Eco-Efficiency (Factor X) for Electrical and Electronic Products and a Case Study on Home Appliances in a Household

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Many institutes and companies are currently researching into eco-efficiency and Factor X as evaluation methods for environmentally conscious design. However, no standard method has been established. Moreover while the eco-efficiency of each home appliance is being improved, the increasing number and size of such home appliances may increase the overall environmental impact. This paper begins with describing a practical eco-efficiency (Factor X) indicator developed to evaluate environmentally conscious products or services. This indicator gives a rationalized relationship between their functional performance and environmental impacts. Next, the paper presents a brief case study of Factor X done in Japan that compared home appliances from 2003 with those from 1990 using such indicators. The number of home appliances used in a household increased 1.2 times from 65 to 79. However, GHG (greenhouse gas) emissions per year was 0.64 times the former amount, dropping from 8456 to 5383 kg–CO₂eq/year, and the new resources and discarded resources per year became 0.99 times the previous amount, dropping from 231 to 228 kg/year. Therefore, GHG Factor X was 1.9 and Resource Factor X was 1.2. Although based on a restricted evaluation model, these results quantitatively show the potential to improve functional performance (as evaluated by the number of home appliances) and at the same time reduce their environmental impacts (as evaluated by GHG emissions and new resources and discarded resources). These results also show that Resource Factor X is more difficult to improve than GHG Factor X. Improving Resource Factor X and establishing a sound material-cycle society requires not only technological innovation and reform of the social system, but also a significant change in people’s awareness.

Keywords: eco-efficiency, Factor X, home appliances, global warming, resources

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 such as global warming, resource depletion, and pollution. Solving these global environmental problems requires environmentally conscious products and services (hereafter called ECPs) that have reduced the environmental impacts and improved functions.

Promoting the development and diffusion of ECPs requires a distinct indicator for ECPs. This indicator can be used as a design criterion by product developers, as a decision-making criterion by company managers, and as a purchase criterion by consumers (users and customers).

The prevailing method for evaluating the environmental impact of a product is the Life Cycle Assessment (LCA). Another is the Product Assessment, which has been used in Japan since the “Law for Promotion of Utilization of Recyclable Resources” was enforced in Japan in 1991. (Revised in 2001 by the “Law for Promotion of Effective Utilization of Resources.”) However, newer concepts, such as ‘eco-efficiency,’ which was developed by the WBCSD (World Business Council for Sustainable Development) and ‘Factor,’ which was proposed by the Wuppertal Institute (Germany), are now internationally recognized as being more effective concepts or indicators of sustainable development.

More recently, by extending these concepts were extended by Yamamoto et al., who have proposed an enhanced ‘Factor X’ which is the initial ‘Factor’ multiplied by ‘eco-efficiency,’ as defined by the following equations:

\[
\text{eco-efficiency} = \frac{\text{product or service value}}{\text{environmental influence}} \quad (1)
\]

Factor X

\[
\text{Factor X} = \frac{\text{eco-efficiency of the evaluated product or service}}{\text{eco-efficiency of the reference product or service}} \quad (2)
\]

Eco-efficiency and Factor X can be enhanced by improving the product or service value and by reducing environmental impact. In other words, eco-efficiency and Factor X can assess technological progresses from the aspects of both product or service value and environmental impact.

Many institutes and companies are currently researching into eco-efficiency and Factor X. However, no generally applicable methods of measurement and evaluations for specific objects are currently available, and no standard method has been established. Moreover while the eco-efficiency of each home appliance is being improved, the increasing number and size of such home appliances may increase the overall environmental impact.

The author proposed earlier the eco-efficiency (Factor X) indicator and has evaluated not only eco-efficiency (Factor X) of a single product but also eco-efficiency (Factor X) of home appliances in a household by focusing on a product group as case studies of this indicator. This study intends to (1) improve the precision of the indicator including mathematical descriptions, and (2) predict the reuse and recycling effect in improving Resource Factor X. This paper, therefore, is a developmental extension and analysis of the previous studies.

