H-9 Study on material flow models to assess achievement towards sustainable production and consumption (Abstract of the Final Report)

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1. Background

"Changing unsustainable patterns of consumption and production" is one of the key elements of the Johannesburg Plan of Implementation adopted at WSSD (World Summit for Sustainable Development) in 2002. The importance of sustainable production and consumption (SPC) was reiterated at G8 environmental ministers meeting in Paris and G8 Summit at Evian in 2003. In Japan, the Fundamental Plan for Establishing a Sound Material-Cycle Society was established in 2003, and it also served as one of programs of a 10-years framework in the Johannesburg Plan. Based on the experiences in three numerical targets based on material flow accounting in the Fundamental Plan, Japan has played leadership role in the field of material flows and resource productivity. Japan's proposal at 2003 G8 environmental ministers meeting to launch an international joint research project on material flow accounts has lead to the OECD council recommendation on material flows and resource productivity in April 2004.

In order to adequately contribute to such policy demands, it is necessary to develop indicators and other quantitative tools that make the concept of SPC more concrete, guide socio-economic activities to right direction, and assess achievement towards SPC. In particular, considering her leadership in international policy dialog, Japanese research community is encouraged to play a leading role in material flow studies. For example, the current knowledge on so-called hidden flows behind raw material acquisition is not sufficient, although the issue is particularly relevant to Japan as a big importer of natural resources. Also in the domestic policy context, material flow studies are expected to contribute to the establishment of a Sound Material-cycle Society.

2. Objectives

Reflecting such policy needs and on the basis of the precedent studies, this research project aims to make further methodological development in material flow analysis, derived indicators and other related analytical tools such as input-output analysis models, and to demonstrate their usefulness by applying them to practical case studies focused on specific industries, materials, regions as well as international comparisons. By our precedent projects, various kinds of MFA (Material Flow Analysis / Accounting) have been practiced and the related indicators have been derived. However, more integrated and sophisticated tools are necessary, which can be applicable across the various scales of systems; from one company to the global society. In this project, particular attention shall also be paid to interlinked, indirect, and/or induced problems, which are hidden behind tangible problems and often trans-located to far distant areas from those of our direct concern.

3. Methods, results and discussions

(1) Development of the multi-scale material flow model and its policy applications

We have maintained both international and domestic research collaborations as in the past years. We attended several international scientific meetings and two working groups (one for Environmental Information and Outlooks and the other for Sustainable Material Management) under the OECD Environmental Policy Committee, to conduct a review regarding the status of the research on Material Flow Analysis (MFA) and its application to policy formulation and evaluation in European countries, as well as to introduce the contribution of MFA and the related indicators to a policy formulation in Japan. As for the domestic activities, we hosted in total five workshops during three years project. The workshops were successful, attended by about 700 participants in total including invited foreign speakers. We came to reconfirm that it was quite important to exchange the views and share the common information with the experts from resources-rich countries regarding the "hidden" environmental and social impacts behind the cross-boundary trade of the resources.

We reviewed the interrelationship between MFA and other system analytic tools such as economic Input-Output analysis, Life Cycle Assessment (LCA), and found that the symbiosis between these tools is very effective in systematic description and understanding of environmental implication of material flows.

Focusing on material balance and energy balance between inputs and outputs of a sector defined in an input-output system, this study confirmed the fundamental condition which unit environmental burden of the sector theoretically has to meet for its consistency with the input-output system. Based on that condition, we classified conventional approaches to build environmental data used for an input-output analysis into the two types. The approaches were characterized by whether the sectoral environmental burden was obtained exogenously (the exogenous estimate approach) or determined endogenously on the basis of the input structure of burden causes expressed in an input-output table (the endogenous estimate approach). Moreover, the endogenous estimate approach was used to find the embodied energy and CO_2 emission intensities of individual sectors on the basis of the approximately 400-sector classification of Japan's 2000 IO table. The data were made available to the public through the webpage.

