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Eco-efficiency evaluation system based on material flow analysis

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ABSTRACT

Eco-efficiency is an appropriate measure of circular economy as well as a research hotspot of sustainable development issue. In addition, material flow analysis (MFA) is an important instrument and method applicable to eco-efficiency evaluation and eco-efficiency indicator combined with material flow analysis indicator is the best measure indicator evaluating development of national circular economy. Therefore, this thesis combines with theory of material flow analysis and eco-efficiency and establishes eco-efficiency evaluation indicators in allusion to different spatial dimensions, which are respectively regional direct eco-efficiency (RDE), regional total eco-efficiency (RTE) and Holistic eco-efficiency (HE).

KEYWORDS

Sustainable development; Material flow analysis(MFA); Eco-efficiency evaluation.

Eco-efficiency refers to competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing environmental impacts of goods and resource intensity throughout the entire life-cycle to a level at least in line with the Earth's estimated carrying capacity. It is a reflection of concept of sustainable and harmonious development among economy, society, resources and environment.

ECONOMY-WIDE MATERIAL FLOW ANALYSIS

Material flow analysis (MFA) takes conservation of mass as the law, and conducts quantitative analysis of flows and stocks of materials in a well-defined system and input and output of materials.[1] Through studying and summarizing source and path of material flow, damage of ecological system on economic growth can be evaluated, and further its main reasons for environmental pollution can be found out. Based on research level, material flow analysis (MFA) can be divided into economy-wide material flow analysis, material flow analysis of industrial sector and product life cycle assessment (PLCA).[2] Therein, economy-wide material flow analysis method pays special attention to analytical research on material input and output of economic system and natural environment to the holistic system. Moreover, this method develops rapidly and has been widely applied to regional sustainable development research.

Economy-wide material flow analysis (EW-MFA) is a research method, which replaces monetary unit with mass unit, traces all materials entering economic system and the overall process from extraction in natural world to human economic system flowing through all links of economic system and finally going back to natural environment.[3] (TABLE 1)

TABLE 1 : Essential indicators of material flow accounts

Classification of indicators	Quantifiable indicators	Computational formula of quantifiable indicators
Input indicators	Direct material input (DMI)	Domestic material extraction and import
	Total material input (TMI)	Direct material input and domestic hidden flows
	Total material requirement (TMR)	Total material input and imported hidden flows
Output indicators	Domestic processed output (DPO)	Trash output and acyclic dissipation
	Total domestic output (TDO)	Domestic processed output and domestic hidden flows

Input indicators

Direct material inputs (DMI) measure the direct input of materials of natural resources for use in economic system, in other words, all materials which are of economic value and are used in production and consumption activities. DMI can be calculated as domestic (used) extraction plus imports, namely:

DMI = Domestic extraction +imports

② Total material input (TMI) includes direct material input and hidden flows of domestic input material (also known as unused extraction in the park, namely material resources for economic activities not used during production or consumption process), of which computational formula is listed as follows:

TMI = Direct material inputs +domestic hidden flows

③ Total material requirement (TMR) is an indicator measuring total material of the holistic natural world consumed by an economic system. Total material requirement (TMR) can be calculated as the sum of total domestic material requirement and total imported material requirement, namely:

TMR = Total material input +imported hidden flows

Output indicators

Domestic processed output (DPO) refers to the total mass of materials which have been discharged and dissipated into air, water and soil during production, use and consumption process, and recycling substance is not covered. A part of dissipation flow naturally circulates to the process of growth of plants and uncertain quantity for this part is very hard to estimate and will not be included.

DPO = Domestic trash output + acyclic dissipation

Total domestic output (TDO) is the sum of domestic processed output (DPO) and domestic hidden flows (HF), which refers to the total material output of economic activities to the environment. This indicator shows the total mass of materials discharged into the environment due to economic activities.

TDO = domestic processed output + domestic hidden flows

ECO-EFFICIENCY EVALUATION

Eco-efficiency aims to combine material efficiency and economic efficiency for production with sustainable development target and social justice concept under a title. Thus, eco-efficiency is destined to mean reducing use of material and further decreasing negative influence on the environment. In the meantime of reducing mass of material, the relatively increasing economic welfare must be produced and the economic welfare must be allocated in a fairer manner.[4]

Computational formula of eco-efficiency can be listed as: EP=EV÷CI

Therein EP stands for eco-efficiency, EV economic value of product and CI consumption of material resources of product and environmental influence.

