STUDY ON CHINA'S REGIONAL ECOLOGICAL FOOTPRINT AND IDENTIFICATION OF "BROWN SECTORS" AND "BROWN PATHS"

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This paper discusses two problems related to the calculation of Ecological Footprint (EF). One is the oversimplification of actual in-situ impacts when measured in EF. The other is its limited policy implication. To address these problems, this paper presents a regional approach for EF calculation by using interregional input-output model and provides an empirical analysis for China focusing on regional diversity and interdependency. By the identification of "brown sectors" and "brown paths" in terms of their high environmental load, this paper provides an insight on how to reduce regional EF more effectively. Key sectors analysis and Structural Path Analysis are used for this purpose.

Key Words: *regional ecological footprint, interregional input-output model, key sectors analysis, Structural Path Analysis, policy implications, China*

1. INTRODUCTION

Ecological Footprint (hereafter EF) has been used as an indicator of sustainability since its introduction by Rees and Wackernagel[1)] in early 1990s. By using productive land as measure, the novelty of EF is translating different ecological impacts into areas of land appropriation. This facilitates accounting the total anthropogenic impact by one indicator. Comparing area of land appropriated with area of land available provides an indication whether a nation or a region is sustainable or suffering ecological deficit.

As an aggregate indicator, EF has made contributions to conducting international comparison of ecological impacts caused by each nation (e.g. *Living Planet Report 2004*[2)]), as well as to raising public awareness and attracting the attention of political regime. However besides these, we also expect to know what actions should take to change current trajectory and how to reduce EF effectively. Unfortunately, EF in existing literature provides few policy suggestions apart from either including more land, reducing population, or reducing consumption per head[3)]. Therefore, authors of this paper argue against the utility of EF as a pragmatic guideline for achieving sustainability.

In addition, the conventional method for calculating EF uses global average yields as weights to measure the impacts caused by each nation's consumption without tracing the origins of consumption. This implies only the quantity of consumption and the variety of consumption influence the level of national EF, while geography-specific factor endowment and resource endowment, differences in technology, efficiency and in production and process method, etc. do not matter. This over-simplification of in-situ impacts fails to interpret the real situation and is mere an improper allocation of global responsibility.

In this context, we insist on taking spatial heterogeneity into account and tracing the in-situ impacts. We choose China because of her largest population on this globe. Even a small change in EF per capita can have great influence on global EF. Moreover, China has geographical diversity in nature endowment and ever-increasing economic and social disparity since its opening-up in late 1970s. How does regional EF differ from national EF and from one another? Which region is responsible for what responsibility? How to reduce regional EF effectively?

To address these issues, the present paper presents a regional approach for EF calculation. We use interregional input-output (hereinafter IO) model, which enables to trace the origin of impacts, to count embedded impacts associated with inter-sectoral and interregional transactions, and to reveal regional interdependency.

In order to draw policy implications, we try to identify "brown sectors" and "brown paths". We extend key sectors analysis to help identify "brown sectors". A "Brown sector" is defined as a sector that one unit production of this sector induces environmental load higher than the average level, and at the same time, one unit production in each of the other sectors causes environmental load of this sector higher than the average.

An economic transaction between two region-specific sectors is usually composed of a chain of trade flows. For example, transaction between region R's sector *i* and region S's sector *j* may not happen directly, but via trade flow from region R's sector *i* to region T's sector *k*, then from region T's sector *k* to region S's sector *j*. In this case, we regard transaction between region R's sector *i* and region S's sector *j* as consisting of two paths. By using Structural Path Analysis, we decompose the transaction between each pair of sectors into its component paths. We calculate the environmental load of each path and rank all paths upon their environmental load. A "Brown path" is defined as one who is on the top list of ranking.

Results from "brown sector" and "brown path" analysis can be used for setting priorities to facilitate effective reduction in regional EF.

2. METHODOLOGY

(1) Calculation of regional EF by interregional IO model

EF is defined as "*total area of productive land and water area 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*".