Using this I-O based database, we defined a new indicator, "eco-velocity of consumption", analogous to velocity in physics. The indicator not only identifies the environmental soundness of consumption growth and technological advance but also indicates whether and to what extent our society is shifting toward sustainable consumption. This study demonstrated the practicability of the indicator through a case study in which we calculated the eco-velocities of Japanese household consumption in 2 years: 1995 and 2000. The rate of technological advance during the periods concerned was quantified in terms of the embodied carbon dioxide emission per yen of product. The results showed that the current growth rate of Japanese household consumption was greater than the rate of technological advance to mitigate carbon dioxide emissions.

We have further designed MSMFM (Multi-Scale Material Flow Model) to analyze the interdependency of the material flow including hidden flows and resource consumption and environmental impact associated with the flow among various scales such as production processes, enterprises, industrial sectors and countries. Particularly, in addition to the same method of constructing material flow data based on monetary Input-Output tables as that used in MDPIOT (Multi Dimensional Physical Input Output Tables) developed in our previous study, we designed a method for incorporating material flow data into the model by internally calculating material flows based on the individual technological data in bottom-up fashion for major production processes and the material balance between compositions of inputs and outputs. Founded on these methods, we compiled empirical data on the basic raw material production sectors and energy conversion sectors for the model. Moreover, in order that the model performs a case study on an evaluation framework that connects a specific technology and its material flow, as described below, we incorporated related technological data into the model. A case study was conducted, focusing on iron & steel production in Japan and China. Material flows under a few scenarios, which differentiate the production capacity and technological level of two countries, were examined by MSMFM. It was found that if the same energy efficiency is accomplished in steel industry for two countries, the larger the share of steel production in China is, the smaller the total CO_2 emission of the two countries is. This is because it is more effective in CO_2 reduction to replace the carbon-intensive coal-fired electricity in China, compared to replacing less carbon-intensive electricity from diversified primary energy source in Japan, by gaseous byproducts from steel making process.

In addition, in order to evaluate the material flow and the environmental effects due to technological changes, preliminary design of the “technological change evaluation” sub-module was conducted by using the Waste Input-Output model. In the case study of the technological changes, first, the material flows were accounted for the advanced loop-closing technologies utilizing the recyclable resources including scrap metals, waste biomass and the other industrial wastes. Then, several scenarios were designed to develop the industrial eco-system in the industrial estate using the advanced loop-closing technologies. The results showed the decreased or increased amount of both direct and indirect carbon dioxide emission and the waste generation. The inducement coefficients were also analyzed to clarify the factors of such changes in the induced environmental loads.

(2) Development of an environmental impact evaluation method based on material flows between regions

With the announcement of the “Basic Plan for Establishing Recycling-Based Society” in May 2003, the targets have been set for the amount of material flows. To achieve these targets, it is a necessary to grasp material flows among domestic regions and to design policy based on Life Cycle Thinking for to decrease environmental load. In this study, the purpose is to make clear interregional material flows which reflect regional characteristics such as production, consumption, and interregional trade at a prefectural level in Japan, and to suggest a method for sustainable production and consumption (Region-based LCA method) which can importantly consider indirect effects by interaction among the regions for assessment of sustainable production and consumption.

Firstly, interregional material flow matrices, with high reliability, have been made by using 47 regional Input Output tables, statistics and models. On the basis of them, we can quantify the economic and environmental effects in the interior or exterior regions by regional activity. Moreover, by suggesting a Dependence effect Index (DI), we were able to analyze the trend for economic and environmental dependence on other regions, and the effect degree for each industry. Therefore, it is expected that regional policy will be applied to improve the tendency of regional dependence effects to keep economic and environmental balance.

Secondly, the Life Cycle Region-specific Assessment Method (LCRAM) was proposed as a new Region-based LCA method by applying interregional material flow matrices. Especially, it enables us to consider regional characteristics for indirect effects that have been not reflected in regional evaluation. LCRAM consists of an Expanded Interregional input Output analysis method (EIOM) and a regional database. EIOM can efficiently identify the affected regions of indirect effects caused by a regional activity. And regional database reflect structural features (Interregional Trade, industrial structure and energy consumption) and environmental features (geographical location, climate, natural conditions, and population density). Comparing evaluation results for each of the regional database was found to show considerable differences in evaluation results due to regional characteristics.

