AN INTERREGIONAL ECOLOGICAL FOOTPRINT ACCOUNTING WITH AN APPLICATION TO CHINA

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The concept of the ecological footprint (EF) has been applied as a proxy to measure the level of resource consumption necessary to sustain a given population. This paper proposes a methodology for an interregional accounting of EF for China based on the multi-regional and multi-sectoral input-output approach. Eight regions are defined for China and the land use is classified into 5 major categories. With special emphasis on agricultural land use, this paper shows a distinction of total EF across regions and a high level of inter-dependency of land use among regions. In addition, the paper also presents the impacts of the international trade on domestic land use and its implications for the re-shaping of the EF.

Key Words: *ecological footprint, interregional input-output analysis, interregional EF accounting, land use, agriculture land use*

1. INTRODUCTION

Land has long been regarded as an essential natural asset to sustain our life, to provide our dwelling and the space for various human activities. It also functions as a carrier for most of the resources, a sink for wastes and an interaction with the hydrological cycle, the nutrient cycle and the atmospheric cycle. More recently, the productivity land has been applied as a surrogate – the ecological footprint – to measure the sustainability of a city, a nation and the world. The ecological footprint (EF) is formally defined as the total area of productive land and water required continuously to produce all the resources consumed and to assimilate all the wastes produced, by a defined population, wherever on earth that land is located[1)]. In addition to the original accounting with the EF concept for 146 nations and for the world[2)], other applications including input-output analysis[3)], land disturbance-based approach[4)] and physical input-output tables[5)] were extended to more specific land use accounting at the national level.

Land use is of special importance for China, a country with the largest population in the world and rapid economic development in the last two decades. Though occupies about 960 million hectares, the third largest land area in the world, China has only 0.11 ha/cap of arable land[6)], less than half of the world average. Whether the Chinese nation can survive sustainably on the scarce land is a great concern not only to the country itself, but also to the rest of the world.

National accounting of EF for China is important, however, with 31 provinces (including autonomous regions and metropolitans), the mainland of China varies substantially from its north edge down to the south, and from its east coastal area to the interior west part. The discrepancies reflect not only on the income distribution, consumption pattern, population density, but also on the resource endowment. Therefore, a more detailed regional as well as interregional EF accounting is crucial to comprehend the regional perspective of land use in

China.

This paper presents an application of interregional input-output analysis to the calculations of regional EF. The emphasis is placed specially on agriculture land use. Section 2 explains the methodology followed by its application to China's regional EF accounting in section 3. Section 4 presents the results and the discussions of the limitations of the analysis in section 5 conclude the paper.

2. METHODOLOGY

(1) Land embodied in domestic consumption

The interregional analysis in this paper applies the Multi-regional Input-output Model for China (CMRIO)[7]. The CMRIO defines China as 8 regions and 30 sectors in each region.

The interregional and inter-sectoral relationship is Chenery-Moses type and defined as:

$$X = TA'X + TF' + E - M \qquad (1)$$

with X: the total output; T: the interregional trade coefficient matrix; A': a diagonal matrix and each element on the principal diagonal representing regional technical coefficient matrix; F': the final demand; E: the export; and M: the import.

If we define $A = TA'$, $F = TF'$, Equation (1) can be expressed as:

$$X = AX + F + E - M \qquad (2)$$

Since CMRIO treats imported goods as homogeneity as domestically produced goods, the model is an import competitive type.

In order to present a pure domestic linkage multiplier, we differentiate domestic inputs from imported goods by introducing the import ratio $\hat{M}$ as follows:

$$\hat{M} = \begin{bmatrix} \hat{M}^A & 0 & \cdots & 0 \\ 0 & \hat{M}^B & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \hat{M}^H \end{bmatrix} \qquad (3)$$

with $\hat{M}^R (R = A, B, \cdots H)$ being defined as the ratio of import to the total domestic demand.

Equation (2) is therefore transformed as:

$$X = AX + F + E - \hat{M}(AX + F) \qquad (4)$$

We can further obtain Equation (4):

$$X = \left[I - \left(I - \hat{M}\right)A\right]^{-1}\left[\left(I - \hat{M}\right)F + E\right] \qquad (5)$$

$\left[I - \left(I - \hat{M}\right)A\right]^{-1}$ is the Leontief inverse matrix.

