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Analysis of over-consumption of natural resources and the ecological trade deficit in China based on ecological footprints

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ABSTRACT

China has experienced unprecedented economic development in recent years and is now facing severe challenges caused by the over-consumption of resources and by ecological and environmental degradation. To assess the influence of resource exploitation and ecological trade, we have developed an index of excessive resource consumption based on the concepts of ecological deficit and ecological over-shoot, and we have used the ecological trade deficit to assess the pressure created by the export and import of resources and products. Our analysis indicated that China's consumption footprint surpassed its biocapacity in 1983, leading to an ecological deficit, and the production footprint surpassed its biocapacity in 1986, leading to an ecological over-shoot, as the over-consumption of natural resources grew. By 2010, 3.6 times the current area of bioproductive land was needed to provide sufficient resources to meet the consumption. China has been encouraging the development of exporting enterprises by implementing a series of financial and tax incentives, which have stimulated the economy in the short-term but have gradually increased the ecological trade deficit since 2000.

1. Introduction

China has been on the road of industrialisation and urbanisation since the structural reform and policy of openness that began in 1978, which has since transformed the country from a low-income developing country to the second largest global economy. China's gross domestic product (GDP) and per capita income have increased more than 110- and 50-fold, respectively. The total energy consumption was 3.25 billion tonnes of standard coal in 2010, which was 6-fold higher than the 0.57 billion tonnes in 1978. In 2007, China consumed 36.4% of the world's iron and steel production, 51.7% of the cement production, and 15.9% of the energy production, but its GDP accounted for only 6% of the gross global product (Li and Yu, 2011).

Despite substantial socioeconomic achievements, concerns are growing over water availability and pollution, land degradation, and depletion of exhaustible resources (Pan, 2012). High resource consumption increases air, water, and soil pollution, and the environmental problems that developed countries have faced for nearly 100 years have emerged rapidly and intensely in China in the last 20 years. The existing extensive mode of economic development – rapid industrialisation and urbanisation – is thus considered to be unsustainable, and supporting the ambitious goals of building an economically viable and environmentally sustainable society is difficult over the long term.

The continuous rapid consumption of resources in China has also drawn global attention; some arguments have been raised on the potential negative impact of Chinese consumption on global natural resources. The ability of these resources to meet the next stage of development would be a great challenge for China and the world. The Rio + 20 document "The Future We Want" acknowledged in 2012 the need to further mainstream sustainable development at all levels, integrating economic, social, and environmental aspects. Developing countries such as China will play increasingly important roles in shaping the future of humanity, thus the evaluation of the sustainability of China's use of natural resources is very important.

Ecological footprint (EF) and biocapacity (BC) are simple tools for measuring ecological sustainability (Wackernagel et al., 1999). These can be used to assess the status of a country's or a region's development by comparing the consumption and production of resources in the region, thereby identifying the status of the regional ecological security and the potential for sustainable development (Chen et al., 2010; Liu et al., 2011). The ecological footprint (EF) is a simple but comprehensive measure of the fundamental conditions necessary for sustainability, which might be used to set up national ecological asset accounts (Monfreda et al., 2004) and evaluate the human appropriation of land (Salvo et al., 2015).

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Also it is a resource and emission accounting tool for measuring the direct and indirect human demands on the planet's regenerative capacity for comparison with the global BC (Wackernagel et al., 1999; Herendeen, 2000; Monfreda et al., 2004; Galli et al., 2012a,b). Ecological footprint have attracted the attention of many scholars and have become important indicators of the demands on ecological carrying capacities (Rees and Wackernagel, 1994; Wackernagel and Rees, 1996; Rees, 2000; Zhang et al., 2000; Lenzen and Murray, 2001, 2003; Lewan and Simmons, 2001; Aall and Norland, 2005; Vuuren and Bouwman, 2005; Gao and Liu, 2011; Bastianoni et al., 2012; Shao et al., 2013).

Relationship of EF and BC can be compared, and two results can be drawn, an EF > BC represents an ecological deficit (ED), so ED countries are ecological debtors; an EF < BC represents an ecological surplus (ES), so ES countries are ecological creditors (Rugani et al., 2014). Furthermore, based on the relationship of EF and BC, some indicators have been developed, including external biocapacity dependence (EBD), external resource dependence (ERD) (Galli et al., 2015), and Ecological footprint contribution index (EFCI) (Li et al., 2014), which are indicators to evaluate an area's dependence and ecological pressure on the outside area in terms of resources and ecological services. These indicators further extended the application of EF and BC in different study areas and provided a clearer description to consider the sustainability of development on local level.