This paper begins with describing a practical eco-efficiency (Factor X) indicator developed to evaluate ECPs. Next, the paper presents a brief case study of Factor X done in Japan that compared home appliances from 2003 with those from 1990 using such indicators. Finally, the potential and problems in improving Resource Factor X will be discussed based on this case study.
2. Developing an Indicator for Environmentally Conscious Product or Service (ECP)

2.1 Problems
When the “Law for Promotion of Utilization of Recyclable Resources” was enforced in Japan in 1991 (Revised in 2001 by the “Law for Promotion of Effective Utilization of Resources”), the home appliances industry began using product assessments. Product assessments, however, are based on the environmental impact aspect, and an assessment is needed that can handle the environmental impact aspect as well as strengthen technology. Moreover since the assessment system is a checklist-type qualitative assessment and the extent of accomplishment and improvement is not quite clear, a quantitative method is also needed.

2.2 Basic concept
In order to solve the problems, functions take into account the objective of evaluating and promoting technological progress. The reason is that the fundamental purpose of using a product is to use the functions provided by the product; we own products for this purpose. In other words, because products serve as function-providing equipment, the product or service value derives from the functions it provides.

“Function” means the concept which presents work provided by a product (and recognized by users). “Functional performance” is defined as the quantitative amount of function provided by a product (and recognized by users). Then the basic concept for an ECP indicator is that “the functional performance provided by a product over its life cycle is improved while its environmental impacts over its life cycle are reduced”.

This basic concept can also evaluate and promote the shift to dematerialization (functional thinking, decoupling, etc.). Consequently, the concept of ECP indicators coincided with that of eco-efficiency and Factor X. This resulted in more effective use of eco-efficiency and Factor X.

2.2.1 Functional performance provided by a product over the life cycle
The functional performance provided by a product over the life cycle should be evaluated on actual data. However, the actual data depends on the way to use by each person or natural condition. Therefore, the functional performance is evaluated using the default data estimated on a standard measurement method defined in each industry or specified in the product catalog. Life span is evaluated using design life, which is estimated at the design stage. Units for life span include years, hours, minutes, seconds and number of times. As shown in Fig. 1, the functional performance provided by a product over the life cycle is described below.

\[
P_{\text{fc}} = P_{\text{ave}} \times L_s \cong P_d \times L_s
\]

(3)

\(P_{\text{fc}}\): Functional performance provided by a product over the life cycle
\(P_{\text{ave}}\): Average functional performance provided by a product per unit life span
\(P_d\): Default functional performance estimated on a standard measurement method defined in each industry or specified in the product catalog
\(L_s\): Life span of a product

Fig. 1 Functional performance provided by a product over the life cycle.

(1) Functional performance
The default data are used for functional performance. This facilitates easy understanding by users and benchmarking by product developers or managers.

It is often said that immeasurable objects cannot be controlled. Quantification helps specify, manage and prioritize targets, provides society with information, etc. Quantification is particularly effective in design. Qualitative evaluations, which do not provide distinct evaluations of increases in environmental impact and improvements in functional performance, have often failed to identify increases in environmental impact. Quantitative evaluations provide an opportunity to review whether or not improvements in functions justify an increase in the environmental impact, and whether a new function is meaningful or merely an extension of conventional ways of thinking, etc. Quantitatively presenting the relationship between function and environmental impact will make it easier to set and control targets, which will lead to greater technological progress and an increase in product competitiveness. As a long-term objective, functional performance improvements should be decoupled from environment impacts through technological innovation. This will require changes in perception, such as reconstructing function. Although it is far from easy, research on quantitative evaluations should continue. After all, the development of corporate financial indexes took several decades.

(2) Life span
Life span evaluations enable the assessment of the eco-efficiency (Factor X) of a product group or product system with a different life span. Moreover, life span evaluations can be used to design products with longer usability by longer life, easier maintenance, and upgradeability.

2.2.2 Environmental impacts of a product over the life cycle
As shown in Fig. 2, the environmental impact of a product over the life cycle is presented below.

\[
E_{\text{fc}} \cong E_{\text{dlc}}
\]

(4)

\(E_{\text{fc}}\): Environmental impacts of a product over the life cycle
\(E_{\text{dlc}}\): Environmental impacts of a product over the life cycle when being used by default data

Factor X (Eco-Efficiency) indicator focuses on three critical concerns of the prevention of global warming,
effective utilization of resources and specific substances as environmental aspects.

