特集「循環型社会のLCA」

研究論文

エコサービスの分類及び評価手法の提案： セメント製造における都市ごみ処理のケーススタディ

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Proposals for Classification and an Environmental Impact Evaluation Method for Eco-Services: Case study of Municipal Waste Treatment in Cement Production

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Synopsis: Various eco-services have been recently introduced in Japan as a proactive approach to create a sustainable society. These eco-services include a wide range of businesses and each eco-service has its own unique characteristics. It is necessary to systematically classify these eco-services into different categories to understand the development trend as well as to promote these eco-services with regard to sustainable development. In addition, overall environmental impacts and economic benefits of these eco-services need to be quantitatively evaluated using a life cycle approach to ensure the real benefits of eco-service business. Two different scenarios for a municipal waste treatment system by comparing landfill and recycling in cement production were used as a case study. The overall environmental impacts of these scenarios were quantitatively evaluated in this research by using a life cycle impact assessment (LCIA) method known as “LIME”. Study results indicated that the use of municipal wastes in cement production could reduce overall life cycle impacts

Key Words: eco-services, LCIA, municipal wastes, cement production, LIME

1. Introduction

In recent years, environment-related activities in Japanese industries have become one of the main components in their businesses. The prefix “eco” is used for materials, products, technologies and services in which environmental issues are considered during the development phases. Studies by Nguyen et al. [1] revealed the commercialization of nearly 1000 different types of eco-materials, eco-products and eco-services were merchandised in Japan in 2005. In addition, a recent study by the same group identified about 250 different eco-service businesses that were reported in the annual environmental reports of 200 Japanese companies out of more than 500 published environmental reports. Japanese industries have apparently started to shift their business to services with support of advanced technologies and information technology. The spread of eco-services seems to be crucial to achieve further reductions in environmental burdens caused by business activities.

Eco-service is defined as those services that can (or can be expected to) reduce overall environmental burden compared to conventional businesses which are focusing on sales of products [2]. Enhancement of environmental performance can be achieved through the reduction of resources and energy required for production, distribution and consumption of products as well as handling of used products. In order to widely promote the eco-service businesses, a holistic evaluation of the environmental and economic performance is necessary, which allows to demonstrate and prove scientifically the idea of shifting a product-based economy to a service-based economy; thus being a stepping-stone on the path to sustainable development. Due to their variety and diversification, currently commercialized eco-services in Japan are difficult to evaluate and compare one with another. It is, therefore, essential to perform evaluation not before classifying existing eco-services into appropriate groups. By observing this order, classification and evaluation of

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eco-services can (1) provide a clear picture of influences caused by eco-services to a sustainable economy; (2) help industrialists to design a better eco-service; and (3) help end-users or customers to select the most appropriate eco-service according to their needs. The recent development of eco-services in Japan has revealed that existing classification methods [3],[4],[5],[6] can not be accurately applied because eco-services have become increasingly complicated.

Goedkoop et al. [5] and Tagusari [6] tried to classify eco-services by considering the relationship between product and service. Four types of eco-services are identified as Ps (meaning a service connected to products), Sp (meaning a service in that provider can add products), PS (meaning a service in that products and services are developed in combination to provide their function fulfillment), and STCH (meaning an innovation service that substituting an existing PS system by an improved one). Unlike Goedkoop and Tagusari, White [4] proposed a classification method based on material science perspectives. This method classifies eco-services into two main groups, non-material services and material services. Insurance, banking, and health care belong to non-material services, whereas product leasing and renting, warranties, and maintenance belong to material services. A relatively more comprehensive classification of eco-services was proposed by Tukker [3]. This method classifies eco-services into eight different groups. They are product related, advice and consultancy, product leasing, product renting and sharing, product pooling, activity management, pay per service unit, and functional result.

These classification methods allow to roughly classify traditional eco-services. However, due to limitations in classification boundaries, their application to newly developed business models is quite difficult. For instance, the ESCO business (Energy Service Company), which is offered by Hitachi Company to provide comprehensive energy-related service, consists of two types of services, a consultancy service (non-material service according to White's method) and a leasing service (material service according to White's method). In addition, it is impossible to classify this service using the methods by Goedkoop et al. [5] and Tagusari et al. [6] since it consists of the two eco-services Ps and Sp. Furthermore, this type of service can not be completely classified by

using classification method proposed by Tukker, because the service can be considered as being either product oriented, use oriented, or result oriented.

This paper proposes a new classification method, which is more practical and allows to reflect the diversification of eco-services. In addition, a quantitative evaluation of total environmental impact caused by municipal waste treatment in cement production facilities is performed as case study by applying a life cycle assessment procedure.

