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Rating of ecomaterials from the sustainability perspectives: A semi-quantitative method (SAM)

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According to around 270 annual environmental reports in 2002 published by Japanese companies, about 359 so-called ecomaterials were commercially available. This study was attempted to introduce a rating method for ecomaterials from the sustainability perspectives to help design engineers, managers, and consumers in selecting the appropriate materials for sustainable production and consumption. The objective of this study was to develop a simple and common guideline which is understandable by lot of people without much experience in this field. This semi-quantitative method employed the life cycle concept, and The Natural Step (TNS). Twelve indicators, which were sub-grouped into four system conditions of TNS, were also included. A sustainable index was calculated to rate ecomaterials into 4 grades ranking from positively used materials to immediately avoided materials based on its life cycle inventory data. The study results indicated that biodegradable thermoplastics (Bi-NF, and Bi-PE) and recycled polystyrene were better than synthetic plastics in term of sustainability. This methodology could be used as a new tool which is useful for product and process designers, decision makers as well as consumers for a sustainable society.
Key words: ecomaterial, sustainability rating, Life Cycle Assessment, sustainable development

1. INTRODUCTION

Life Cycle Assessment (LCA) has been introduced and applied widely as one of ecological assessment tools of a product or service. Most LCA case-studies focused on limited ecological impacts such as energy and material consumption, green house gases, ozone depletion gases and human health impacts. However, traditional LCA does not clearly indicate a comprehensive picture of overall social and ecological impacts of products, especially when the socio-economic factors such as the distribution of resources, wealth, cultural changes are taken into consideration in this picture.

Recently, many authors have attempted to define the concept of sustainability such as The Natural Step concepts (TNS) [1], Eco-economy [2], or Herman Daly's principles for sustainable development [3]. However, there is no current assessment for material, product or service itself from the view point of sustainability.

This paper aims to introduce a method for sustainable rating eco-material and eco-product, and for assisting in improvement of product and service toward the sustainability.

2. ECO-MATERIALS CONCEPT AND STATUS

The concept of eco-material was proposed by a group of material scientists in Japan in the late 1980s. At the beginning stage, eco-material concept was focusing on the development of materials which could contribute to the environmental conservation and protection as indicated in its name. To achieve the objective, environmental issues and functional properties of materials were considered including structural materials in construction or automobile as well as special functional materials such as semiconductors or solar cells. From a view of material science, eco-materials should pose at least one out of 10 superior properties compared to the traditional material [4].

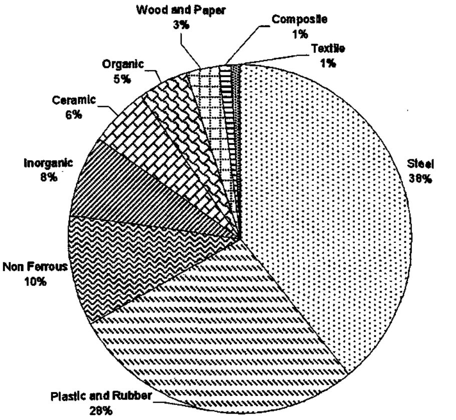

Fig. 1: Ecomaterial distribution in Japan industries

Currently, many Japanese companies showed their efforts in the development of eco-materials. Based on the environmental reports in 2002 of 40 Japanese companies which were available in English and indicated the development of ecomaterials, 359 eco-materials were identified. Among the industrial sectors, iron and steel industry was the leading one in the field of eco-materials development (38%) in Japan (Fig. 1). The main focus of eco-materials in iron and steel industry was on the development of high tensile steel, wear resistant steel, non hazardous coating steel, high magnetic induction steel. The second leading industry was plastics and rubber (28%). Areas of eco-material development include biodegradable plastics, non-halogen flame retardant plastics, VOCs (volatile organic compounds)-free plastics, or heavy metal-free polymers.

