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TIME-SERIES MFCA FOR ASSESSING RECYCLING POLICIES FOR REGIONAL RESOURCE CIRCULATION

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Abstract

In a life cycle assessment (LCA) it is difficult to account for external temporal response and to comprehensively display detailed results. We proposed an assessment framework that used material flow cost accounting (MFCA) and life cycle simulation (LCS) to implement a time-series analysis of recycling policies. With the proposed framework, we expressed the structural changes in the treatment and recycling of household organic waste in Kitakyushu over the 50-year period from 2000 to 2050. Three scenarios were examined by using a performance indicator involving material flows and environmental loads.

KEYWORDS: *material flow cost accounting, life cycle assessment, life cycle simulation, organic waste, resource circulation society*

1. Introduction

Substantive actions on a regional scale are needed if we are to realize the goal of becoming a recycling society. Particularly in cities, where population and resources are concentrated, the 20th Century economic model has created serious environmental loads. In response, many resource-circulation policies are being developed with the cooperation of the public, industries, and local governments.

Resource-circulation policies can be appropriately evaluated from several viewpoints, including global warming, which is one of the most important environmental issues we face. Because such policies are created by diverse groups of people, the measures taken must be explained in such a way that a variety of people can understand them. In recent years, life cycle assessment (LCA) has been applied to evaluations of the infrastructure and economic activity in an area as well as to a product. The results of an LCA are not always easy to understand, because LCA is a complicated system that uses enormous amounts of data. The development of an environmental information infrastructure is needed so that decision-makers in industry and government can intuitively and comprehensively understand LCA results. Material flow cost accounting (MFCA) has attracted attention as a new

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method of environmental management accounting. Such an application would make it possible to express environmental loads in a local area along with material flows. Because various indicators can be evaluated, use of MFCA will make it easier to understand present conditions, identify problems, and evaluate the effects of regional resource-circulation policies. Moreover, all of the stakeholders will be able to share the information by using a common information infrastructure.

In the evaluation of resource-circulation policies for a city or other social infrastructure, it is necessary to consider external conditions over the long term. Generally, LCA deals with static parameters, such as operational status or diffusion ratio. Recently, however, life cycle simulation (LCS) has been used to consider changes in external conditions over time. Such a dynamic evaluation may also be useful in the context of a city or other regional infrastructure.

In this paper, we propose a new way to express the dynamic structure of resource circulation and environmental loads by using a time-series accounting system based on MFCA. Furthermore, as part of our fundamental study of reducing wastes and environmental loads, we implemented an LCS case study that evaluated three waste treatment and recycling scenarios over the 50-year period from 2000 to 2050 in Kitakyushu, Japan.

2. Application of MFCA to regional resouce circulation

2.1 Summary of MFCA

MFCA is an environmental management accounting method developed by the Institut für Management und Umwelt (IMU) in Germany. The method was said to have taken the environmental management project of the UN Division for Sustainable Development (UNDSD) "one step further". Many domestic and foreign companies have shown increased interest in, and use of, MFCA (Shibata and Matsumoto 2006).

Briefly, MFCA looks at the waste products that accompany the manufacture of products. The manufacturing cost of the waste product is then calculated in the same way as it would be for the primary product (Figure 1). MFCA is a management tool that provides quantitative data in both physical and monetary units, and it provides incentives for waste reduction (Nakajima and Kokubu 2002).

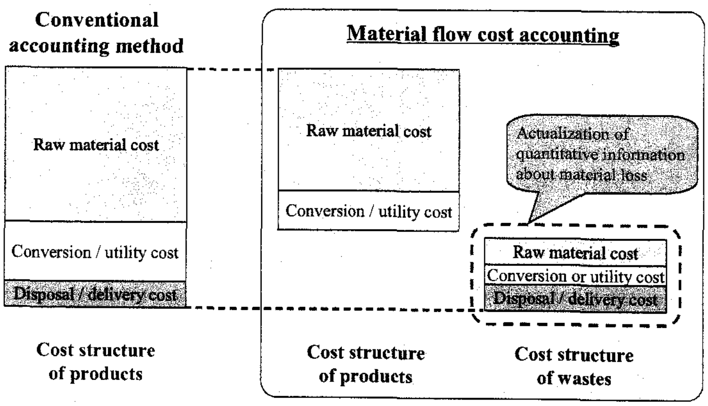


Figure 1. Comparison of the concept of product cost between conventional accounting and MFCA

