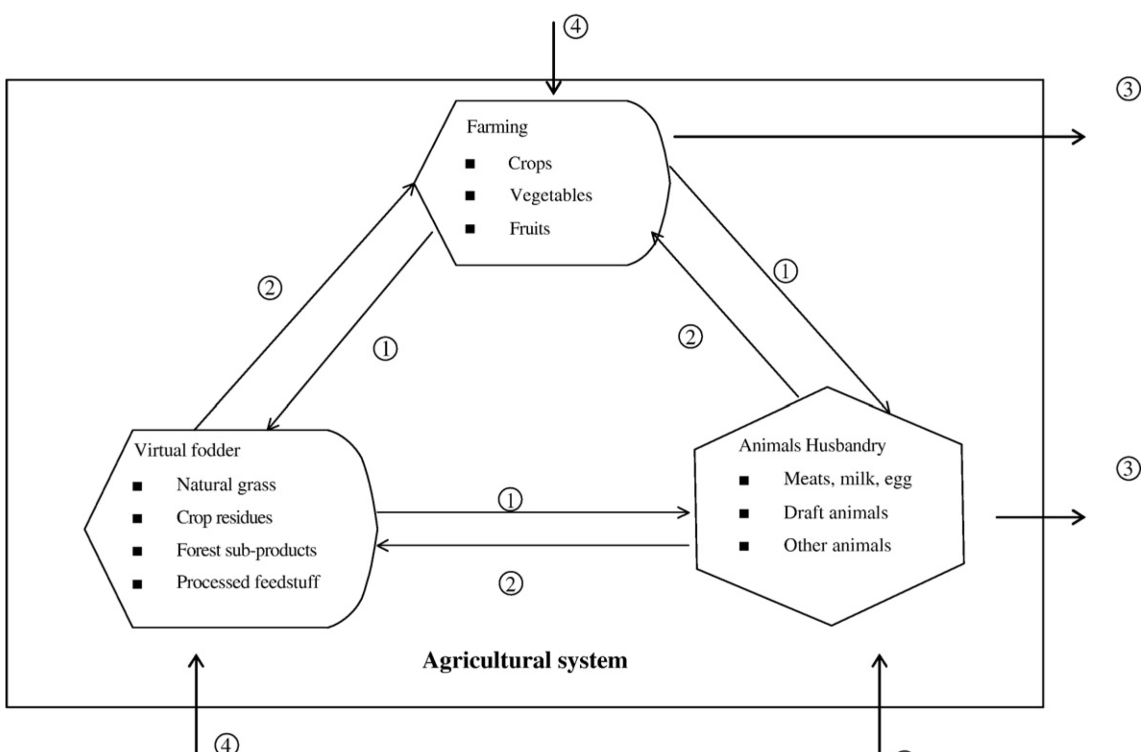

Fig. 1 – Defining the boundary of the agricultural system in the present study. ① fodder or feedstuff; ② crop or animal residues; ③ farming or livestock outputs for final use; and ④ input energy (direct and indirect) from other sectors.