3. SUSTAINABLE RATING METHODOLOGY (SAM)

3.1 SAM model

Sustainable rating methodology (SAM) is based on the four system conditions of TNS and a concept of life cycle. The four system conditions of TNS provide a scientific-based framework while the life cycle concept provides details of impacts throughout the whole life cycle of materials or products (Fig. 2). This assessment method is considered as a semi-quantitative method in which some of indicators assessed quantitatively and others assessed qualitatively. In addition, the final single index is qualitatively aggregated. Life cycle inventory and other qualitative data of eco-materials was used for the assessment.

As indicated in Fig. 2, twelve indicators used in the assessment were grouped into four groups related to four system conditions of The Natural Step. Some of these indicators are used commonly in life cycle assessment (LCA) such as the global warming potential (GWP), ozone depletion potential (ODP), photo-oxidant chemical potential (POCP), acidification, nutrient enrichment, human toxicology, and energy. The others are rarely used such as recyclability, biodegradability, scarcity, and place of extraction.

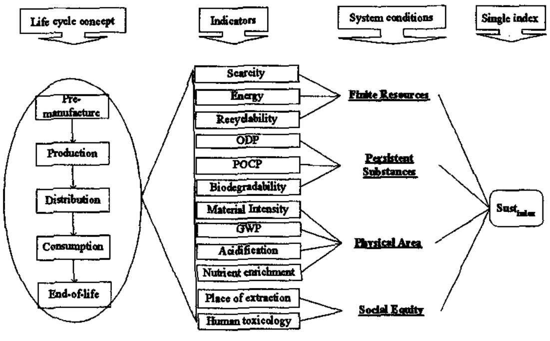

Fig. 2: Model of Sustainable Rating Methodology

3.2 SAM calculation method

Each indicator was assigned a 3 or 1 or 0 point based on the developed criteria (Table I). For ODP, POCP, nutrient enrichment, and human toxicity indicators, comprehensive lists are in Hauschild's publication [5]. For material intensity indicator, a report of the factor 10 club included a comprehensive list of several materials as well as how to calculate the material intensity of each material and product [6]. In addition, the World Resource Institute has published information of the reserve of some finite materials such as oil, natural gas, coal, metals [7].

Then, a sustainable index was calculated to rate ecomaterials into 4 grade ranking (Table II) from positively used materials to immediately avoided materials using equation 1-3. Table III indicated the weighting factors for system condition for calculation.

Theoretically, the higher value of Sustindex, the better ecomaterial is.

Table I: Criteria for SAM

System condition	Indicator	Criteria		
		3	1	0
Finite resource	Scarcity	Renewable, nonrenewable (>50 yr)	Nonrenewable (25~50 yr)	Nonrenewable (<25 yr)
	LC energy (yen/MJ)	≥ 65.6	16.4~65.6	<16.4
	Recyclability	$\geq$ 80% recycled	36~80% recycled	<36% recovered
Persistent substance	ODP	<0.01	0.01~0.4	>0.4
	POCP	<0.005	0.005~0.5	>0.5
	Biodegradability	>60% degraded in 28 days (ready test)	>70 % degraded in 28 days (Inherent test)	<70 % degraded in 28 days (Inherent test)
Physical area	Material Intensity	<2 (MI)	2~7 (MI)	>7 (MI)
	GWP (C-eq) yen/kg	≥ 2650	530~2650	<530
	Acidification	≤ 0.7	0.71~1.1	>1.1
	Nutrient enrichment	1	1.1~4.5	>4.5
Social equity	Place of extraction	> 80% raw material extracted in third world	50~79% raw material extracted in third world	<50% raw material extracted in third world
	Human toxicology	Not yet being classified as human toxicity	Irritating and hazardous	Carcinogenic or mutagenic or, EDCs.

$$\delta_i = \frac{S_i}{S_{i-\max}} = \frac{S_i}{3} \qquad (1)$$

$$\delta_{S_j} = \frac{\sum_i^n \delta_i}{n} \qquad (2)$$

$$Sust_{index} = 1000 \times \sum_j w_j \delta_{S_j} \qquad (3)$$

Where: S_i is point given for each indicator,

δ_i and δ_{S_j} are deviation from defined sustainability level of indicator and system condition, and

w_j is weighting factor of each system condition.