2.2 Meso-scale MFCA

We previously studied the development of a new evaluation method that made use of MFCA, because we considered MFCA to be potentially useful for the evaluation of meso-scale resource circulation (Matsumoto et al. 2002; Shibata and Matsumoto 2006).

The fundamental work in developing MFCA is in measuring the flow of raw materials. The material flow should be surveyed from the input of the raw materials to the output of products or waste. The mass balance for every kind of material is measured and recorded at a measuring point called the "quantity center". In a conventional MFCA applied to a single production line, every process in the production line corresponds to a quantity center. If every factory or industrial sector is considered to be a quantity center, then the applicable boundary of MFCA can be enlarged to the industrial cluster or regional supply chains (Figure 2).

When applying this type of analysis to a regional area, however, it is necessary to pay particular attention to many factors. The products and the material losses must be defined, as must the constituent elements of cost and the description unit (whether monetary or physical). The resource-circulation structure must be able to include external influences and the venous industrial process.

We call the type of MFCA proposed in this paper "meso-scale MFCA".

2.3 Advantages of meso-scale MFCA

Development of meso-scale MFCA makes the meso-scale resource circulation more obvious and generates the following tangible benefits. (1) Meso-scale MFCA provides essential information to local governments. The quantitative indicators derived from an MFCA output table will allow local administrators to better understand both the nature and the degree of problem areas from the viewpoint of the environmental and economic optimization of regional resource circulation. This improved understanding should lead to more effective planning. (2) It will be possible to evaluate the necessity of, and renewal period for, exisiting facilities, as well as the adequacy of newly built infrastructure, because MFCA can deal with both stock and flow information on the unitary

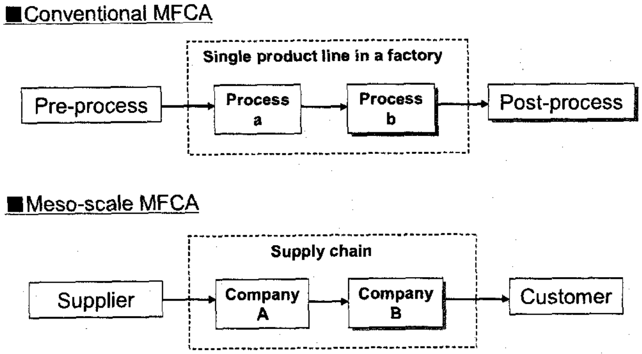


Figure 2. The concept of quantity centers for conventional and meso-scale MFCA

accounting frame. (3) Meso-scale MFCA will become an effective measure of regional safety management, because MFCA can trace the flows of toxic substances that can have serious effects on the human body and ecological systems. (4) Meso-scale MFCA will be a beneficial tool for building consensus, because the position of each subject in the supply chains is clear.

Because MFCA is a technique that was originally designed to track the material flow of raw materials used in manufacturing processes, it is unsuitable for comprehensively expressing a complicated supply chain consisting of a great many companies and industrial sectors. The use of an environmental accounting system such as an input-output (I-O) table seems to be more suitable for such analyses.

2.4 Data construction

Two types of scale are used for meso-scale MFCA. One is a resource-circulation structure (e.g., the circulation of an organic resource throughout an entire region) that includes a number of industrial sectors. Another is an industrial chain (e.g., supply-chain or eco-town project) that consists of several companies or factories within a given industry. Each type requires a different approach to data construction in terms of how a quantity center is defined.

When the entire circulation of a resource is the object of the analysis, industrial sectors (e.g., agricultural producers and processors) in the given area are defined as the quantity center. In this type of analysis, activity data should be acquired through a top-down approach. Data should be estimated on the basis of macro-data (e.g., existing regional or national statistics). Micro-data should also be used, as needed.