Conventional calculation of EF provided by its proponents[4] and polished by Monfreda, et al.[5] works by the following steps. First, they select several major commodities and calculate their net domestic consumptions by adding import to domestic production less export. Next, they transform consumption into equivalent area of productive land. In doing so, they classify productive land into several land types (e.g. crop land, forest, grass land, etc.) and divide the consumption of specific commodity (e.g. rice) by global average yield. In the third step, the authors try to aggregate areas of different land types by using the so-called equivalence factors as weights to uniform the productivity of different land types into average productivity of all land types. Finally the aggregate land area is divided by domestic population to obtain EF at per capita level.

This calculating procedure has received many criticisms (van den Bergh and Verbruggen, 1999[6]; Ayres, 2000[7]; Opschoor, 2000[8]; Cornelis van Kooten and Bulte, 2000[9]). Authors of this paper argue about three points. One is that only direct land appropriation is counted while indirect impacts associated with the life-cycle of commodity is not taken into account. Next is the use of global average yield. As mentioned above, this is a re-allocation of impacts rather than a representation of actual in-situ impacts. Finally is the use of equivalence factors. While agreeing upon the idea of using equivalence factors to aggregate different land types, however, we doubt the criterion upon which they are derived. The equivalence factor is derived based on the ratio of global average productivity of each land type to the global average productivity of all land types. However, land usually has multiple functions and productivity is only one of them. Substitution land use from one type to another type may not cause change in productivity, but may cause other ecological changes, such as soil erosion, climate change, meteorological change and nutrient circulation, etc.

In this context, the present paper considers both direct and embodied land appropriation by using interregional IO model. Actual area of land appropriation is used in stead of land area in terms of global average yield. Since the determination of more reliable equivalence factors based on a comprehensive evaluation of multifunction is beyond the scope of this paper, we do not use any equivalence factor and the aggregation of different land types is based on simple addition.

K.B. Bicknell, et al. proposed a methodology for EF calculation by applying national input-output model to the New Zealand in 1998[10]. The basic idea is to extend conventional IO model to include land use factor. This study extends Bicknell's method to regional EF calculation by using the Multi-regional Input-Output Model for China 2000 (hereafter CMRIO), developed by the Institute of Developing Economics[11]. CMRIO categorizes China into eight regions (see **Fig. 1**) with 30 sectors in each region (see **Appendix**).

a) Basic interregional IO model

The basic model is formulated as:

$$X = AX + F + E - M \qquad (1)$$

with X: total output vector (240x1) for 30 sectors in eight regions; A: inter-sectoral and interregional transaction coefficient matrix (240×240); F: final demand matrix identifying origin and destination (240×8); E: export vector (240×1); and M: import vector (240x1).

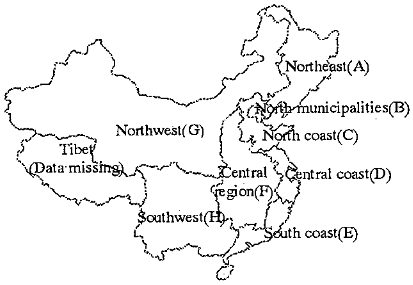

Fig.1 Eight regions in China.

CMRIO is import competitive type of model. In order to show domestic linkages among regions, we transform it into import non-competitive type by defining import ratio matrix as follows:

$$M = \hat{M}(AX + F) = \hat{M}AX + \hat{M}F \qquad (2)$$

Substituting M in *Eq.(1)* with *Eq.(2)*, we obtain *Eq.(3)*.

$$X = \left[I - (I - \hat{M})A\right]^{-1}\left[(I - \hat{M})F + E\right] \qquad (3)$$

$(I - \hat{M})A$ is notated as $A^* = \left[a_{ij}^*\right]_{240\times240}$ in this paper, indicating domestic transaction coefficients. We denote the Leontief inverse matrix as $B = \left[I - (I - \hat{M})A\right]^{-1} = \left[b_{ij}\right]_{240\times240}$, showing domestic output of sector i required to satisfy one unit domestic final consumption in sector j.

b) Regional EF

First, we pre-multiply Leontief inverse matrix B by direct land use matrix L:

$$\overline{B} = L\left[I - (I - \hat{M})A\right]^{-1} = LB \qquad (4)$$

where $L = \left[l_{ij}\right]_{240\times240}$ is a diagonal matrix showing direct land use per unit output of each sector in each region. $\overline{B} = \left[\overline{b}_{ij}\right]_{240\times240}$ is defined as land multiplier matrix representing land appropriation embedded in the transaction from sector i to satisfy one unit final demand in sector j.