Table II: Four grades of ecomaterial using SAM

Grade	Mili-point	Description
A	600-1000	This material can be used absolutely for the long-term to achieve sustainable development
B	400-599	This material can be used with care on the impacts. It should be substituted or dematerialized as soon as possible
C	200-399	This material should be substituted
D	0-199	This material should not be used at all

Table III: Four grades of ecomaterial using SAM

	Finite resource (wl)	Persistent substances (w2)	Physical area (w3)	Social equity (w4)
Mean	0.21	0.26	0.21	0.32
Std	0.09	0.15	0.07	0.1

4. PLASTIC CASESTUDY

In order to test the SAM, plastics were selected as a case-study. In this case-study, twelve synthetic thermoplastics, two biodegradable thermoplastics, and two recycled plastics were assessed (Table IV). Biodegradable plastic in this study was defined as a polymeric material which is made from biomass, and changed into lower molecular weight compounds where at least one step in the degradation process is through metabolism in the presence of naturally occurring organism. The life cycle inventory data of twelve synthetic plastics was obtained from life cycle assessment software named Sigma Pro. v.5.1 produced by the Pre Consultant B.V in the Netherlands. The data for two biodegradable plastics was obtained from the environmental product declaration (EPD) of Novamont in Europe. Data for recycled plastic such as polystyrene (PS-R) and YB-chip was obtained from Ecoleaf program (Japanese EPD program).

Study results showed that biodegradable thermoplastics (Bi-NF, Bi-PE, TPS, PLA were better than synthetic plastics in term of sustainability (Fig. 3). These plastics were graded into group A defined in Table II which indicated that these could be used positively. There were four main positive aspects when using these plastics. First of all, these biodegradable plastics were made of corn starch (a renewable resource). Secondly, the life cycle energy consumption of these plastics was relatively smaller than synthetic plastic (less than 25%). Thirdly, global warming potential of these plastics was almost negligible due to the natural cyclic system of renewable resource. Finally, at the end-of-life, these biodegradable plastics would not create any serious problem associated with disposal, since they biologically degraded within one or two months. However, one issue needs to be carefully considered is the management of land or agriculture field. Use of chemical fertilizers might create different environmental problem.

Table IV: $Sust_{index}$ values of studied plastics

Plastic	Symbol	$Sust_{index}$
Acrylonitrile Butadiene Styrene	ABS	408
Low density polyethylene	LDPE	483
Polyacrylonitrile	PA 66	370
Polybutadiene	PB	521
Polycarbonate	PC	521
Polyethylene Terephthalate	PET	457
Polymethyl Methacrylate	PMMA	468
Polypropylene	PP	567
Polystyrene	PS	452
Polyvinyl Chloride	PVC	342
Starch biopolymer (NF type)	Bi-NF	748
Starch biopolymer (PE type)	Bi-PE	806
Thermoplastic starch	TPS	759
Polylactic acid	PLA	680
Polystyrene based chip	YB chip	710
Polystyrene recycled	PS-R	736

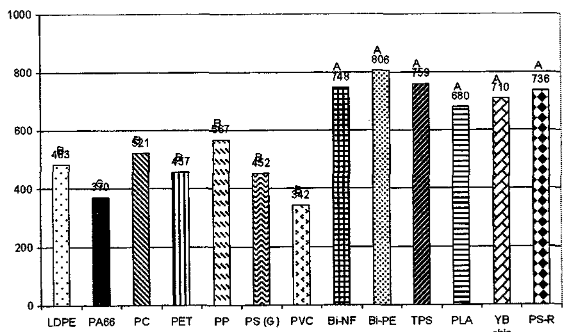

Fig. 3: Results of SAM study on plastics

Recycled plastics like PS-R and YB chip were also grouped into class A. The life cycle inventory (LCI) data obtained for these plastics indicated several advantages including low cost, low energy consumption, low greenhouse gases emission. This suggested the equivalent importance of natural recycling system (biodegradation) and artificial recycling system.