When an industrial chain is the object of the analysis, the company or factory is defined as the quantity center. In this instance, a bottom-up approach should be used to accumulate micro-data from each company. Care must be taken when acquiring and processing material flow and LCA data, because multiple companies—some of them possibly in competition with one another—will be included as the object of analysis.

The MFCA proposed in this paper is environmental accounting on the meso-scale. The activity data needed to create the accounting tables should be derived from both micro- and macro-data. We expect that, if companies and governments structure these data as environmental accounting, an effective "micro-meso-macro" cooperation in environmental accounting can be formed through the development of meso-scale MFCA.

3. Time-series MFCA

An adequate evaluation of regional resource-circulation policies should account for time, as mentioned previously. Furthermore, including time in the analysis will contribute to the improvement of environmental accounting as a whole.

If a method of using time-series environmental accounting for a given resource (or a product) could be developed, "vertex comparison" (e.g., between past and present) of various indicators derived from the accounting tables would be possible. We would then be able to identify the environmental loads imposed by the economic activity surrounding that resource, as well as the effectiveness of efforts to reduce the environmental loads.

There are some general manuals on how to develop environmental management accounting techniques such as MFCA, but the actual accounting method used in a given situation varies so that the most effective environmental management can be implemented. A "horizontal comparison" (e.g., between corporations or regions), therefore, has little meaning unless the same accounting methods are used.

A flow cost matrix (FCM) is one of the main results of an MFCA analysis. It is a tabular format that can comprehensively express the structure of material flow and cost. The FCM also accepts varied levels of detail on the description of contents of the table.

A schematic diagram of a time-series MFCA is shown in Figure 3. Each FCM from multiple points in time (t1, t2, and t3) requires MFCA analysis results based on activity data from those points in time. Because the system boundary would commonly need to be changed over time in the case of MFCA analysis intended for multiple time points, the format of the FCM has to remain constant for each time period.

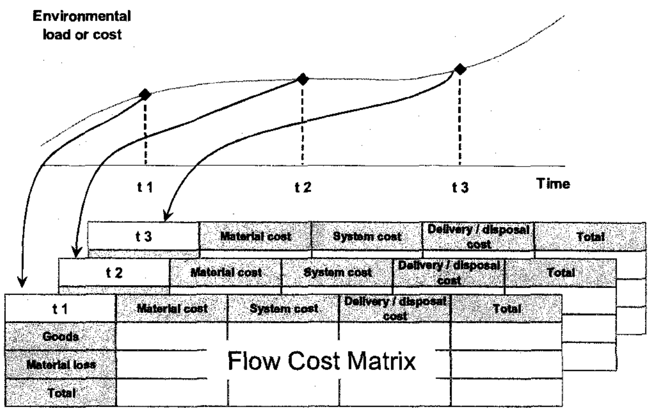


Figure 3. Schematic diagram of a time-series MFCA

4. Case study: treating and recycling organic waste in Kitakyushu

4.1 Object of analysis

We examined the treatment and recycling of household organic waste in Kitakyushu and tried to express the structure of resource circulation and environmental load for the 50-year period from 2000 to 2050. To be more precise, the object of this analysis was Kitakyushu's waste treatment and recycling system, which consists of a waste treatment system, a sewage processing system, and a garbage recycling system (Figure 4). The raw material inputs to the system boundary in the analysis are domestic drainage, organic kitchen waste, and burnable garbage (excluding organic kitchen waste). Both a waste disposal treatment system and a sewage treatment system are included in the