Finally, a simple case-study for inducement of semiconductor industry, as a comparison between LCRAM and Generic Method (GM), was carried out. Meanwhile, a comparison with a 9-region IO table (a multi-regional IO analysis made by the Ministry of Economy, Trade and Industry in Japan) was performed to verify the necessity and reliability for LCRAM. It was found that the results produced by GM often may be an underestimation or overestimation. On the contrary, the results from LCRAM indicated a high consistency of over 97%, which shows that it can reflect the regional characteristics for the indirect effects. As a result, we verified the importance to consider the regional characteristics of the indirect effects, and the influence of considering the regional characteristics for indirect effects is considerable. Also, LCRAM is an efficient method to consider the regional characteristics for the effects to regions, through all stages of an activity.

In conclusion, it is possible to discuss economic and environmental effects that include rebound effects on the other region due to a certain region's policy, because interregional material flow matrices and LCRAM in this study can show quantitatively the indirect effects as well as direct effects. Therefore, it is expected this work will contribute to enabling us to frame an actual and efficient global environmental policy based on the regional structural features and environmental features. And, further discussion and continuous examination will be conducted to consider the interaction among the regions for the construction of sustainable societies.

(3) International Interdependence of Material Flows and their Comparison among Countries

1) International Trade, Material Flow and Ecological Footprint (Nagoya University)

With economic globalization, countries are strengthening interdependence of environmental loads through trade of goods and services. While some countries are transferring economic activities with higher environmental loads to foreign countries, other countries are enjoying economic growth by specializing in the production of export goods that embody larger environmental loads. Analysis of this international interdependence is useful for better understanding of the common but differentiated responsibilities of countries to protect the environment. This study quantifies the transaction of energy, CO_2 and land embodied in goods and services traded in the Asia-Pacific region for the years of 1985, 1990 , 1995 and 2000. The result demonstrates the largest flow of environmental loads is formed centering the United States and China. China, in particular, is achieving economic growth by taking over the responsibilities for CO_2 emissions.

2) Economic dependency and environmental impact in the urban areas (Hiroshima University)

The study is motivated by a simple question that what interregional economic relations between two cities in different countries would be and what the environmental implications can be drawn, particularly in the case of cities at different development stages. This study aims to empirically measure the changes in economic interdependence and induced CO_2 emissions between Beijing and Tokyo from the early to mid-1990s using multidimensional input-output tables. The study finds that although the trade volume from Beijing to Tokyo was just two or three times larger than the flow in the opposite direction, the induced CO_2 emissions in Beijing were approximately 90 times larger than in Tokyo. This is partly explained by the larger size of demand in Tokyo, the larger induced production coefficient and higher carbon intensity in Beijing, and a larger portion of energy-intensive goods exported from Beijing. Export from Tokyo to Beijing is growing because of the increase in demand from Beijing. As a result, although the imbalance of induced environmental burdens between two cities is decreasing, it still remains quite large. The study also shows that large environmental imbalance may arise between cities that are different stages of development.

3) Economic dependency and environmental impact in the urban areas (Nagoya University)

This study discusses the essence and bias of conventional method and places concerns on 1) the importance of tracing and delineating spatially heterogeneous ecological impacts; 2) inappropriate weighting and aggregation scenario; and 3) embodied impact rather than apparent one. To address these problems, this study provides an alternate approach for regional Ecological Footprint calculation for China with special emphasis on interregional dependency. Interregional input-output analysis is used to count land appropriation embodied in both inter-sectoral and interregional transaction of goods and services. This approach helps to traces the origin of interregional flow of renewable resources and unveils the actual responsibility disguised by interregional trade. This study draws the conclusion that regional Ecological Footprint differs greatly from one region to another in China. Interregional trade is unbalanced showing convergence of renewable resources from less developed regions to more developed regions, worsening existed regional disparities.

