“Ecological Rucksack” of High-Definition TVs

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In order to verify the effectiveness of the “Ecological Rucksack” as an indicator on resource utilization for electrical and electronic equipments, the Ecological Rucksack of 36-inch high-definition TVs produced in 1993 and 2003 has been estimated in cooperation with the Wuppertal Institute in Germany. The Ecological Rucksack (abiotic material) of the 1993 product was 19 tons (product mass 91.0 kg) and that of the 2003 product was 7.7 tons (product mass 79.5 kg), therefore, an approximate 11 tons or 60% reduction. The breakdown of the Ecological Rucksack (abiotic material) of the 1993 product indicated that the values associated with the print circuit board mounted inc. electronic components (hereafter called PC board) represented approximately 50% of the total, followed by power consumption during use at 40%. The PC board represented less than 10% of the product mass but occupied approx 50% of the Ecological Rucksack (abiotic material). The smaller and lighter PC boards employed in the later product substantially contributed to the reduction of Ecological Rucksack. As evident in the example of the PC board, the consideration of Ecological Rucksack reveals the hidden material flow and presents a new approach to resource utilization.

However as for the materials used over the life cycle of a high-definition TV set, the factors obtainable from the MI factors table represented only 25% of the product mass. By applying the MI factors of materials with equivalent properties, the rate of MI factors increased to 99% of the product mass, thereby enabling an estimation of the Ecological Rucksack for a TV set. The estimation made this time around underlined the fact that further examination of the data was required for the PC board, because it would strongly affect the evaluation results for determining the Ecological Rucksack of a high-definition TV set. Further enhancement of the database is therefore required for enabling applications to electric and electronic equipment.

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1. Introduction

Technological advancements have brought us convenience and comfort. At the same time, our growing production and consumption of convenient products has directly and indirectly led to global environmental problems including global warming, resource depletion and pollution. To solve these global environmental problems, environmentally conscious products and services (hereafter called ECPs) that have less impact on the environment while improving benefit are required.

To promote the development and diffusion of ECPs, a distinct indicator for ECPs is required as a criterion to be used by designers and developers who actually develop products in enterprises, as a judgment criterion used by company managers for decision making, and as a purchase criterion used by consumers (product users, customers).

The most prevailing method currently used for evaluating the environmental impact of a product is the Life Cycle Assessment (LCA). However, a comprehensive environmental impact evaluation method has not been standardized and the current evaluation is based on the LCCO₂ or greenhouse gas emissions over a product's life cycle, leaving the evaluation of resource utilization insufficient.

As an indicator for resource utilization, Schmidt-Bleek and other researchers at the Wuppertal Institute in Germany proposed the “Ecological Rucksack” and “MIPS (Material Input per Service unit)” in 1992.¹⁾ The Ecological Rucksack refers to the total “Material Flow” generated by the product during its life cycle other than the product itself, including the material flow for energy production. The MIPS indicates the total material consumption including the Ecological Rucksack. The products we use consume a large quantity of resources throughout their life cycles in addition to the

products themselves, and in most cases, these resources outweigh each product. The concept of the Ecological Rucksack provides an opportunity to identify resource utilization, including the invisible or hidden material flow.²⁾

In this paper, a TV set is used as a representative item of electrical and electronic equipment and an attempt to estimate the Ecological Rucksack of a high-definition TV is carried out for the first time in the world.

Based on the estimated results, the effectiveness of the Ecological Rucksack is then verified. In addition, the applicability of the Ecological Rucksack to the criteria for electric and electronic ECPs is examined.

2. Ecological Rucksack

The MIPS refers to the material intensity per unit quantity of service over the entire life cycle of a product. In other words, it is the material consumption quantity from cradle to grave per service or functional unit.¹⁾

The Ecological Rucksack refers to the total material flow produced by the product over its life cycle other than the product itself but including the material flow required for energy input. The “material flow” here includes not only the material flow produced or chemically modified by human beings for its economic value, but also any material movement or transfer of resources from one location to another that affects ecological attributes, even including the sand, gravel, mineral, ore and water for power generation. The Ecological Rucksack is the value of MI excluding the product mass.