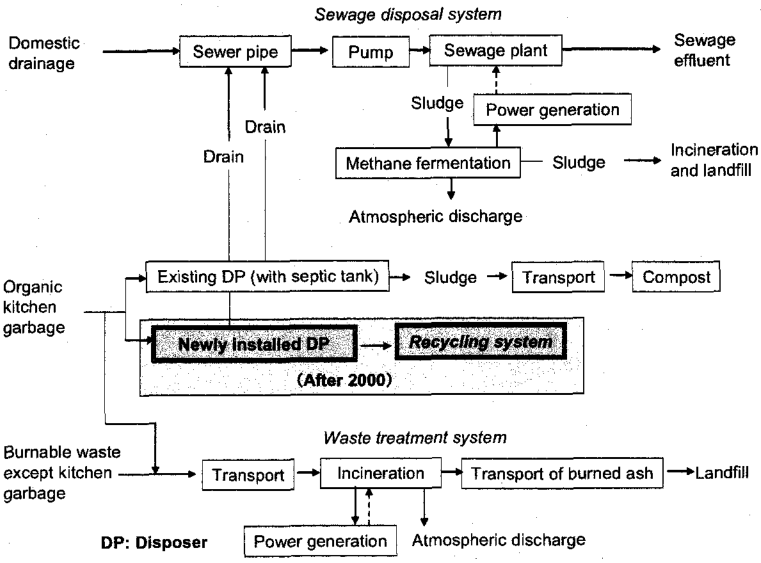
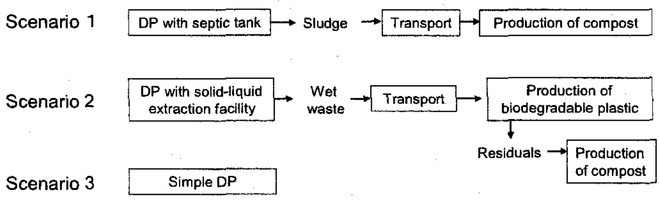


Figure 4. Flow chart for the system of sewage processing, waste treatment, and garbage recycling in Kitakyushu



Scenario	Recycling method after separation by DP
1	Production of compost by use of septic sludge
2	Production of biodegradable plastic by solid waste, and compost by saccharification of residues
3	No additional recycling

Figure 5. Separation and recycling methods for organic kitchen garbage in the three scenarios

system boundary, because setting the type of waste disposal unit called the "disposer" used for garbage separation affects both systems.

Although the disposers with septic tanks are currently the most popular type of the disposer in urban areas, there are other possible types of the disposer. Hence, it is necessary to evaluate which combination of disposal and recycling methods is best. We applied a time-series meso-scale MFCA to this complex structural system and expected that the relationship between material loss and environmental load could be demonstrated with the passage of time.

Three scenarios were developed (Figure 5). We assumed that half of the apartment buildings built

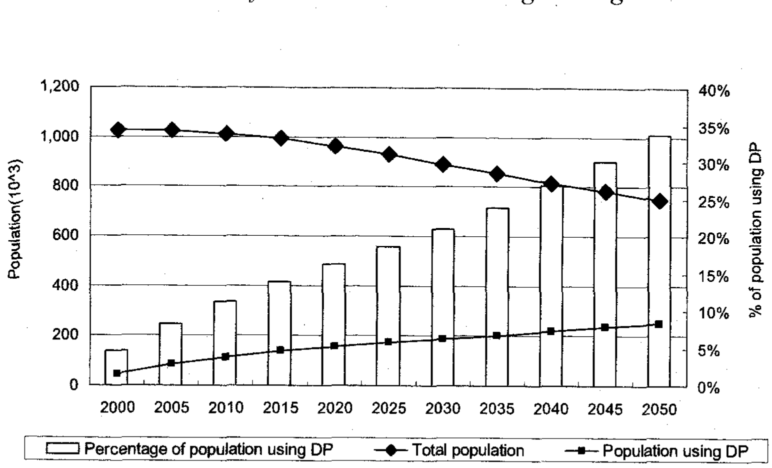


Figure 6. Population and diffusion ratios for the disposal methods used in each of the three scenarios