Next, we calculate regional EF by pre-multiplying the domestic final demand matrix $\left[(I - \hat{M})F\right]$ by the land multiplier matrix $\overline{B}$. Dividing EF by regional population, we obtain EF at per capita level, notated as *ef* hereinafter. It shows land appropriated to satisfy the lifestyle of one average person in each region.

$$\begin{aligned} EF &= L\left[I - (I - \hat{M})A\right]^{-1}\left[(I - \hat{M})F\right] \\ &= \overline{B}\left[(I - \hat{M})F\right] \end{aligned} \qquad (5)$$

c) Land classification and data

Land use is classified into three major categories in this study: agricultural land, built-up land and energy land. Agricultural land includes four sub-categories (see **Table 1**). Energy land is defined as forest area required annually to sequester CO_2 emissions from anthropogenic activities. It should be mentioned that energy land in terms of forest area in our calculation is hypothetical forest rather than actual forest while forest as a sub-category of agricultural land is actual forest required to satisfy our consumption related to forest products. Year 2000 is set as reference year.

Table 1 Classification of land use and data source .

Land-use category	Explanation	Data source
Agricultural land	land appropriated by agricultural sector including four sub-categories: cropland, forest, pasture, and fishery area	a) China Agriculture Yearbook 2001[12] b) Forth investigation on the nation-wide inventory of forest resources[13), 14] c) China Stock Raising Yearbook 2001[15]
Built-up land	Land appropriated by human settlement, industrial sites and transportation	National land-use survey[16]
Energy land	Forest area required to sequester CO_2 emissions (hypothetical land rather than actual land)	a) China Energy Statistical Yearbook 2000-2002[17] b) Fang, et al. (1998)[18]

(2) Key sectors analysis

Rasmussen[19] introduced backward and forward linkages as measures of economy-wide structural interdependence. Hirschman[20] subsequently developed their applications to the identification of key sectors whose backward and forward linkages create more than average impacts on the whole economy. It has been generally asserted that investing in key sectors would facilitate production impulses and thus stimulating overall economic growth.

Considering regional diversity in economic structure, technology mix, land endowment and efficiency, etc. and their influences on the intensity of EF, authors of this paper suggest the extension of key sectors analysis to EF analysis. We apply Hirschman's method to identify those sectors whose per unit growth requires more EF than average regional level. We call these sectors "brown sectors" since they have above average EF intensity. Cutting down the final demand or constraining the production of these sectors can result in more than average reduction in global EF intensity. This is useful to design a cost-efficient or cost-effective strategy for EF reduction.

We first identify economical key sectors and then extend it to identify "brown sectors".

The definitions of backward and forward linkages are based on Leontief inverse matrix *B*. Let $B_{.j}$ and $B_{i.}$ be the column and row summation of matrix *B*, defined as column multiplier and row multiplier.

$$B_{.j} = \sum_{i=1}^{n} b_{ij}, \qquad B_{i.} = \sum_{j=1}^{n} b_{ij} \tag{6}$$

Let V be the global intensity of matrix *B*:

$$V = \sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij} \tag{7}$$

Rasmussen proposed two types of indices, the power of dispersion for the backward linkages BL_j, and the indices of the sensitivity of dispersion for forward linkages FL_i. Their definitions are given in *Eq. (8)* and *Eq. (9)*.

$$BL_j = \frac{\frac{1}{n}\sum_{i=1}^{n} b_{ij}}{\frac{1}{n^2}\sum_{i,j=1}^{n} b_{ij}} = \frac{\frac{1}{n}B_{.j}}{\frac{1}{n^2}V} = \frac{B_{.j}}{\frac{1}{n}V} \tag{8}$$

$$FL_i = \frac{\frac{1}{n}\sum_{j=1}^{n} b_{ij}}{\frac{1}{n^2}\sum_{i,j=1}^{n} b_{ij}} = \frac{\frac{1}{n}B_{i.}}{\frac{1}{n^2}V} = \frac{B_{i.}}{\frac{1}{n}V} \tag{9}$$

BL_j is the ratio of column average to the average global intensity, while FL_i is the ratio of row average to average global intensity. A key sector is defined as one of which both BL_j and FL_i are greater than 1. $BL_j > 1$ means a unit change in final demand in sector *j* will generate an above-average increase in all sectors' activities in the economy. Similarly $FL_i > 1$ means a unit change in all sectors' final demand will create an above-average increase in sector *i*.