ECO-EFFICIENCY EVALUATION INDICATOR BASED ON MATERIAL FLOW ANALYSIS

In strict accordance with eco-efficiency theory and computational formula of eco-efficiency, evaluation contents of eco-efficiency can be divided into economic development, consumption of material resources and environment stress. Therein GDP stands for economic development, and consumption of material resources and environment stress can be quantized with the help of material input and output indicators of material flow accounts.

In strict line with features of spatial influence of domestic development on resource consumption and environment stress, based on theory of economy-wide material flow analysis, by researching influence of consumption of material resources on domestic economy, resources and environment and combining with characteristics of material flow analysis indicator, eco-efficiency evaluation indicator in allusion to different spatial dimensions can be established, respectively regional direct eco-efficiency (RDE), total regional eco-efficiency (TRE) and holistic eco-efficiency (HE).[5] Regional direct eco-efficiency (RDE) refers to overall efficiency of regional economy, resource and environment formed by direct input and output material in economic system of this region in a certain period. Total regional eco-efficiency (TRE) refers to overall efficiency of regional economy, resource and environment formed in this region by total direct and indirect input and output material in economic system of this region in a certain period. Holistic eco-efficiency (HE) refers to overall efficiency of a whole range of economy, resource and environment formed due to material requirement and output of development of economic system of this region and other regions in a certain period. Computing method of eco-efficiency indicator and its subsystem indicator of these three dimensions is shown in TABLE 2.

Except for direct material consumption and environment stress of this region, calculation of total regional eco-efficiency shall also take the consumption of indirectly used material and environmental press caused by it into consideration. Therefore, material resource consumption indicator includes directly input and consumed material resource and indirectly input and consumed material resource in this region, which are respectively expressed by material flow indicator DMI and DHF, of which the sum is material flow indicator-total material input (TMI); environment stress indicator refers to total mass of materials generated in this region which may have effect on the environment in this region, including direct output part of economic system and indirect output part; direct output part is expressed by material flow indicator DPO and indirect output part by DHF; and the sum of two parts is material flow indicator—total domestic output (TDO). Material flow indicator DHF not only reflects material resource consumption in the process of material extraction but also pressure generated on regional environment by the material resource consumption.

TABLE 2 : Computing formula of regional eco-efficiency indicator based on material flow analysis

	Regional direct eco-efficiency (RDE)	Total regional eco-efficiency (TRE)	Holistic eco-efficiency (HE)
Economic value	GDP	GDP	GDP
Consumption of material resources	DMI	TMI	TMR
Environment stress	DPO	TDO	TDO+IHF
Computing formula	$\frac{GDP}{DMI + DPO}$	$\frac{GDP}{TMI + TPO}$	$\frac{GDP}{TMR + (TPO + IHF)}$

Calculation of holistic eco-efficiency not only takes regional consumption and environment stress of material resource but also influence of operation of economic system of this region on other regions into account. Thus, its material resource consumption and environment stress shall cover more widely. Material resource consumption indicator is expressed by material flow indicator TMC and environment stress indicator includes the environment stress of economic development in this region on imported region of material resources besides local environment stress. In consequence, it shall be expressed by material flow indicator TDO+IHF.

Therefore, similarities and differences of regional eco-efficiency indicator of three dimensions can be summarized as follows: regional direct eco-efficiency and total regional eco-efficiency are differentiated by whether influence of hidden flows on material resource consumption and environment in this region has been taken into consideration or not, and the same in that research scope is economic system in this region; total regional eco-efficiency and holistic eco-efficiency are differentiated by whether research scope gets involved in economic system except for this region or not, and the same in that the influence of hidden flows of material metabolism has been taken into consideration or not.

CONCLUSIONS

To proceed regional eco-efficiency evaluation by applying material flow analysis indicator is characterized by: (1) strong feasibility and high degree of accuracy; (2) hidden flows can be checked so that influence of resource extraction on ecological environment and other process neglected in previous research can be corrected; (3) material flow accounting shall uniformly take mass of material as unit and resource consumption and quantity of pollutant discharged can be directly transferred into unit of mass, convenient for calculation. Based on metabolism of regional material resources, this thesis analyzes regional economic system with analysis method of material flow and brings material flow analysis indicator into eco-efficiency theory and establishes eco-efficiency evaluation system based on material flow analysis.

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