Other synthetic plastics such as polyolefin (LDPE, and PP), PET, PS were graded into group B which indicated that these material could be used with care on their impact. The impacts here include the use of energy for whole life cycle, use of finite resources, and the use of flame retardant. Some advantages of polyolefin and PET are 1) being easy to be recycled; 2) emitting non-toxic byproducts in the incineration (if these contain non-halogen flame retardant), 3) having relatively chemical stability.

Collecting and recycling system for polyolefin and PET are now ready in Japan and other developed countries. According to the council for PET bottle recycling, Japan has a world best PET bottle recycling rate (34.5% in 2000, compared to 22.3% in US and 22% in Europe). Additionally, in 2002, an estimated of 46% of PET bottles was collected and recycled in Japan [8]. Those PET bottles were reused for soft drinks, soy sauce and liquors.

Beside the A and B group of polymers, PVC and PA 66 were graded into group C. These materials should be substituted as soon as possible and only be used where other polymers could not be used. The life cycle energy consumption of PVC and nylon 66 were relatively high compared to other synthetic polymers. In addition, there is a controversial concern on the emission of dioxin associated with the end of life of PVC.

Further more, no investigated polymers were graded into group D.

5. COMPARISON WITH OTHER METHODS

Result of this study was compared with other material selection guidelines which are used by three electronic companies in Japan. Due to the agreement, these three guidelines are only stated as guideline of company X, Y, and Z. These qualitative guidelines were developed for plastics only.

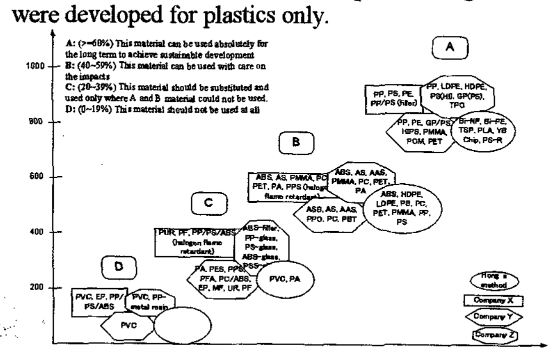

Fig. 4: Comparison of plastic classification methods

Fig. 4 showed the comparison of the study and other methods. As indicated in this figure, there are two main differences in the results. First of all, for group A, SAM result showed only biodegradable plastics and recycled plastics, while other three guidelines showed different kinds of plastics including PP, PE, thermo-polyolefin (TPO). It should be noted that in three guidelines, no biodegradable or recycled plastic was investigated due to requirements of mechanical and chemical properties of electronic equipment. In the SAM result, most of synthetic polymers were graded into group B.

The second main difference is the grade of PVC. All guidelines graded PVC into group D where this material should not be used at all (Table II) while the SAM result indicated it in group C. A major concern of electronic companies is the emission of toxic substances such as the intermediate, ethylene dichloride (EDC) or vinyl chloride monomer, when PVC is used, especially in the incineration. This concern should not seriously affect the overall impact of PVC in term of sustainability for two reasons. First the emission of dioxins by manufacturing, using and incinerating of PVC were not great as suspected (only 0.24% of the total emission), and so small compared to other processes [9]. Secondly, PVC has some more advantages than other synthetic polymers including the self-extinguish flammability, highly weather resistance. In addition, its chemical and mechanical properties are relatively better than some other polymers. This is why PVC is still widely used, and its demand is expected to increase.

6. DISCUSION AND CONCLUSION

This study was to attempt to rate eco-materials and eco-products into different grades from the view point of sustainability. A case study indicated that it was possible to rate eco-materials using twelve indicators of four system conditions of TNS. This rating result would help product designers select the right materials for their eco-product. This rating method expected to cover wide range of eco-materials including those in iron and steels, metals, ceramics, paper. From the selection, eco-products would be developed, manufactured and marketed.

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