Extension of this method to EF analysis can be conducted by calculating $B_{.j}$, $B_{i.}$, BL_j, FL_i for land use multiplier matrix $\overline{B}$ defined in *Eq. (4)* instead of for *B*.

A "brown sector" can be therefore defined as one whose unit final demand (in monetary terms) requires more EF than average global intensity.

(3) Structural Path Analysis (SPA)

Leontief inverse matrix indicates an aggregate relationship between any two sectors, which actually consists of many interactions with other sectors. Crama et al[21] and Defourny and Thorbecke[22] introduced Structural Path Analysis to disaggregate Leontief inverse matrix into paths contributing to the aggregate interaction between any two sectors. Based on the same idea, this study extends SPA to EF analysis (see also Lenzen[23]). By ranking the EF intensity of each path, we identify those "brown paths" which contribute most to resource throughput and emissions. From environmental policy point of view, cutting down or cutting off these paths could effectively reduce environmental burdens.

Decomposition of Leontief inverse matrix is conducted by series expansion:

$$B = (I - A^*)^{-1} = I + A^* + A^{*2} + A^{*3} + \cdots \tag{10}$$

A similar decomposition of land use multiplier (or emission multiplier) $\overline{B} = LB$ is written as follows:

$$\overline{B} = LB = LI + LA^* + LA^{*2} + LA^{*3} + \cdots \tag{11}$$

We define $\overline{B}_{.j}$ (row summation of $\overline{B}$) as EF multiplier for sector *j*, representing EF embodied in transactions from all sectors to satisfy one unit final demand in sector *j*.

$$\begin{aligned}\overline{B}_{.j} &= \sum_{i=1}^{n} \overline{b}_{ij} = l_j + \sum_{i=1}^{n} (l_i a^*_{ij} + l_i \sum_{k=1}^{n} a^*_{ik} a^*_{kj} + \\ &\quad l_i \sum_{k=1}^{n} \sum_{m=1}^{n} a^*_{ik} a^*_{km} a^*_{mj} + \cdots) \\ &= l_j + \sum_{i=1}^{n} l_i a^*_{ij} + \sum_{i=1}^{n} l_i \sum_{k=1}^{n} a^*_{ik} a^*_{kj} + \\ &\quad \sum_{i=1}^{n} l_i \sum_{k=1}^{n} \sum_{m=1}^{n} a^*_{ik} a^*_{km} a^*_{mj} + \cdots \end{aligned} \qquad (12)$$

EF induced in direct path from industry *i* to final demand in sector *j* of the first order is represented by $l_i a^*_{ij}$, while EF embodied in an indirect path between *i* and *j* via *k* of the second order is $l_i a^*_{ik} a^*_{kj}$, and so on. There are *N* paths of first order, N^2 paths of second order and generally N^n paths of *n*th order. Ranking of all paths upon the value of EF can help identify "brown paths", which are on the top list of the ranking

3. RESULTS

(1) Regional EF

Fig. 2 shows regional *ef* and its composition of sub-categories. The national average *ef* is 0.8 ha/cap, while regional *ef* ranges from 0.4 ha/cap in central region (code F) to 2.4 ha/cap in northwest region (code G). Energy land has larger share in total regional *ef* except for northwest region (code G), in which pasture land plays outstanding role. Energy land in north municipalities (code B) and central coast (code D) accounts for more than 75% of total regional *ef*. It shows in more developed regions, such as metropolitans and southeast coast (code B, D and E), energy land contributes more to regional *ef*. While in less developed regions, such as central and west inland area (code F, G, and H), more agricultural land is appropriated to support regional consumption. This could be explained as change of lifestyle with economic development and its impacts on regional *ef*. Compare to agricultural land and energy land, built-up land makes limited contribution to regional *ef*.