Land embodied in the interregional and inter-sectoral flow of goods and services to support the final demand can be obtained by pre-multiplying the final demand matrix by the land multiplier matrix:

$$L = D\left[I - \left(I - \hat{M}\right)A\right]^{-1}\left[\left(I - \hat{M}\right)F\right] \qquad (6)$$

where $D\left[I - \left(I - \hat{M}\right)A\right]^{-1}$ is the land multiplier and D is defined as:

$$D = \begin{bmatrix} D^A & 0 & \cdots & 0 \\ 0 & D^B & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & D^H \end{bmatrix} \qquad (7)$$

Each $D^R (R = A, B, \cdots H)$ is a 30×30 diagonal matrix with $d_j^R (R = A, B, \cdots H, j = 1, 2, \cdots 30)$ on the principal diagonal being the region-specific land coefficients for 30 sectors. Land coefficient for a specific sector in a region is defined as land used in that region to produce one unit output by the sector.

(2) Land embodied in the imports

The CMRIO model did not provide information on the origin of imports. Alternatively, we use local land multiplier d_j^R for imports from the rest of the world to sector j in region R..

Land embodied in the imports consists of two fractions, i.e. land embodied in the imports to directly satisfy the final demand (*LMF*) and land embodied in the imports to serve the intermediate demand (*LMI*). See Equations (8) and (9).

$$LMF = D\left[I-\left(I-\hat{M}\right)A\right]^{-1}\left(\hat{M}F\right) \tag{8}$$

$$LMI = D\left[I-\left(I-\hat{M}\right)A\right]^{-1}\left(\hat{M}AX\right) \tag{9}$$

3. CHINA'S ECOLOGICAL FOOTPRINT CALCULATION

The CMRIO is constructed based on data mostly in 2000. In order to make it consistent with CMRIO, the ecological footprint accounting in this study adopts data in the same base year.

The classification of land use in this study integrates the land classification for EF analysis proposed by Wackernagel[8] and the definition provided by the Chinese Government [9] with an adjustment according to the availability of statistical data.

Land use is classified into five major categories in this study. They are agriculture land, consumed land, waters, energy land and land of limited availability.

Data for each land category has been collected at both the provincial level and the national level. According to data availability and consistency, the interregional IO analysis is conducted only for agriculture land use. In this study, agriculture land is further divided into cropland, forest-land, pasture land and fishing ground. For consumed land, waters, energy land and land of limited availability, IO analysis is not applied.

For energy land, we use the estimation of the land area needed to sequester the CO_2 emitted from burning fossil fuels provided by Wackernagel, et al[8]. They suggested the land-for energy ratio as one hectare of average forest sequestering annually the CO_2 emissions generated by the consumption of 100 gigajoules of fossil fuel. The calculations are divided into two steps. One is the estimation of CO_2 emissions from burning of carbon-based fuels available for consumption in each region. The second step is converting CO_2 emissions into forest-land required to sequester the emitted CO_2 by applying the land-for-energy ratio. For the calculation of CO_2 emissions, we apply the so-called reference approach, provided by the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories[10].

4. Results

(1) Regional EF accounts

The region map is presented in Fig.1. The regional matrix of EF account is shown in Table 1.

Agriculture land is the largest contributor to the total ecological footprint for most of the regions (*A, E, F, G, H*) in China, followed by the energy land. The urban build-up area and transportation land play minor role. The EF profile features China's land use and consumption pattern as agriculture land dependency. In addition, energy land is a potential land use category especially for metropolitans, such as *Region B* and *Region D*.

On the one hand, the total EF ranges from about 0.5 ha/cap in *Region C, E* and *F* up to 3.59 ha/cap in *Region G.* On the other hand, agriculture land can make up 61% of total EF in *Region H* but down to 21% in the *Region B.* In contrast, energy land constitutes 74% of the total EF in *Region B,* while in *Region G,* it accounts for only 9% of the total E F. Urban built-up area varies from 0.5% of the total EF in *Region B* to

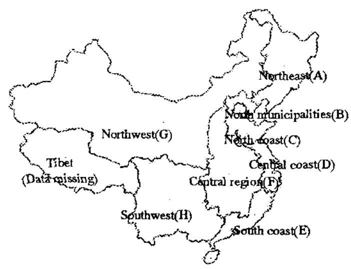

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Fig.1 China 8-region map

Table 1 Regional matrix of EF accounts 2000 (ha/cap)