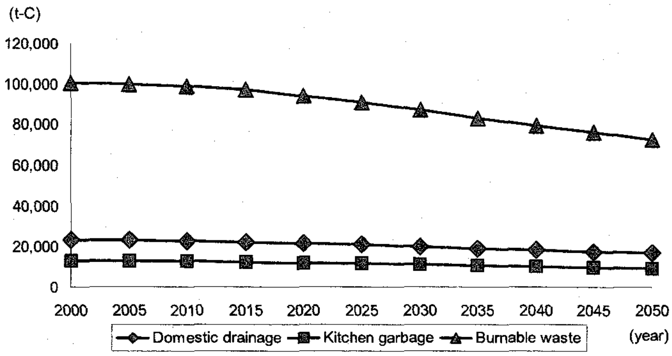


Figure 7. Material inputs for all three scenarios

after 2000 in all scenarios would have some type of disposer. In scenario 1, the newly installed disposers would have septic tanks, and septic sludge would be composted. In scenario 2, the kitchen organic waste would be processed in a newly built disposer with the solid-liquid extraction facility, and the collected solid sludge would be used to produce biodegradable plastic. In scenario 3, the disposers with no waste water treatment system would be installed. We call this a "simple disposer".

Changes in external conditions—population, the percentage of the population using a disposer, the emergence of domestic drainage and waste, and so on—for the 50-year period were taken from Matsumoto et al. (2003). The temporal transitions of the population and the amount of material input are shown in Figures 6 and 7, respectively. The population of Kitakyushu will decrease in the long term, and the amounts of domestic drainage, organic kitchen garbage, and burnable garbage will also decrease.

4.2 Development of the meso-scale MFCA

On the basis of the above-mentioned conditions, we performed a case study of the dynamic changes in material flow and environmental load from 2000 to 2050 for Kitakyushu under the LCS concept. The meso-scale MFCA that expressed the result of the LCS was developed as follows.

In the case of a corporate MFCA, the cost of production (material cost, system cost, and delivery and disposal cost) is compiled in monetary terms every time raw materials arrive after having passed through a manufacturing process. In the case of meso-scale MFCA intended for a city or region, the quantity center where cost information is measured corresponds to each company and industrial sector. Therefore, measurement in monetary terms and the method of disclosure are generally more difficult because of differences in MFCA development or because of potentially advantageous or disadvantageous relationships between the parties (i.e., they could be competitors who do not wish to share information with each other).

The primary areas of concern with a meso-scale MFCA are to analyze whether the whole environmental load is reduced and to present the relationship between the material flow and the environmental load visually and comprehensively. Thus, it is useful to evaluate the amounts of raw material and waste and the environmental load accompanying production in physical terms as a first step. This does not mean, however, that evaluation in monetary terms is not useful. If measurement of a company's data and disclosure of compiled data is possible, development of an MFCA in monetary terms would have important meaning. In this study, however, all data were compiled in physical terms, and the word "cost" was applied to the physical amounts to be consistent with conventional MFCA analysis.

Material cost was defined as the amount of raw material that was input to the system boundary. The unit used was an integrated physical term that represented the carbon content of the raw material (i.e., domestic drainage, organic kitchen garbage, and burnable garbage except organic kitchen garbage). Because we needed to integrate each amount of multiple material inputs, we used the most elemental component of organic waste, the carbon content, as the material cost. Because the system cost in a conventional MFCA was originally considered to be an indirect cost, we defined the system cost as the life cycle CO_2 ($LCCO_2$) derived from the energy consumption accompanying the conversion, disposal, and delivery of products or waste. We chose $LCCO_2$ because it is a causative substance of external diseconomy and an indicator of growing concern. $LCCO_2$ data were provided by the LCS analysis. Carbon-neutral CO_2 was not accounted for as a system cost. $LCCO_2$ was allocated to a product or by-product on the basis of the carbon content of each material.

Products were defined as the amount of compost and biodegradable plastic produced by recycling. Material loss was defined as the amount of final disposal waste generated in the processes of sewage disposal, waste treatment, and recycling and the amount of atmospheric discharge that accompanied incineration. The contribution of pollution removal was defined distinctly from the products. The amount of total carbon (TC) contained in the final effluent after water treatment was applied to the indicator such that a smaller TC content in the final effluent meant the higher performance of venous process in the evaluation of the material flow.