For agricultural EF, we conduct analysis on the relationship between regional dependency (in terms of net appropriation of agricultural land of other regions') and economic development (in terms GDP) as shown in **Fig.3**. It indicates that at some extent, the more a region develops, the more it depends on other regions for agricultural land. This shows shrinkage of agricultural land in more developed regions, i.e. a trend of changing land use from agricultural purpose to others on one hand. While on the other hand, agricultural land is more intensively tilled in less developed regions in order to support demand in more developed regions. This might lead to the convergence of wealth into more developed regions while making less developed regions at the risk of land degradation due to over exploitation and over grazing.

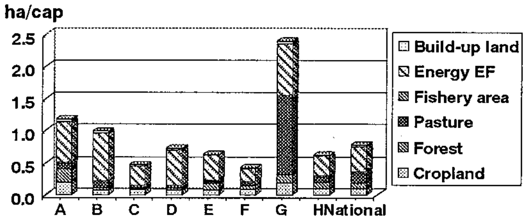

Fig.2 Regional *ef* account

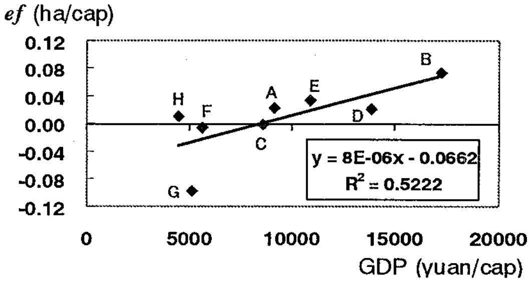

Fig. 3 Regional interdependency of agricultural land and GDP.

For energy use related CO_2 emissions, we analyze the relationship between emissions per capita and GDP per capita for eight regions and show the result in **Fig.4**. A kind of positive linear relationship can be seen, showing that emissions of CO_2 increase with regional economic development.

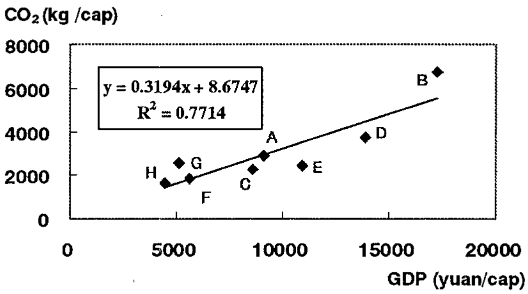

Fig. 4 Regional CO_2 emissions and GDP.

(2) Identification of "brown sectors"

Because agricultural land and energy use related CO_2 emissions are two different issues unique to each sector, we extend key sectors analysis for both respectively. Here we use CO_2 emissions to indicate energy use associated impacts instead of energy land because energy land is just hypothetical land rather than actual land.

Table 2 shows top five sectors in eight regions in terms of agricultural land use. This implies that one unit final demand in these top sectors demands more than regional average agricultural land use, showing more intensity of agricultural EF. It shows a similar pattern for all regions that agriculture (sector 1), manufacture of food products (sector 6) and textile goods (sector 7) have above-average intensity in agricultural EF.

Table 2 "Brown sectors" in terms of agricultural EF.

Rank	Sector by code							
	A	B	C	D	E	F	G	H
No.1	1	1	1	1	1	1	1	1
No.2	6	6	6	6	6	6	6	6
No.3	7	7	7	7	9	7	7	7
No.4	8	8	8	9	12	8	8	8
No.5	30	12	9	8	8	10	10	9