EF	Region *A*	Region *B*	Region C	Region *D*	Region *E*	Region *F*	Region *G*	Region *H*	National
Agriculture land	0.619	0.207	0.155	0.148	0.278	0.290	1.759	0.468	0.451
Urban build-up area	0.003	0.005	0.002	0.002	0.002	0.002	0.002	0.001	0.002
Industry land	0.025	0.014	0.019	0.013	0.013	0.017	0.033	0.013	0.018
Transportation land	0.009	0.003	0.005	0.003	0.002	0.004	0.008	0.004	0.005
Waters	0.019	0.011	0.010	0.018	0.008	0.015	0.041	0.009	0.016
Energy land	0.536	0.733	0.333	0.402	0.249	0.168	0.331	0.179	0.281
Land of limited availability	0.083	0.015	0.040	0.014	0.022	0.041	1.419	0.096	0.176
Total EF	1.294	0.988	0.564	0.601	0.575	0.536	3.593	0.769	0.947
Population (million persons)	106.55	23.83	158.23	137.89	129	351.47	115.48	237.21	1259.66

0.06% in *Region G,* which reflects the difference in the magnitude of urbanization.

(2) IO analysis on agriculture land use

Whilst depicting the EF accounts, we also focus our attempt at interregional IO analysis on agriculture land. The emphasis is placed on a calibrated accounting of land use embodied in the interregional and inter-sectoral flow of goods and services and land embodied in the international trade between each region and the rest of the world.

a) Regional agriculture EF

Table 2 provides the results of agriculture land use accounting by applying the CMRIO model.

Embodied land use includes all croplands, pasture lands, fishing grounds and part of forest-lands (i.e. timber, charcoal wood, wood with special usage, bamboo woods and economic woods). The direct land use, which constitutes the rest of the forest-lands, is regarded as land with ecological function.

Table2 Regional agriculture EF (ha/cap)

Region	Embodied land use	Direct land use[1]	Land embodied in imports	Agriculture EF
A	0.261	0.349	0.009	0.619
B	0.151	0.027	0.029	0.207
C	0.116	0.031	0.008	0.155
D	0.098	0.042	0.008	0.148
E	0.111	0.155	0.012	0.278
F	0.154	0.111	0.025	0.290
G	1.341	0.377	0.042	1.760
H	0.203	0.263	0.002	0.468

The variation of agriculture EF is 11 times across regions, showing different dependency on agriculture lands. The embodied agriculture land differs from about 0.1 ha/cap in *Region D* up to its 13-folds in *Region G.* The direct land use plays unevenly role in structuring regional agriculture EF, from 56% in *Region A* and *E,* respectively, to 13% in *Region B.* Land embodied in imports also varies substantially from 14% in *Region B* down to less than 1% in *Region H.*

b) Agriculture EF embodied in trade

Table 3 shows the interregional dependency on agriculture land use.

The matrix implies an inequity of interregional trade from the viewpoint of agriculture land use. *Region A, B, D, E* and *H* are the beneficiaries of land use, while *Region C, F* and *G* suffer loses. In particular, *Region B* is the best winner featured by a pure dependent on all other regions and *Region G* is an absolute loser, which supports land to all other regions.

Land embodied in the trade between China and the rest of the world is described in Table 4. Generally speaking China is a net provider of agriculture land embodied in the international trade. From regional prospect, *Region B* and *F* are gainers of agriculture land through international trade of goods and services in all sectors, while all the other regions are supporters.