2. Method

2.1 Classification of eco-services

The proposed classification of eco-services was carried out applying the following approach. First, distinguished types of eco-service with common characteristics in various eco-service businesses were identified. These distinguished types are called "Eco-service elements". The "eco-service elements" consist of simple business models which have similar characteristics. For example element of functional sales consists of rental, leasing, sharing, and functional assurance. In these simple business models, service providers do not sale products, but function required by customers. Service providers still own the product. Based on the viewpoint of material engineering, the eco-service elements were then grouped into two distinguished eco-service categories called material-related and non material-related services (Figure 1).

Eco-service elements were determined by using information collected from the annual environmental reports and homepages of more than 200 Japanese companies. Approximately 250 eco-services which had been reported in Japan in 2005 were analyzed to identify common characteristics with respect to different several eco-services. In this way, the common characteristics of eco-service elements could be determined.

2.2 Evaluation method

In the next step, a life cycle approach was used to evaluate overall environmental and economic impacts caused by eco-service. In most situations, overall environmental impacts can be converted into monetary values by applying life cycle impact assessment (LCIA) methods such as EPS [7], ExternE [8], and LIME [9]. Among these three LCIA methods, ExternE and LIME are based on the concept of external cost, or externalities, which are

Figure 1. Eco-service elements proposed in this study.

defined as a cost caused by social or economic activities of one group and imposed on another group [8]. In this study, LIME has been used as evaluation method to assess the external cost of eco-services born by Japanese society, because LIME has been developed particularly for Japanese industries and society. LIME (Life-cycle Impact assessment Method based on Endpoint modeling) is an end-point assessment method based on damage calculation. The degree of damage caused by consumption and emission depends on the specific environment even if the same quantity of substances is dug out of or released into the environment. LIME is a specific method tailored and applicable to the environment within Japan, while EPS and ExternE are methods that have been developed and are used in European countries. LIME consists of eleven types of characterization factors based on simulation models steered by parameters that reflect Japanese geographic conditions. These characterization factors are used to calculate the amount of damage to four safeguard subjects (human health, social welfare, biodiversity, primary production) by using causal relation modeling. The environmental burden is integrated as external cost by using conjoint analysis to determine weighting factors that work as economic indicator [9].

It should be noted that the external cost calculated from LIME is different from the real cost like amount of investment or running cost to operate a production plant. Society is the beneficiary from the saving of external cost, not the company or investor. Therefore, the LIME result is interpreted as added value generated by a system, product, or service in favour of a society.

3. Eco-service elements as essential part of the classification method

Using information on 250 commercialized eco-services collected from 200 companies, seven different types of material-related eco-services and four different types of non material-related eco-services were identified (Figure 1). These eco-service elements have been labeled alphabetically for easy identification. In addition, eco-services are also identified and divided into simple and complex business models. The simple business model consists of only one eco-service element, while the complex model contains two or more eco-service elements. Examples of simple business models are car sharing (eco-service element A), jet engine maintenance (element B), used beverage can recycling (element C), and eco-funds (element K). The complex eco-service business

model is more comprehensive. Some eco-services consist of 4 elements contained in one model. Examples of complex business models are lighting assurance service (elements A and C), used automobile part sales (elements C and I), ecological office management services such as ITOKI (element C and K), ESCO business (elements A, E, H, and I), and energy solution service businesses such as H-drive of HITACHI (element E, H, I, and J).

Due to its ability to classify the majority of commercialized eco-services in Japan, this classification of eco-service is more practical than existing methods. When each eco-service is analyzed in detail after having applied this classification method, the effects of eco-service elements contributing to reduced environmental load are easier to be understood. In addition, elements can easily be identified whose combination offers successful business opportunities.

4. Case study

4.1 Reviews on use of cement kiln for waste treatment

Use of rotary cement kiln for waste incineration and treatment has been applied since the last decade in Europe and other countries. However, it was not used to incinerate municipal solid wastes, but mainly applied for thermal treatment of hazardous wastes such as discarded rubber tires, spent organic solvents, and paint residues as alternative fuel [10]. Several studies on the overall environmental impacts of thermal recycling of wastes in cement kilns using a life cycle approach have been conducted in Europe [11],[12],[13]. CEMBUREAU reported that use of cement kiln for waste incineration “demonstrated a significant overall improvement in environmental performance”[11]. In addition, several merits of waste incineration in cement production were identified like partial replacement of non renewable fuels and resource (clinker), complete destruction of organic substance, capability of handling both hazardous and non hazardous wastes, and advantages of investment [10]. However, the use of cement kiln for waste incineration has some disadvantages which are the necessity of specific treatment of wastes prior to incineration, emission of volatile heavy metals such as mercury and cadmium, and issues concerning final product (cement) specification. Moreover, the previous LCA studies on the incineration of wastes in cement kilns have not taken constraint of landfill into consideration. The case study in this paper

was conducted to overcome the limitations of previous studies as well as to validate the concept of eco-service classification scheme explained above.