In more general terms, MI is referred to as the Total Material Requirement (TMR), and Ecological Rucksack the Hidden Material Flow (HMF).³⁾ The HMF is sometimes compared to the “spirit behind material” in Japan.⁴⁾ The relationship of these expressions is shown below.⁵⁾

$$\text{MIPS} = \text{Material Input per Service unit} = \text{MI}/\text{S} \quad (1)$$

$$\text{Ecological Rucksack} = \text{MI} - \text{Net weight} \quad (2)$$

The MI factors refer the material intensity values for the single/individual materials or modules, expressed in kg/kg, indicating the mass (kg) of the materials consumed for each kg of the subject material. The unit kg/kg may be replaced with g/g or t/t. When electric energy is consumed, the material input quantity used for producing the energy is calculated by kg per kWh. MI value of a product can be calculated by using the MI factors of basic materials, thus the input quantity of both material and energy can be calculated by using the same unit of measure such as kg or t. In the MIPS concept, the material inputs are divided into five different input categories. These five categories are abiotic materials, biotic materials, water, air, and moved soils. It is permissible and often makes sense to compile the following categories equally; abiotic materials, biotic materials, and moved soils

(but here, only erosion). However the category “water” should likewise be examined separately and the category “air” should also not be summed up with others.⁵⁾ The inputs encompassed in five categories are shown in Table 1.^{5,6)} Examples of MI factors are shown in Table 2.⁷⁾

3. Target Products for Estimation of Ecological Rucksack

The Ecological Rucksack of 36-inch high definition TVs of 1993 and 2003 are estimated and compared. The product specifications of the 1993 product and 2003 product are shown in Table 3 and a photo of each product is shown Fig. 1. The high definition TV of 1993 used in this estimation is the de facto first commercialized high definition TV. The high definition TV of 2003 was the latest model when the estimation was started. These high definition TVs as target products were produced, marketed, and recycled in Japan.

Table 1 Inputs encompassed in five categories (abiotic material, biotic material, water, air, and moved soil).

Category	Inputs encompassed in five categories
Abiotic material	<ul style="list-style-type: none"> Mineral raw materials (used extraction of raw materials, such as ores, sand, gravel, slate, granite) Fossil energy carriers (amongst others coal, petroleum oil, petroleum gas) Unused extraction (overburden, gangue etc.) Soil excavation (e.g. excavation of earth or sediment)
Biotic material	<ul style="list-style-type: none"> Plant biomass from cultivation Biomass from uncultivated areas (plants, animals etc.) (Domesticated animals are already part of the technosphere, and are therefore referred back to biomass taken directly from nature, e.g. plant or animal fodder.)
Water	(Separated according to processing and cooling water) <ul style="list-style-type: none"> Surface water Ground water Deep ground water (subterranean)
Air	<ul style="list-style-type: none"> Combustion Chemical transformation Physical transformation (aggregate state)
Moved Soil	<ul style="list-style-type: none"> Mechanical earth movement or Erosion

Table 2 Examples of MI factors.

	MI (Material Intensity) [t/t]				
	Abiotic Material	Biotic Material	Water	Air	Moved soil
Gold (estimated)	540000	—	—	—	—
Silver (estimated)	7500	—	—	—	—
Copper (primary)	348.47	—	367.2	1.603	—
Fibre glass (R-glass)	10.84	—	296.3	2.007	—
Polystyrene (high impact)	2.78	—	175.3	3.150	—
Electric Power (All OECD-Countries)	1.55	—	66.7	0.535	—

Table 3 Product specifications of high-definition TVs.