Table 3 Agriculture EF embodied in the interregional trade (ha/cap)

	A	B	C	D	E	F	G	H	Total net flow*
A	**0.2608**	0.0031	-0.0041	-0.0003	-0.0002	-0.0049	-0.0148	-0.0008	-0.0220
B	-0.0031	**0.1506**	-0.0104	-0.0009	-0.0005	-0.0075	-0.0459	-0.0013	-0.0696
C	0.0041	0.0104	**0.1158**	0.0029	0.0024	-0.0019	-0.0055	0.0004	0.0127
D	0.0003	0.0009	-0.0029	**0.0985**	0.0006	-0.0069	-0.0074	-0.0010	-0.0165
E	0.0002	0.0005	-0.0024	-0.0006	**0.1114**	-0.0111	-0.0128	-0.0039	-0.0300
F	0.0049	0.0075	0.0019	0.0069	0.0111	**0.1540**	-0.0018	0.0022	0.0327
G	0.0148	0.0459	0.0055	0.0074	0.0128	0.0018	**1.3408**	0.0085	0.0967
H	0.0008	0.0013	-0.0004	0.0010	0.0039	-0.0022	-0.0085	**0.2033**	-0.0040

*Total net flow is land embodied in exports minus land embodied in imports.

Table 4 Agriculture EF embodied in the international trade with the rest of the world (ha/cap)

	A	B	C	D	E	F	G	H	National
Land embodied in export	0.0199	0.0284	0.0134	0.0185	0.0274	0.0043	0.0704	0.0043	0.0172
Land embodied in import	0.0091	0.0286	0.0083	0.0077	0.0119	0.0245	0.0418	0.0020	0.0155
Net export*	0.0108	-0.0001	0.0050	0.0108	0.0155	-0.0202	0.0286	0.0023	0.0017

* Net export is land embodied in export minus land embodied in import

C) Agriculture EF and land endowment

Table 5 Regional agriculture EF and land endowment

Region	EF (ha/cap)	Land endowment (ha/cap)	Deficit* (ha/cap)
A	0.6190	0.6001	0.0189
B	0.2066	0.0737	0.1329
C	0.1552	0.1590	-0.0038
D	0.1482	0.1100	0.0382
E	0.2783	0.2236	0.0547
F	0.2897	0.2663	0.0234
G	1.7592	2.0628	-0.3036
H	0.4682	0.4632	0.0050
National	0.4507	0.4577	-0.0070

* Deficit is EF minus land endowment.

Table 5 is a comparison of regional agriculture EF and land endowment. The results show that at the national level, China still can balance its agriculture land use with the endowment of productive land. However, at regional level, most of the regions, including *Region A, B, D, E, F* and *H*, overshoot their agriculture land use beyond their geographic boundaries. Region *C* and *G* have balance for agriculture land use.

6. Discussions

The results of this study are derived from interregional IO analysis, which based on several assumptions.

The first assumption is related to the homogenous region used for the definition of eight regions in the CMRIO model. The second assumption is made when introduces the trade coefficient $\hat{t}_i^{RS}$ in formulating the interregional trade flow in the CMRIO model. The third assumption is put forward when define $\hat{M}$ as the ratio of imports to the total domestic demands. The underlined assumption is that each domestic sector imports goods from the rest of the world at the same ratio. Fourthly, regional land coefficients (in hectare per unit output) are applied as substitutes for land coefficients of the rest of the world, assuming that if goods are not imported to satisfy the domestic demands, then locally produced goods might be a better substitute and local land is therefore used to support the production. In addition, imported goods are treated miscellaneous in the model without identification of their origins. All of these assumptions might more or less influence the results of EF accounting.

Finally, this study is limited its application of interregional IO analysis on agriculture EF. Because the available data on industry land and energy land is not consistent with its counterparts in the IO model, the interregional model cannot be directly applied for industry land and energy land accounting. Further efforts on the disaggregation of integrated data are necessary. For agriculture land IO analysis, the application of CMRIO model also constrains a more detailed analysis on each sub-category of agriculture land.

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中国への地域間エコロジカルフットプリント勘定の適用に関する研究

周新・井村秀文・森杉雅史

定量の人口の生活を維持するため必要な資源消費水準を図る尺度として，近年多くの研究でエコロジカルフットプリント（EF）の概念が用いられている．本研究ではこれを踏襲すると共に，多地域及び多部門の地域間産業連関表を用い，EF 勘定による中国における諸地域間の相互依存性を定量化する手法を提案する．ここでは中国国内を 8 つの領域に区分し，また土地利用を 5 つの主要項目に分類している．とりわけ農用地の利用に注目し分析を進めた結果，EF には大きく地域差が存在し、また EF 勘定で見た場合の地域間の相互依存性は非常に高いことが示された。さらに後半において，国家間の交易に起因する国内土地利用への影響、及び EF 依存構造へのインパクトについても考察を加える．