However, given the indicators above, it is still in lack of an indicator to clarify the ways by which ecological deficit can be compensated. Generally speaking, ecological deficit, if occurred in a country or region, need to be compensated by over consumption of local resources (ecological overshoot) or importing resources from other countries (ecological trade deficit). Therefore, we have applied the concepts of ecological deficit (ED) and ecological overshoot (EO) based on the comparison of EF and BC to calculate the resource excessive consumption index (RECI) which can be applied on local scale. Through the analysis of RECI, we evaluated the overconsumption of natural resources in China and the potential impact of international trade on China's EF and BC. With the increase in international trade, the importation of resources may be able to compensate the consumption of native natural resources, and products could be exported, indicating the potential influence of the national EF at global scale. The indicators will also be helpful for practitioners at a given national scale to evaluate their natural resources consumption and production, and potential trade 'threat' to the other countries.

2. Methods

2.1. Ecological footprint and biocapacity

The EF relates to a population or to the production of economic goods or services is the total area of terrestrial and aquatic ecosystems required to produce all the resources consumed and to absorb all the wastes generated (Bagliani and Martini, 2012) and can be compared to the available global BC (Wackernagel et al., 1999; Monfreda et al., 2004; Galli et al., 2012a). There are six land-use types for measuring the ecological footprint: cropland, forestland, grazing land, fishing grounds, built-up land, and carbon uptake land which is always called carbon footprints (EF_{carbon}) (Borucke et al., 2013; Cheng et al., 2011). The EF and EF_{carbon} are calculated as in Eqs. (1) and (2):

$$EF = \frac{Q}{Y_n} \times Y \times r \quad (1)$$

$$EF_{carbon} = \frac{P_c(1 - S_{ocean})}{Y_c} \times r \quad (2)$$

where Q is the amount of a product harvested or CO_2 emitted, Y_n is the national average yield of product Q (or its carbon uptake capacity for carbon dioxide emission), Y and r are the yield and equivalence factors, respectively, for the land-use type in question, P_c is the annual anthropogenic emission (production) of carbon dioxide, S_{ocean} is the fraction of anthropogenic emissions sequestered by oceans (approximately one-third; IPCC, 2001), and Y_c is the average annual rate of carbon uptake per hectare of global forests.

BC reflects the entire biologically productive area and represents the maximum level of resource supply, which is the counterpart of the footprint (Wackernagel and Rees, 1996; Wackernagel et al., 1999; Monfreda et al., 2004). BC is calculated as:

$$BC = \sum_{i=1}^{n} a_i \times r_i \times Y_i \quad (3)$$

where a_i is the area of land type i (global hectares, gha), Y_i is the yield factor of land type i, and r_i is the equivalence factor of land type i.

The EF of consumption (EF_C) was calculated to properly allocate the embodied footprints of product trade flows and to track the BC (Galli et al., 2012; Borucke et al., 2013):

$$EF_C = EF_P + EF_I - EF_E \quad (4)$$

where EF_P is the EF embedded in locally produced products, EF_I is the EF of imported or input products, and EF_E is the EF of exported or output products.

The data used in the calculation of ecological footprints (include EF_C, EF_P, EF_I, EF_E) and biocapacity were drawn from the Statistical Yearbooks of China published by the government from 1980 to 2011. The yield and equivalence factors may vary annually with land-use pattern and regional technological development, but the variation normally has a small effect on the total time series of EFs. We thus adopted previously published yield factors (Xu et al., 2003; Wackernagel et al., 1999). The calculation of P_c was based on the accounting methods of carbon dioxide emissions published in the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC, 2007; Li, 2013), and Y_c was obtained from Venetoulis and Talberth (2008).

2.2. Recourses excessive consumption index and ecological trade deficit

The EF is usually calculated using data for consumption, but globalisation and international trade has reduced the consumption of native commodities, which has forced the calculation of EF_P. If EF_C < BC, the consumption of a country is below its capacity. If EF_C > BC, the country has an ED, which must be compensated by importation or by over-consumption of native natural resources. Increasing ED have increased ecological pressures caused by the consumption of resources and the sequestration of carbon dioxide emissions by industry and the daily life of local residents (Li et al., 2014). This relationship is described by:

$$ED = EF_C - BC \quad (5)$$

Ecological deficits can be compensated in two ways: either the deficit is balanced through imports (ecological trade deficit); or the deficit is met through over consumption of domestic resources, leading to natural capital depletion (ecological overshoot).

The domestic ecological overshoot (EO) has connect with footprint of production and biocapacity (Monfreda et al., 2004). If EF_P < BC, the natural resources consumed by production in a country is below its capacity and will not produce excessive ecological pressures, but if EF_P > BC, then the production in the country is

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