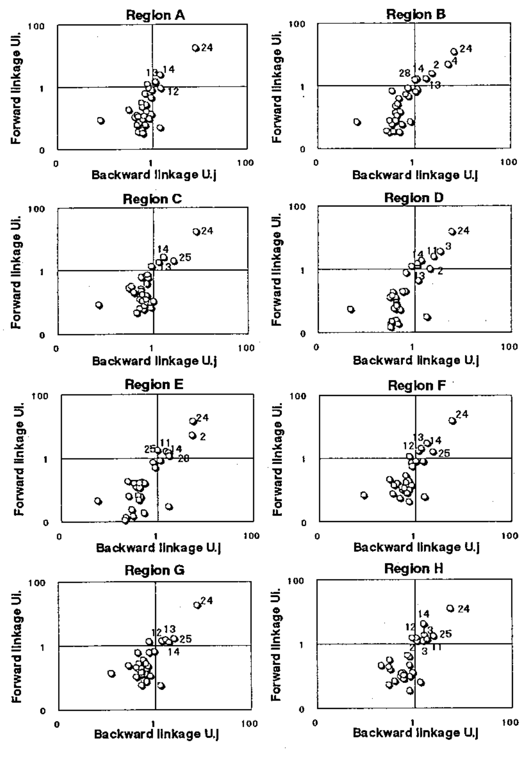

Fig.5 "Brown sectors" in terms of CO_2 emissions

In terms of embodied CO_2 emissions (see **Fig. 5**), though different regions show somewhat differences in the layout of backward and forward linkages, a general feature is that electricity sector (code 24) has largest intensity of CO_2 emissions, much higher than the global intensity (i.e. the origin of each figure in **Fig.3**). In addition, metal smelting and processing (code 14), gas production and supply (code 25), nonmetal mineral products (code 13) and chemical industry (code 12) also show above-average intensity of CO_2 emissions.

(3) Identification of "brown paths"

We conduct SPA for agricultural EF and CO_2 emissions, respectively. **Table 3** shows ranking of top 30 "brown paths" in terms of high intensity of agricultural EF and CO_2 emissions, respectively. A path, for example "G1G6", indicates the final demand of sector 6 in region G provided by sector 1 in region G. The order of path represents the *n*th order in the series expansion of agricultural land or CO_2 multiplier matrix $\overline{\boldsymbol{B}}$. The value of path displays the intensity of agricultural EF or of CO_2 emissions embodied in per unit final demand provided via that path. The share in the parenthesis shows the responsibility of this path to the total intensity which equals to the row summation ($\overline{B}_{.j}$ in *Eq.(12)*) of agricultural land or CO_2 multiplier matrix. Ranking is defined based on the value of each path.

For agricultural EF, the top one path is G1G1 of the 0^{th} order, followed by G1G6 and G1G7 of the first order. According to the share, G1G1 of the 0^{th} order accounts for 71.6% of the total intensity of agricultural EF via all paths to satisfy one unit demand of sector 1 (manufacture of food) in region G, showing relative importance of path G1G1.

It can be seen that a quite number of paths among top 30 paths attribute to the supply from agricultural sector in region G. This can be explained by various factors such as relatively lower productivity of agricultural land in region G, extensive land use, lower technology and lower efficiency, less rotation systems influenced by physical endowment, etc. Detailed study is desirable to find the answer but it is beyond the scope of this paper.

For CO_2 emissions, the ranking of top 30 "brown paths" shows that paths originating from electricity supply sector (code 24) have major responsibilities for constituting sectoral intensity of CO_2 emissions. This result is consistent with the identification of sector 24 as a "brown sector" in terms of CO_2 emissions from key sectors analysis.

Table 3 Ranking of top 30 "brown paths".