The system boundary of each scenario was adjusted in light of the substitution effect obtained from recycling, because the system boundary changed as garbage separation and recycling of septic sludge and organic kitchen garbage became more common. The substitution effect was expressed in virtual $LCCO_2$ accompanying generation of products equivalent to recycled products.

Generally, the primary interest for an MFCA of a waste treatment system is the measurement of

Table 1. Flow cost matrix (in physical terms) for scenario 2 in 2050

Scenario 2 2050		Material cost 【t-C/year】				System cost ($LCCO_2$) 【t-CO_2/year】												
			Sewage	Waste			Sewage disposal				Recycling of kitchen garbage				Waste treatment			
			Domestic sewage	Organic kitchen garbage	Burnable waste		Pipe	Pump	Plant	Incineration and landfill	Separation	Transport	Compost	Bio-degradable plastic	Transport	Power generation	Transport of burned ash	Landfill
Products		**1,600**	-	1,600	-	**21,259**	-	-	-	-	18,931	235	159	1,934	-	-	-	-
Recycling	Compost by septic sludge	180	-	180	-	459	-	-	-	-	193	107	159	-	-	-	-	-
	Compost by saccharification of residues	653	-	653	-	9,590	-	-	-	-	8,626	59	-	905	-	-	-	-
	Biodegradable plastics	766	-	766	-	11,210	-	-	-	-	10,113	69	-	1,028	-	-	-	-
Pollution removal		**174**	169	6	-	**24,726**	14	334	16,096	-	8,283	-	-	-	-	-	-	-
Final effluent		174	169	6	-	24,726	14	334	16,096	-	8,283	-	-	-	-	-	-	-
	(Removal of TC)	17,274	16,693	580	-													
Substitution effect by recycling		-	-	-	-	**-58,587**	-	-	-7,202	-	-	-	-74	-6,703	-	-44,608	-	-
Substitution of chemical fertilizer		-	-	-	-	-234	-	-	-	-	-	-	-74	-160	-	-	-	-
Substitution of plastic from petroleum		-	-	-	-	-6,543	-	-	-	-	-	-	-	-6,543	-	-	-	-
Substitution of public electricity		-	-	-	-	-51,810	-	-	-7,202	-	-	-	-	-	-	-44,608	-	-
Material loss		**97,580**	16,693	7,808	73,079	**96,242**	14	334	16,096	41,646	21,310	89	0	1,367	1,029	12,334	124	1,900
Final disposal / Atmospheric discharge	From sewage disposal	17,274	16,693	580	-	66,372	14	334	16,096	41,646	8,283	-	-	-	-	-	-	-
	From waste treatment	79,320	-	6,241	73,079	15,387	-	-	-	-	-	-	-	-	1,029	12,334	124	1,900
	From recycling of garbage	987	-	987	-	14,484	-	-	-	-	13,028	89	-	1,367	-	-	-	-
Total		**99,355**	16,862	9,414	73,079	**83,641**	28	667	24,990	41,646	48,524	323	86	-3,402	1,029	-32,274	124	1,900

the amount of waste and the indirect costs that accompany waste treatment (Kokubu 2006). Therefore, the way products and material losses are viewed in an MFCA intended for a venous industry is different from how they would be viewed in an MFCA for an arterial industry. In the future, it will probably be necessary to look at how we define the removal of pollutants and the decreases in waste and detoxification as products and material losses.

4.3 MFCA analysis results

Using these methods, we implemented the development of a meso-scale MFCA for the three waste treatment and recycling scenarios. The results for scenario 2 for 2050 are shown in Table 1 as an example of the development of an FCM. In this scenario, there is 99,355 t-C of total raw materials: 174 t-C arrives as final effluent after sewage processing, 1,600 t-C is consumed as raw material for recycling products, and 97,580 t-C is landfilled and emitted as material loss. The material loss ratio is very high (98% of the input), because it is assumed that all final residual generated by sewage processing and waste treatment is landfilled. The total system cost ($LCCO_2$) is 83,641 t-CO_2. Of this, 45,985 t-CO_2 accompanies the generation of products. Another 58,587 t-CO_2 comes from the substitution effect from the generation of recycled products and thermal recycling in sewage processing and waste treatment. The amount of waste treated at solid-liquid extraction facilities is assumed to be increasing in this scenario as the number of people using disposers increases, and the amount of $LCCO_2$ from home garbage separation is 48,524 t-CO_2 and the max in all processes.