Produced in	1993	2003
Product No.	TH-36HV10	TH-36D50
Product	36-inch high-definition TV	
Product weight	91.0 kg	79.5 kg
Annual power consumption during use	630 kWh/year	229 kWh/year

Fig. 1 Appearance of high-definition TVs.

Table 4 Materials with non-MI factors and materials of MI factors converted for them.

Materials with non-MI factors	Materials of converted MI factors
Alloy steel	Pig iron
Processed steel (painted sheetmetal)	Pig iron
Aluminum alloys (1000, 6000)	Aluminum (primary)
Synthetic rubber	Styrol butadien rubber, SBR
Electric glass, lead glass	Fibre glass (R-glass)
PC boards* of a TV	Generally used PC boards*

*PC boards: Print circuit boards mounted inc. electronic components

4. Estimation of Ecological Rucksack of High-Definition TVs

The Ecological Rucksack of the high-definition TVs takes into account life cycle stages from the resource mining to product recycling or disposal. It was estimated by using the MI factors developed by the Wuppertal Institute. They include the published data (as of October 28, 2003)⁷⁾ and the data separately provided. The data are not chronologically organized, nor are classified by region except for energy. Energy data are regionally categorized. For example, electricity data have four headings of Germany (public network), Germany (industrial customer generation), European OECD, and all OECD countries. From this, the estimation was used same data for both the 1993 product and 2003 product. As for electricity, all OECD countries data were adopted for estimation, because high definition TVs as target products are produced, marketed, and recycled in Japan.

Materials without MI factors used MI factors of the raw materials processed in the previous processes or MI factors of the similar characteristics to these raw materials. Accordingly, the estimates might be lower than actual values. Table 4 indicates materials with non-MI factors and materials of MI factors converted for them.

For production stage, estimation was based on the basic construction materials used for the product main unit, accessories, and energy consumption in the “assembly” stage. The energy consumption in the “assembly” stage was given by dividing the total amount of energy consumed at an assembly factory (Ibaraki and Utsunomiya Factories, Matsushita Electric Industrial Co., Ltd.) by the number of units assembled. For print circuit boards mounted inc. electronic components (hereafter called PC boards), separately provided data were adopted, which include energy and materials input in the “production” stage of PC boards. However the materials associated with the “production” stage of the basic construction components such as yield loss (except PC boards) were not included, because they are purchased from suppliers and these data couldn’t be gotten.

For usage stage, estimation was made with the energy consumption during use. In calculating energy consumption during use, both operation and stand-by were taken into consideration. The life was given as eight years for both 1993 and 2003.⁸⁾ Only approximately 1% of TVs need repairs. Since the repairs do not have a major impact on our total operations, they are not included in this estimation.

For recycling and disposal stage estimation was based on energy consumption in the recycling stage, which was given by dividing the total amount of energy consumed at a recycling factory (Matsushita Eco-technology Center) by the number of units treated. Almost only energy is consumed at the recycling factory.

5. Results of Ecological Rucksack of High-Definition TVs

The estimated results of Ecological Rucksack of 36-inch high-definition TV sets are shown in Table 5.

As indicated in Table 5, the Ecological Rucksack (abiotic material) of a 36-inch high-definition TV was 19 tons (product weight 91.0 kg) for the 1993 product, and 7.7 tons (product weight 79.5 kg) for the 2003 product. These data represent a reduction by approximately 11 tons or 60%. The Ecological Rucksack (water) was reduced by 360 tons from 560 tons to 200 tons, and the Ecological Rucksack (air) was reduced by 3 tons from 5 tons to 2 tons.

The breakdown of the Ecological Rucksack (abiotic material) of the 1993 product consists of around 48% for the PC board, followed by 41% for the power consumption in the usage stage.