4) Changes in agricultural land productivity and ecological footprint in China (Hiroshima University and Nagoya University)

This study estimates changes in the ecological footprint (EF) in China's agricultural sector in 1985 and 2003 with special focus on the process of agricultural modernization. Agricultural modernization can bring in the land productivity improvement while increasing production factors including fertilizer, agricultural machinery and irrigation which causes various environmental burdens. These positive and negative impacts associated with land are evaluated with EF. The changes in EF during the period between 1985 to 2003 are measured and compared by type of crops and regions. As a result, the total EF has increased by 22.5 million hectar during the study period. Moreover, the EF index appeared to be extremely deteriorated especially in the case of rice, corn, and cotton.

5) Applications of Ecological Footprint and Hidden Flows (Doshisha University)

Ecological Footprint (EF) has become one of the most popular sustainability indicators in recent years. EF has been widely used as policy guiding tool and educational tool, especially in Europe, and Australia. For example, Cardiff City Council in Wales has used it for policy changes. The Government of Western Australia has set a numerical target to reduce its EF. Swiss Government has decided to publicize the EF figures in its official statistical yearbook every year. The reasons for this popularity are: existence of competent researchers, computer-based calculators (especially in UK), support and corroboration of NGOs, educators, journalists, and publishers.

We have assessed the energy costs and EF for Prolonged Impact Management (PIM) of “hidden flows” associated with nuclear energy (including radio-active wastes). The results showed that these could be fairly significant, depending on assumptions. For example, if we are to manage the wastes for 24,000 years, the PIM costs could be as much as 80% of power generated. If management duration was extended to one million years, then the costs could be 1,600% of electricity produced.

(4) Research on quantification of hidden flows

Ore-TMR (Total Materials Requirements) and Ecological Rucksack are the similar concept to express the amount of hidden materials flows by extraction of natural resources from the litho- and eco-sphere. The term of "hidden material flow" was used in the international collaboration of resource flow analysis in 1990's and defined that the portion of the total material requirement that never enters the economy. While these flows never enters the economy in those days of waste treatment of soils and waters were not completed, the amount of the total material which is mined and treated becomes to give important effect on the economy in these days with environmental considerations. Then we should rename it as "Total Ingest Material from nature" and should refine as the total amount of natural material which is ingested into techno-sphere and need treatment to return to eco-sphere.

In this research, the estimation method of ore-TMR and its application to material flow analysis are introduced. In the application to MFA on recycling, TMR consideration clearly shows the effective material flow than conventional weight flow. TMR consideration also gives the information of rare metals' content in products. This information is available to give guideline of resource productivity. Most important advantage of TMR consideration is to be able to compare any products which include various values of resources with the same resource parameter. Resource parameter should be one of three important parameter of sustainability: 天地人(tian, di, ren : heaven, earth and being) according to ancient Chinese Wise. The results of this work are as following.

1) The hidden flows of mineral resources are numerically expressed by TMR.
2) The fundamental data are getting to be open by environmental reports of companies by the enhancement of the company's stewardship, and physical data can give information to estimate remaining unaccesable minings.
3) TMR of biomass is still on discussion. The problem is which the worked soil is to be counted or not.
4) Ecological footprint is a complementary index to TMR. It is not adequate to integrate TMR into ecological footprint.
5) TMR gives some basic parameter to resource depletion, but the relation is not one-to-one correspondence.
6) TMR rather gives good relation with the time-average price of metals.
7) The relation to price does not seem to include the environmental cost yet now.
8) TMR is one of environmental stress factors, but further investigations and discussions are required to relate TMR to any environmental impact.
9) TMR can be used as an inventory parameter in LCAs. TMR should be reduced into factor 8.

The list of TMR is attached to apply them.