4.4 Temporal transition of performance indicators

Material flow

The material loss ratio for material inputs decreased in scenarios 1 and 2 (Figure 8). In these scenarios the collected organic material is recycled to compost and biodegradable plastic. Conversely,

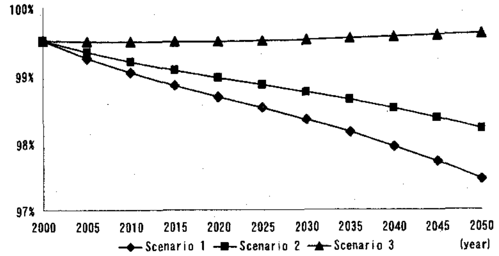


Figure 8. Material loss ratios for all three scenarios

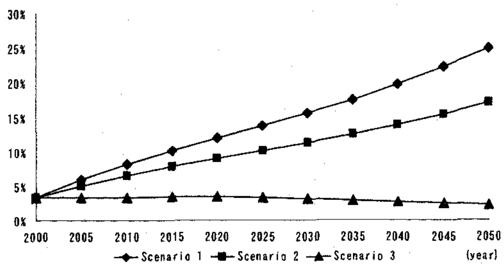


Figure 9. Ratios of recycled products produced from kitchen garbage for all three scenarios

the material loss ratio increased slightly in scenario 3; this is because the amount of sewage sludge would increase over time because a great deal of garbage flows into the sewage processing system. In all three scenarios, most of the organic kitchen waste would ultimately be discharged into the environment in the form of fire ash and CO_2.

Organic kitchen garbage was assumed to be the main raw material input for recycled products. The ratio of generation of recycled products from organic kitchen garbage increased in scenario 1 and decreased in scenario 3 (Figure 9). In light of the present level of technology and production scale, the compost from septic sludge can be considered to be more dominant than the biodegradable plastic from organic kitchen garbage in terms of resource utilization. There are some problems, however, in expanding the application of compost, particularly in urban areas. Conversely, plastic is indispensable for everyday life and industrial activity, and we expect that the recycled plastic will be used as a substitute for plastic generated from petroleum. If the industrial technology improves and the production scale expands with the increased demand, we expect that more organic kitchen garbage will be recycled.

Environmental load

The environmental load ($LCCO_2$) of the entire analytical system is shown in Figure 10. These $LCCO_2$ levels account for subtractions from the load owing to recycling. Levels of $LCCO_2$ for scenario 2 are higher than those for scenarios 1 and 3. The amount of $LCCO_2$ by the processes of scenarios 2 and 3 relative to that of scenario 1 is shown in Figure 11. In scenario 2, we assumed that the disposer with the solid-liquid extraction facilities would increasingly be used, and most of the advantage relative to scenario 1 originated in the separation process by the disposer. In scenario 3, we assumed that the simple disposer would become more widely used, and $LCCO_2$ reduction was achieved as a result of a reduction in the separation process by the disposer in spite of an increase in sewage treatment and sewage sludge disposal.

The influence of the garbage separation process is significant in reducing the overall levels of $LCCO_2$. In scenario 2, 58% of the $LCCO_2$ for the entire system was influenced by the disposer installed in each home in the city. The environmental load resulting from separation by the disposer is shown in Figure 12.