The PC board weight constituted less than 10% of the product mass, but its rate in the Ecological Rucksack (abiotic material) was the largest, exceeding 48%. A reduction of the PC board weight from 8.0 to 3.5 kg greatly contributed to the reduction of Ecological Rucksack. The reduction of the second largest item, the power consumption, from 5,040 to 1,832 kWh, also contributed to the reduction of Ecological Rucksack.

As already described, this estimation does not include the materials associated with the “production” stage of the basic construction components such as yield loss (except PC boards). So estimation is made by assuming them to be 10% of the basic construction component mass. The ecological Rucksack (abiotic material) of them is approximately 1% of the entire ecological Rucksack (abiotic material), with no substantial influence.

6. Discussions

6.1 Effectiveness of Ecological Rucksack

In order to discuss the effectiveness of Ecological Rucksack, we plan to analyze the reason why the rate of reduction from the 1993 product to the 2003 product was larger in Ecological Rucksack than in product mass. Since data for gold and silver only include abiotic materials and there are no water and air-related information, for analysis, abiotic materials sufficient to applicable data are adopted. Figure 2 indicates the rate of each material on materials used in the product and abiotic materials required in the product for the 1993 high-definition TV.

When attention is focused only on the product weight, the reduction of the glass, which represents 54% of the product weight in the 1993 TV set is effective. However, when the Ecological Rucksack is considered as shown in Fig. 2, the abiotic materials of the glass represent 4.7% of the product total abiotic materials. In contrast, the PC board is 8.8% of

Fig. 2 Rate of each material on materials used in the product and abiotic materials required in the product for the 1993 high-definition TV.

the product weight but its abiotic materials represent 80% of that of the product, indicating a greater improvement potential for smaller and lighter PC board. A large portion of a PC board's Ecological Rucksack represents the material flow associated with the energy input in the production stage of the electronic components assembled on the circuit board such as semiconductor devices. An examination only by product mass tends to overlook the “hidden material flow” associated with the energy input in the production stage of the components. It is also evident that lowering the amount of copper used is more effective for reducing the Ecological Rucksack than cutting down the amount of steel or polystyrene resin, even though they represent a greater percentage of the product mass. In addition, the amounts of gold and silver are small enough to be ignored in the product weight but are visible when examined with the Ecological Rucksack. Due to the low content rate of these materials, a large quantity of material flow is required during mining and refinement. This hidden material flow is often overlooked when examining

only the product mass. By taking the Ecological Rucksack into consideration, a new era of resource utilization including the hidden material flow becomes possible, which is often overlooked by only examining the product mass.

However, some people criticize that MI can only assess material flow and not the quality of flow. Schmidt-Bleek accepts the criticism but emphasizes the advantage of using MI to help us argue from a macro viewpoint.²⁾ Since MI is simple and clear by only requiring accumulation of hidden material flow in a product life cycle, it has sufficient advantage as a simplified assessment method. As it does not allow the assessment of the qualitative aspect such as a large environmental impact caused by an extremely small quantity, MI needs to be combined with other indicators.

6.2 Applicability of the Ecological Rucksack to Electric and electronic equipment

Of the materials that are part of a high-definition TV's life cycle, the MI factors applicable from the MI factors table represented only 25% of the product mass. However, by applying the MI factors of materials with equivalent properties, the applicable MI factors increased to 99% of the product mass, thus enabling an estimation of the Ecological Rucksack of high-definition TVs.

The appropriateness of this estimation is verified by evaluating abiotic materials for remaining 1.0% of the product mass in the 1993 product. The remaining 1.0% is assumed to be AAA manganese batteries and plastic materials.

The MI factor of manganese batteries does not exist. The presumption is made, therefore, that the entire quantity of a manganese battery consists of zinc, the largest MI factor among the principal structural materials of manganese dioxide and zinc. The AAA manganese batteries consumed during the 8.0 years of TV product life are 20 units.