		TMR	soil	water
3	Li	1,500	978	526
4	Be	2,500	1,631	875
5	B	140	54	86
11	Na	50	25	25
12	Mg	70	28	42
13	Al	48	18	30
14	Si	34	12	22
20	Ca	90	28	62
21	Sc	2,000	1,330	675
22	Ti	36	13	23
23	V	1,500	992	512
24	Cr	26	12	14
25	Mn	14	5	9
26	Fe	8	6	2
27	Co	600	402	199
28	Ni	260	173	87
29	Cu	360	237	123
30	Zn	36	21	15
31	Ga	14,000	9,388	4,647
32	Ge	120,000	80,716	39,591
33	As	29	20	10
34	Se	70	45	25
35	Br2	1,500	1,009	495
37	Rb	133	88	45
38	Sr	500	331	170
39	Y	2,700	1,808	898
40	Zr	550	368	183
41	Nb	640	413	229
42	Mo	750	494	258
44	Ru	80,000	53,808	26,396
45	Rh	2,300,000	1,547,059	758,824
46	Pd	810,000	544,833	267,239
47	Ag	4,800	3,217	1,596
48	Cd	7	4	3
49	In	4,500	3,025	1,487
50	Sn	2,500	1,680	826
51	Sb	42	28	14

		TMR	soil	water
52	Te	270,000	181,611	89,079
57	La	3,100	2,080	1,028
58	Ce	2,000	1,350	670
59	Pr	8,000	5,381	2,639
60	Nd	3,000	2,018	990
62	Sm	9,000	6,054	2,969
63	Eu	20,000	13,453	6,599
64	Gd	10,000	6,726	3,299
65	Tb	30,000	20,179	9,898
66	Dy	9,000	6,054	2,969
67	Ho	25,000	16,816	8,248
68	Er	12,000	8,072	3,959
69	Tm	40,000	26,905	13,197
70	Yb	12,000	8,072	3,959
71	Lu	45,000	30,269	14,847
72	Hf	10,000	6,733	3,315
73	Ta	6,800	4,575	2,257
74	W	190	125	66
75	Re	20,000	13,454	6,601
76	Os	540,000	364,398	178,736
77	Ir	400,000	268,925	131,908
78	Pt	520,000	353,014	173,151
79	Au	1,100,000	743,449	373,344
80	Hg	2,000	1,345	660
82	Pb	28	16	12
83	Bi	180	118	59
88	Ra	28,000,000	188,337,592	92,378,521
90	Th	9,000	6,058	2,975
92	U	22,000	14,803	7,261
coal		12	*12*	
oil		7		*7.4*
crushed stone		1.4	1.4	0
aggregate		1.4	1.4	0
plastic		10		10
wood			8.0	
cement			3.2	
cereals			330	