Agricultural land use			CO2 emissions		
Rank	Path (order)	Value (share)	Rank	Path (order)	Value (share)
1	G1 G1 (0)	12.62 (71.59%)	1	A24 A24 (0)	52.01 (90.23%)
2	G1 G6 (1)	4.57 (68.20%)	2	G24 G24 (0)	50.61 (93.54%)
3	G1 G7 (1)	3.69 (12.96%)	3	B24 B24 (0)	33.72 (93.56%)
4	A1 A1 (0)	2.62 (61.77%)	4	C24 C24 (0)	31.41 (93.03%)
5	G1 G1 (1)	1.98 (50.79%)	5	F24 F24 (0)	28.88 (87.39%)
6	H1 H1 (0)	1.89 (63.21%)	6	H24 H24 (0)	27.72 (89.27%)
7	G1 G1 (1)	1.45 (19.64%)	7	B4 B4 (0)	24.54 (74.71%)
8	G1 G8 (1)	1.41 (21.41%)	8	D24 D24 (0)	24.20 (87.68%)
9	F1 F1 (0)	1.36 (59.84%)	9	D3 D3 (0)	14.30 (93.25%)
10	G1 G9 (1)	1.35 (31.07%)	10	E24 E24 (0)	13.23 (83.07%)
11	G1 G6 (2)	1.25 (62.90%)	11	E2 E2 (0)	13.00 (90.18%)
12	G1 G7 (2)	1.16 (59.92%)	12	B2 B2 (0)	11.16 (84.25%)
13	G1 G1 (1)	0.99 (23.66%)	13	G25 G25 (0)	10.42 (53.46%)
14	G1 G8 (2)	0.86 (64.13%)	14	D2 D2 (0)	8.75 (72.91%)
15	A1 A6 (1)	0.86 (62.12%)	15	F25 F25 (0)	8.44 (60.80%)
16	G1 G2 (1)	0.76 (22.46%)	16	H25 H25 (0)	7.74 (52.79%)
17	E1 E1 (0)	0.75 (59.14%)	17	G24 G26 (1)	7.56 (76.31%)
18	C1 C1 (0)	0.70 (3.07%)	18	A24 A26 (1)	7.26 (63.28%)
19	G1 G1 (2)	0.56 (55.90%)	19	H11 H11 (0)	7.03 (59.24%)
20	F1 F6 (1)	0.52 (23.68%)	20	B13 B13 (0)	6.68 (57.59%)
21	H1 H6 (1)	0.52 (10.97%)	21	D24 D26 (1)	6.29 (68.19%)
22	B1 B1 (0)	0.48 (6.26%)	22	C25 C25 (0)	5.97 (45.02%)
23	G1 G9 (2)	0.48 (5.30%)	23	A25 A25 (0)	5.95 (51.12%)
24	A1 A7 (1)	0.47 (10.63%)	24	G24 G14 (1)	5.73 (36.57%)
25	D1 D1 (0)	0.47 (22.83%)	25	H3 H3 (0)	5.49 (59.56%)
26	G1 G1 (2)	0.47 (12.28%)	26	G13 G13 (0)	5.34 (41.46%)
27	H1 H7 (1)	0.40 (52.09%)	27	F24 F26 (1)	5.19 (61.93%)
28	G1 G1 (2)	0.39 (37.42%)	28	F14 F14 (0)	5.19 (45.48%)
29	A1 A1 (1)	0.35 (18.16%)	29	G12 G12 (0)	5.00 (44.65%)
30	G1 G7 (3)	0.34 (50.44%)	30	H24 H26 (1)	4.91 (61.54%)

Fig.6 shows the speed of convergence of top paths to the global intensity. It can be seen that the speed of convergence is much faster for agricultural EF than for CO_2 emissions. For example, summation over the value of top 30 paths in case of agricultural EF accounts for 63% of the global intensity, while for CO_2 emissions top 30 paths contribute only 25% to the global intensity. This infers that global intensity of agricultural EF is made up by limited "brown paths" via relatively simple interregional and inter-sectoral structure, while global intensity of CO_2 emissions is made up by in many paths through complicated interregional and inter-secotal network. One policy implication derived from this can be that sectoral policy can be effective to reduce agricultural EF, while for combating CO_2 emissions, integrate economy-wide policies are required.

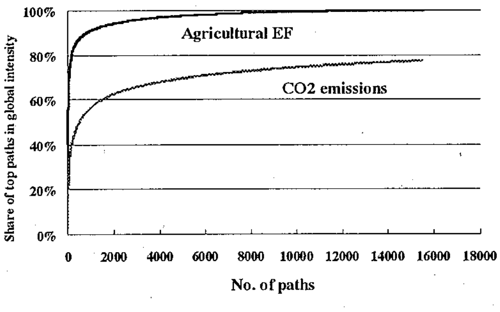

Fig. 6 Speed of convergence of paths.