4.2 Descriptions of systems

In order to validate the aforesaid concept, the municipal waste recycling business that uses the AK (Applied Kiln) system at Hidaka City in Saitama Prefecture has been evaluated as a case study. The AK system is a former cement kiln that has become redundant and been converted to a municipal waste recycling kiln [14].

The treatment of municipal waste in the AK system consists of four main steps. Firstly, collected municipal wastes are fed directly into the waste recycling kiln followed by addition of aerobic fermentation agents. This mixture is then kept under aerobic conditions for three days. After that, the bio-digested materials are sorted and the combustible fraction is used as a fuel for cement manufacturing. Furthermore, the incineration ash generated during the combustion process is used as raw material for cement production. In this way, the “zero emission” target regarding municipal solid wastes is achieved.

Municipal wastes consist of both household combustible and household incombustible wastes. Recyclable wastes and metals are sorted and separated prior to the treatment processes. Combustible wastes from business activities are also fed into this AK system. All municipal wastes generated from Hidaka city are collected and treated in this system, too. The annual amount of municipal waste dealt with amounts to 14,800 tons.

4.3 Classification

The AK system can be classified from the point where collected municipal wastes are separated and added to the kiln together with the fermentation agent up to the point where heat is recovered and combustion ashes are used as input materials for cement production (Figure 2). Therefore, the AK system is classified as complex business model consisting of the two eco-service elements of C (Recycling) and D (Waste treatment).

4.4 Treatment Scenarios

The two scenarios shown in Figure 2 were evaluated. In scenario 1, municipal solid waste undergoes a combustion process at an incineration plant and the ash is landfilled.

Figure 2. Municipal waste treatment scenarios for LCIA.

This scenario was selected as counter-system for comparing the new zero emission system in scenario 2. In scenario 2, municipal waste is recycled using the AK system. Moreover, the exhaust heat generated from the incineration plant in scenario 1 was assumed to have not been recovered in the past. In scenario 2, this heat energy was used for heating up input materials in the cement production process. The transportation process in scenario 1 was calculated based on the distance from the incineration plant to the current landfill site in Hidaka City.

4.5 System boundary

The system boundary of scenario 1 starts at the municipal waste incineration plant and ends at the landfill site for the incineration ash. That of scenario 2 starts at the recycling process of the municipal wastes and ends at the combustion with recovery of energy and materials for cement production.

In scenario 2, the quantity of energy and resources used in the cement manufacturing process are changed because the treated waste materials had been incinerated. Therefore, the respective amounts of increase and decrease in the cement manufacturing process were added or subtracted from the system of scenario 2.

However, environmental impacts (including resource usage and pollutant emissions) caused by equipment manufacturing, eg. manufacturing of the incineration plant and AK system, were not evaluated in this study.

4.6 Functional Unit

In this study, one ton of municipal solid waste was defined as functional unit for evaluation.

Table 1. Inventory analysis result of waste treatment process of Hidaka city.

		Unit	Scenario 1	Scenario 2
Waste treatment process	Electricity	kWh	111	306
	CO ₂	kg	911	867
	Incineration ash	kg	10.7	0
Cement production process	Electricity	kWh	0	84.3
	Coal	kg	0	-251
	Clay	kg	0	-71.1
	CO ₂	kg	0	-691

Figure 3. Results of inventory analysis concerning electricity use and CO₂ emission.

4.7 Results and discussion

4.7.1 Inventory analysis result of the waste treatment process of Hidaka city

The result of the inventory analysis is shown in Table 1 and Figure 3. The life cycle inventory data for municipal waste recycling at Hidaka City used in this study was obtained from a report by Kaneko in 2003 [15].

Inventory results indicated that electric power consumption in scenario 2 was about 3.5 times higher than that in scenario 1 as shown in Figure 2 (390 kW in scenario 2

compared to 111 kW in scenario 1). This is mainly due to higher electricity consumption during the treatment process for municipal wastes in the AK system. More electricity is required in the AK system compared to the conventional municipal waste incineration plants.