Major Publications

1) Moriguchi, Y.: Systematic description of material flows among anthrosphere and ecosphere, *Environmental Science*, **18(4)**, 411-418, (2005), (in Japanese).
2) Moriguchi, Y.: Uses of environmental accounts and requirements for accounting framework, *National Accounts Quarterly*, **131**, 18-23, (2005) (in Japanese).
3) Ichihashi, M., Kaneko, S. and Yoshinobu, H: Economic induced effect and the environmental burden of the international trade among regions – An example of Tokyo and Beijing–, *Environmental system research* , **33**, 305-315, (2005) (in Japanese).
4) Yoshinobu, H., Kaneko, S. and Ichihashi, M.: Comparative study on energy and carbon flow in city and its implication on the local climate change policy between industrial city and service city in Japan, *Environmental system research*, **33**, 389-397, (2005) (in Japanese).
5) Ilseuk Yi et al.: Approach in order to develop Regional LCA method: Examination of site-specific consideration for the indirect effects, *Papers on Environmental Information Science*, **19**, 479-484, (2005) (in Japanese).
6) Yamada, K et al: Web-site Survey of Recent Ecomaterials Developments in Japan, *Materials Transactions*, **46(12)**, 2554-2560, (2005)
7) Sakai, Y. et al.: Waste Input-Output Analysis of Advanced Loop-Closing System by Innovative Production Technology in Steel Industry, *Environmental system research*, **34**, 285-291, (2006) (in Japanese).
8) Nansai, K. and Moriguchi, Y.: Practical Determination of Sectoral Environmental Burdens Applied to Input-Output Analysis, *Journal of Life Cycle Assessment, Japan*: **2(1)**, 22-41, (2006) (in Japanese).
9) Ilseuk Yi et al.: Development of region-based LCA method considering the site-specifics for environmental impact, *Journal of Life Cycle Assessment, Japan*: **2(1)**, 42-47, (2006) (in Japanese).
10) Zhou, X., Shirakawa, H. and Imura, H.: Study on China's regional ecological footprint and identification of brown sectors and brown paths, *Environmental system research*, **34**, 497-506, (2006).
11) Zhou, X., Shirakawa, H. and Imura, H.: Who is responsible for what: Regional ecological footprint calculation for China with special emphasis on interregional dependency, *3rd World Congress of Environmental and resource economists proceedings*, CD-ROM(24pages), (2006).
12) Kaneko, S., Ichihashi, M and Yoshinobu, H: Measuring changes in mutual induced environmental effects between two cities: a case study for Tokyo and Beijing with multiscale international I-O table, *Environmental system research*, **34**, 293-304, (2006) (in Japanese).
13) Toyota, T., Kaneko, S., Zhou, S. and Imura, H.: Changes in agricultural land productivity and ecological footprint in China, *Environmental system research*, **34**, 487-496, (2006) (in Japanese).
14) Wada, Y. and Kishi, M.: Environmental and Social Impacts of Uranium Mining: A Case Study of Ranger and Jabiluka Minesites in Kakadu National Park, Australia, *Doshisha University Research Center of Social Common Capital Discussion Paper*, **14**, (2006) (in Japanese).
15) Nakajima, K. et al.: Estimation of Total Materials Requirement – Energy Resource and Industrial Materials –, *Journal of Life-cycle Assessment, Japan*, **2(2)**, 152-158, (2006) (in Japanese).
16) Moriguchi, Y. : Symbiosis and mutual benefits among LCA, IOA and MFA, *Journal of Life Cycle Assessment, Japan*, **2(1)**, 3-7, (2006) (in Japanese).

17) Moriguchi, Y.: Systematic understanding of material flows for a sound material-cycle society, *Energy and Resources*, **27(4)**, 11-15, (2006) (in Japanese).
18) Nansai, K. et al.: Simple Indicator to Identify the Environmental Soundness of Growth of Consumption and Technology, *Environ. Sci. Technol*., **31(4)**: 1465-1472, (2007).
19) Nakano, K. and Wada, Y.: Methodological Progress of Ecological Footprint Analysis and Some Controversial Issues, *Science for Environment & Sustainable Society*. **4(1)**, 11-22, (2007) (in Japanese).
20) Wada, Y.: Applications of Ecological Footprint and Some Remaining Issues: Inclusion of the Prolonged Impact Management (PIM) Costs, *Journal of Life Cycle Assessment, Japan*, **3(1)**, 3-10, (2007) (in Japanese).
21) Yoshikawa, T., Tabata, T., Shirakawa, H. and Imura, H.: An analysis and rationalization of material cycle between Japan and China - a case study on E-waste -, *Environmental science*, in press (in Japanese)
22) Moriguchi, Y.: Material flow indicators to measure progress toward a sound material-cycle society, *J. Mater. Cycles Waste Manage.* 9(2), in press, (2007)
23) Yano, T. et al.: An analysis on uncertainty in technological efficiency and business balance factors for energy conservation of biomass waste from urban area and its feasibility, *Environmental system research*, **35**, in press, (2007)
24) Ilseuk Yi, Norihiro Itsubo, Atsushi Inaba and Kanji Matsumoto:Development of the Interregional I/O Based LCA Method Considering Region-Specifics of Indirect Effects in Regional Evaluation, *Int. J. LCA*, in press, (2007)