We calculated an eco-efficiency indicator from the amounts of compost and biodegradable plastic

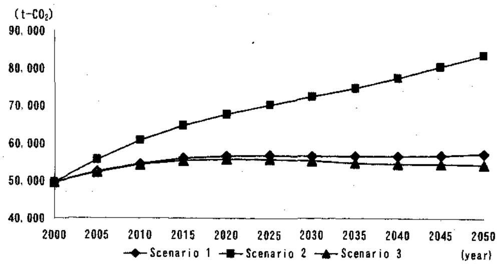


Figure 10. $LCCO_2$ of the entire system for all three scenarios

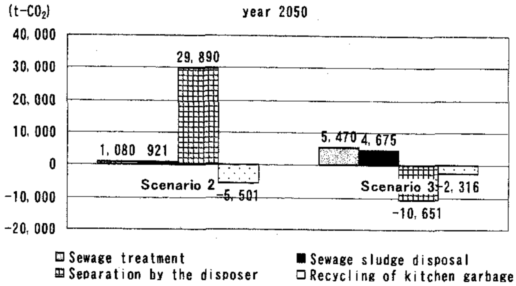


Figure 11. $LCCO_2$ of scenarios 2 and 3 relative to that of scenario 1

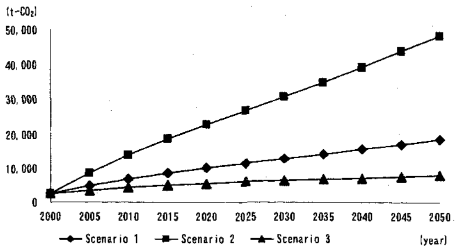


Figure 12. $LCCO_2$ of processes during and after separation by the disposer

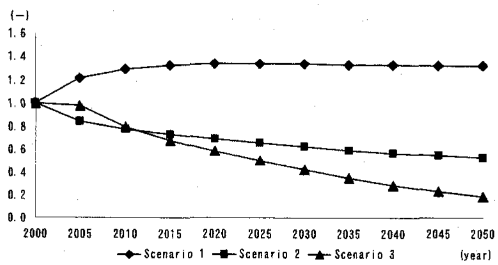


Figure 13. Eco-efficiency of the recycling of organic kitchen garbage

derived from recycling of organic kitchen garbage and the total environmental load required for the recycling of organic kitchen garbage (Figure 13). Eco-efficiency was the highest for scenario 1, and the high level was maintained throughout the period of analysis. In scenarios 2 and 3, eco-efficiency continued to decline after 2000. At the same time, the ratio of products increased in scenario 1 and 2 and decreased slightly in scenario 3 (Figure 9). The eco-efficiency differences arose because increases in energy consumption and environmental load were greater than the increase in volume of generation of products.

5 Conclusion

We proposed an evaluation framework by using time-series accounting tables based on the MFCA concept. Furthermore, we implemented an LCS for material flow and environmental load for three scenarios of processing and recycling of organic kitchen waste in Kitakyushu over the 50-year period from 2000 to 2050. We expressed the LCS results in physical terms in the accounting tables and made temporal transitions of various performance indicators to verify the effectiveness of the proposed methods. We were thus able to consider dynamic changes in external conditions in the analysis and present the results (e.g., generation of products and the environmental load accompanying the material loss) visually and comprehensively. Such dynamic changes in external conditions cannot be considered in a conventional LCA. Moreover, by using temporal performance indicators we were also able to evaluate changes in the structure of resource circulation and environmental loads that accompany changes in the external conditions. In doing so, we demonstrated the prime advantages of meso-scale MFCA in our case study.

The results of the material flow, environmental load, and eco-efficiency analyses for the three recycling scenarios did not enable us to identify a preferred scenario. It is likely that we will need to introduce an expanded physical indicator that includes more than just carbon content and then integrate these results into an evaluation indicator. Furthermore, although our proposed framework can evaluate material flow and $LCCO_2$, it cannot provide a solution for the trade-off between the reduced $LCCO_2$ and increased water consumption that accompany disposer operation.

We plan to conduct a scenario analysis of the material loss reduction that is an original function of MFCA. In addition, we need to develop an application by which we can update plans for environmental facilities, comprehensively analyze both the arterial and venous facets of the food industry, and conduct an analysis that includes monetary terms.

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