4. CONCLUSIONS

The authors of this paper point out two problems related to conventional method of EF calculation. One is using global average yield as weight to transform in-situ specific impacts into uniform impact without tracing the origins of impacts. The other is that limited policy implications can be derived from its calculation procedure. In response to these arguments, the present paper advocates a regional approach for EF calculation and provides an empirical analysis for China. In addition, by the identification of "brown sectors" and "brown paths" in terms of their high intensity of EF and emissions, this paper makes a progress on providing pragmatic policy implications for effective reduction in EF.

By tracing in-situ actual land appropriation of the origins of regional consumption, we can find China's regional *ef* profile varies from national average *ef*. Moreover, as a reflection of regional diversity, there is a great interregional gap (about 6-times). In addition to these differences, this paper also provides an insight on China's regional interdependency. Generally speaking, the more a region develops, the more it depends on other regions for agricultural land. This shows a trend of changing land use from agricultural purpose to others in more developed regions on one hand. While on the other hand, agricultural land is more intensively tilled in less developed regions in order to support the demand in more developed regions. This might lead to the convergence of wealth into more developed regions while making less developed regions at the risk of land degradation due to over exploitation and over grazing.

In our efforts made to derive policy implications, striking numbers imply that cutting down top 30 "brown paths" can reduce 63% of the global intensity of national agricultural EF and 25% of the global intensity of national CO_2 emissions. Therefore we conclude that the identification of "brown sectors" and "brown paths" can help set priorities and facilitate effective reduction in regional *ef*. This is especially pragmatic to developing country like China whose environmental budget is very limited.

In more detail, results from key sectors analysis show that agriculture (code 1), food manufacture (code 6) and textile goods (code 7) are "brown sectors" of agricultural EF. Electricity supply sector (code 24), metal smelting and processing (code 14), gas production and supply (code 25) and nonmetal mineral products (code 13) are "brown sectors" of CO_2 emissions. Cutting down these sectors can help reduce agricultural EF and CO_2 emissions effectively.

Similarly from SPA, paths originated from agriculture sector in region G and in region H make great contributions to global intensity of agricultural EF. While paths started from electricity supply sector hold major responsibilities for global intensity of CO_2 emissions. Therefore, cutting down these paths can facilitate effective reductions in agricultural EF and CO_2 emissions.

ACKNOWLEDGMENT: This study is conducted under the project "Study of material flow models to assess achievement towards sustainable production and consumption". We would express our gratitude to the National Institute for Environmental Studies for its financial and technical supports.

APPENDIX Code of thirty sectors

Code	Sectors
1	Agriculture
2	Coal mining and processing
3	Crude petroleum and natural gas products
4	Metal ore mining
5	Non-ferrous mineral mining
6	Manufacture of food products and tobacco processing
7	Textile goods
8	Wearing apparel, leather, furs and down products
9	Sawmills and furniture
10	Paper and products, printing and record medium reproduction
11	Petroleum processing and coking
12	Chemicals
13	Nonmetal mineral products
14	Metal smelting and pressing
15	Metal products
16	Machinery and equipment
17	Transport equipment
18	Electric equipment and machinery
19	Electric and telecommunication equipment
20	Instruments, meters, cultural and office machinery
21	Maintenance and repair of machine and equipment
22	Other manufacturing products
23	Scrap and waste
24	Electricity, steam and hot water production and supply
25	Gas production and supply
26	Water production and supply
27	Construction
28	Transport and warehousing
29	Wholesale and retail trade
30	Services

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環境システム研究論文集 Vol.34, 2006年10月

中国の地域別エコロジカル・フットプリントと産業間・地域間環境負荷相互依存の検証

周新・白川博章・井村秀文

本研究は，従来のエコロジカル・フットプリントにある２つの問題について取り組んだ．すなわち，現行のＥＦには，第１に地域差を無視し過度に単純化しており，第２に評価結果の政策利用が難しいと言う問題がある．このため，本研究では地域間産業連関表を用いて地域別にＥＦを評価する方法を提案し，中国に焦点を当て，地域別のＥＦの違いと地域間の相互依存関係を検討した．さらに，寄与度分析や経路分析を実施し，産業間・地域間における環境負荷の相互依存関係を明らかにし，地域エコロジカル・フットプリントを効果的に下げるために有効な政策のあり方を検討した．