Moreover, the amount of CO₂ generated by incinerating the waste treated in the AK system as fuel is similar to that generated by incineration of untreated wastes. The total amount of coal combusted in the AK system for cement production is reduced for reason of substitution by using the treated waste materials. As a result, the total CO₂ emissions from the AK system are lowered compared to that of scenario 1. Life cycle inventory data indicated that the entire amount of the CO₂ emitted in scenario 2 was about one fifth compared to scenario 1 (176 kg of CO₂ generated in scenario 2 compared to 911 kg of CO₂ generated in scenario 1).

4.7.2 Environmental impact assessment result of the waste treatment process of Hidaka city

An environmental impact assessment using LIME was carried out for both scenarios using the above inventory analysis results. The LIME results in Table 2 showed that the overall environmental impacts were reduced by approximate 1400 yen (85%) even though electricity consumption in the AK system was higher than for the conventional cement production system (Figure 4).

Figure 4. External cost of municipal waste treatment of the different systems using LIME.

By using the AK system for municipal waste treatment and cement production, the external cost can be reduced by approximate 1500 Japanese yen (one US dollar equals to 110 Japanese yen) per ton of waste, thus saving 22 million Japanese yen per year. The overall environmental impact reduction is mainly due to reduced CO₂ (a greenhouse gas) emissions. CO₂ originating from fossil fuel combustion is lowered as result of substituting coal by treated municipal wastes as fuel for cement production. In other words, thermal recycling has the effect to reduce the overall CO₂ emissions in the AK system. Moreover, the overall environmental impact of resource consumption is lowered, because treated waste materials are used for energy generation and as raw material in cement production. This measure also influences the reduction in overall environmental impacts.

In the above analysis, the environmental impact of land use is not yet included. Land use impact is another aspect in this study. In scenario 2, the AK system does not require any new land area because it is set up in an existing production facility. On the other hand, new sites for final disposal will be required in the future in scenario 1 when municipal wastes are incinerated and landfilled. If a landfill site of the same scale as that at Hidaka city with a capacity of 44,300m³ and a lifetime of 20 years is to be constructed, an external cost of 33 million Japanese yen is added as the impact of land use. Running the AK system, therefore, can result in an additional reduction of 33 million Japanese yen of external costs normally levied on Hidaka city over a period of 20 years. These reductions of external cost would bring benefit to citizen in Hidaka city and surrounding area. The company who is operating this AK system will not benefit from these saving, except the subsidiary from municipal government as disposal charge.

The next step of this study is to identify which eco-service element among those belonging to the two scenarios has the capability to create greater effect on the reduction

Table 2. External cost of municipal waste treatment of the different systems using LIME (unit in Japanese yen per ton of waste).

	Green house gas	Acidifying substance	Urban air pollution	Resource consumption	Waste	Total (Yen)
Scenario 1	1500	3.4	49	20	81	1650
Scenario 2	530	11	170	-460	0	250
(Scenario 1)–(Scenario 2)	1000	-7.3	-120	480	81	1400

Figure 5. External cost of municipal waste treatment of the different systems using LIME (Impact category).

of overall environmental impacts. Results of this study showed that the reduction in overall environmental impacts were mainly due to a decrease in CO₂ emissions in the thermal recycling step (eco-service element C). Therefore, the eco-service containing eco-service element C (recycling) is regarded as the one that has a greater effect on reducing the overall environmental impacts.

On the other hand, eco-service element D (Waste treatment) had smaller influences on the reduction in the environmental impacts compared to that of other elements as shown in Figure 5 and Table 2. The external cost of CO₂ emissions reduces from 1500 Japanese yen per ton in scenario 1 to 1000 Japanese yen per ton in scenario 2, while the external cost of wastes reduces from 8.1 yen per ton to zero yen per ton.

Though having a small effect on environmental impact reduction, eco-service element D (waste management) has a greater influence on setting up a system from an economic viewpoint than recycling (eco-service element C) has. However, the company which operates the AK system can obtain a steady income from municipal governments in the form of disposal fees. Therefore, this element is believed to be the one that greatly contributes to the enactment of an eco-service business.

From the study results it is evident that eco-service element D has a smaller effect on the reduction of the land use impact compared to that of other elements. This eco-service element would, however, have a greater influence on the social acceptability of the AK system in case final disposal landfills are full and construction of a new disposal site would become very difficult.

5. Conclusion

By analyzing more than 250 different eco-services in Japan, this study proposes a new classification method that allows grouping most eco-service businesses into an appropriate classes. In addition, by analyzing each service after classification, the reasons why some eco-services have been successful while others have not can be better understood. Case study results open up the perspective that the AK system can enhance the creation of a recycling-oriented society for sustainable development. This conclusion is mainly based on the effects caused by eco-service element C, or in other words, thermal recycling.

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