The presumed abiotic materials of AAA manganese batteries (Estimated by assuming the entire quantity to be zinc)

$$\begin{aligned}
 &= \text{The mass of the AAA manganese batteries consumed during the 8.0 years of TV product life} \\
 &\quad \times \text{MI factor (abiotic material) of zinc} \\
 &= (9.0 \times 10^{-3} \text{ kg/unit} \times 20 \text{ units/8.0 years}) \times 22 \text{ kg/kg} \\
 &= 18 \times 10^{-2} \text{ kg} \times 22 \text{ kg/kg} = 4.0 \text{ kg}
 \end{aligned} \tag{3}$$

Abiotic materials of plastic materials are presumed by assuming the entire quantity to be polytetrafluoroethylene, the material having the largest MI factor among plastic materials, because the specific material type cannot be identified.

The presumed abiotic materials of plastic materials (Estimated by assuming the entire quantity to be polytetrafluoroethylene)

$$\begin{aligned}
 &= \text{The plastic material mass} \times \text{MI factor (abiotic material) of polytetrafluoroethylene} \\
 &= (91 \text{ kg} \times 1.0\% - 18 \times 10^{-2} \text{ kg}) \times 19 \text{ kg/kg} = 14 \text{ kg}
 \end{aligned} \tag{4}$$

The presumed abiotic materials for remaining 1.0% of product mass/the entire abiotic materials (based on (3) and (4))

$$= (4.0 \text{ kg} + 14 \text{ kg}) / 1.9 \times 10^4 \text{ kg} = 0.095\% \tag{5}$$

Based on (5), the presumed abiotic materials for remaining 1.0% of product mass are only 0.095% of the entire abiotic materials, thus indicating the estimation in this study to be

significant.

However the currently developed MI factors table does not provide sufficient data for quantitatively determining the

Ecological Rucksack of electric and electronic equipment.

Because the Ecological Rucksack allows the expressions of input material and energy in the same unit of measure (kg, t, etc.), it can easily be understood by non-specialists. Further, as pointed out by Schmidt-Bleek himself, the proposer of the Ecological Rucksack, it is effective as a brief assessment criterion.

Hence, further enhancement of the database is required for making it applicable to electric and electronic equipment.

7. Conclusion

- The “Ecological Rucksack” of 36-inch high-definition TVs produced in 1993 and 2003 has been estimated. The Ecological Rucksack (abiotic material) of the 1993 product was 19 tons (product mass 91.0 kg) and that of the 2003 product was 7.7 tons (product mass 79.5 kg), therefore, an approximate 11 tons or 60% reduction.
- The breakdown of the Ecological Rucksack (abiotic material) of the 1993 product indicated that the values associated with the PC board represented approximately 50% of the total, followed by power consumption at approx 40%. From the Ecological Rucksack viewpoint, improvement in the design and manufacturing of the PC boards and energy saving in the product use are effective.
- The PC board represented less than 10% of the entire product mass but occupied approx 50% or the largest portion of the Ecological Rucksack (abiotic material). The smaller and lighter PC boards employed in the later product substantially contributed to the reduction of Ecological Rucksack. The large portion of the Ecological Rucksack associated with the PC board derived from the energy spent during the production stage of the components on the circuit board such as semiconductor devices.
- As evident in the example of the PC board, the use of the Ecological Rucksack reveals the hidden material flow and presents a new approach to resource utilization.

8. Future Tasks

As for the materials used over the life cycle of a high-

definition TV set, the factors obtainable from the MI factors table represented only 25% of the product mass. By applying the MI factors of materials with equivalent properties, the rate of MI factors increased to 99% of the product mass, thereby enabling an estimation of the Ecological Rucksack for a TV set. The Ecological Rucksack is a technique currently under development and the availability of MI factor data is insufficient. The estimation made this time around underlined the fact that further examination of the data was required for the PC board, because it would strongly affect the evaluation results for determining the Ecological Rucksack of a high-definition TV set. Further enhancement of the database is therefore required for enabling applications to electric and electronic equipment.

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