3. Factor X (Eco-Efficiency) as an Indicator for Environmentally Conscious Product or Service (ECP)

Eco-efficiency and Factor X of a product are defined by the following equations.

\[
\text{Eco-efficiency of a product} = \frac{P_{\text{lc}}}{E_{\text{lc}}} \equiv \frac{P_d \times L_s}{E_{\text{dlc}}} \quad (5)
\]

\[
\text{Factor X of a product} = \frac{\text{eco-efficiency of the evaluated product}}{\text{eco-efficiency of the reference product}} \quad (6)
\]

The indicator developed from the viewpoint of prevention of global warming is called “GHG (greenhouse gas) Factor X (GHG efficiency)”. The indicator developed from the viewpoint of effective utilization of resources is called “Resource Factor X (Resource efficiency)”. The item for management of specific substances is called “Specific substances”. This indicator was published in 2001 and first applied in the Matsushita Group in 2002. Since 2003, a number of other companies have applied this indicator.13,20)

3.1 GHG (Greenhouse Gas) Factor X (GHG efficiency)

GHG efficiency and GHG Factor X of a product can be showed as:

\[
\text{GHG efficiency of a product} = \frac{P_{\text{lc}}}{G_{\text{lc}}} \equiv \frac{P_d \times L_s}{G_{\text{dlc}}} \quad (7)
\]

\[
\text{GHG Factor X of a product} = \frac{\text{GHG efficiency of the evaluated product}}{\text{GHG efficiency of the reference product}} \quad (8)
\]

\[G_{\text{lc}}: \text{GHG (greenhouse gas) emissions of a product over the life cycle}
\]

\[G_{\text{dlc}}: \text{GHG (greenhouse gas) emissions of a product over the life cycle when being used by default data}
\]

3.1.1 GHG (Greenhouse Gas) emissions over the life cycle

Focusing only on a certain stage may simply shift the environmental impact to a different stage. Therefore, this indicator takes into account GHG (Greenhouse gas) emissions over the lifecycle.

However since many electronic products have a large impact on energy consumption during operation, many evaluation methods use energy consumption during operation as the representative criterion. Although it is true that many electronic products have a large impact on energy consumption during operation, products also exist that consume greater amounts of energy in stand-by mode, or consumed greater amounts of energy in the manufacture of purchased components and materials. Therefore, each product needs a different approach to reducing their environmental impact. For example, whereas reducing energy consumption during use requires technological development in terms of the product design, in the case of products that use a greater amount of energy in the manufacture of purchased components and materials, strategies such as encouraging green procurement become necessary. It is therefore essential to rank items in order of their environmental impact according to the features of each product. Since this indicator evaluates the product over its lifecycle, it is able to evaluate efforts related to particular product features or promote technological progress in accordance with the product features.

3.2 Resource Factor X (resource efficiency)

Resource depletion and the lack of landfill space are pressing issues, making necessary the effective utilization of resources. In order to conserve scarce resources, the use of new resources at the input side must be reduced. To solve the problem of the lack of landfill space, discarded resources must be reduced at the output side. In other words, the total amount of new resources (input side) and discarded resources (output side) over the life cycle of a product are reduced within the environmental carrying capacity. The Resource efficiency and Factor X of a product can be showed as:

\[
\text{Resource efficiency of a product} = \frac{P_{\text{lc}}}{R_{\text{lc}}} \equiv \frac{P_d \times L_s}{R_{\text{dlc}}} \quad (9)
\]

\[
\text{Resource Factor X of a product} = \frac{\text{Resource efficiency of the evaluated product}}{\text{Resource efficiency of the reference product}} \quad (10)
\]

\[R_{\text{lc}}: \text{new resources and discarded resources of a product over the life cycle}
\]

\[R_{\text{dlc}}: \text{new resources and discarded resources of a product over the life cycle when being used by default data}
\]

3.2.1 New resources and discarded resources over the life cycle

New resources can be calculated by subtracting the reused or recycled resources from the supplied resources. Reused or recycled resources refer to recovered resources such as reused components and recycled materials that are obtained by reprocessing components and materials used at least once. Only the content weight need be considered.

Discarded resources can be calculated by subtracting the reusable or recyclable resources from the supplied resources. Reusable or recyclable resources refer to recoverable resources that can be reused or recycled when the product and related materials come to the end of their life cycle. The

![Fig. 2 Environmental impact of a product over the life cycle.](image-url)
possibility of reuse or recycling should be determined for each product by checking the technical feasibility as well as by considering the flow of such product characteristics as ease of disassembly and sorting, and the uniformity of the materials. The actual application of reuse and recycle, and their technical and functional backgrounds must also be examined. The economic aspect must also be considered from a business point of view.

It is important to note that with current technology, clean virgin materials are often more recoverable at end-of-life than previously recycled materials, where impurity levels may limit future recycling potential. Advances in segregation and recycling technology must address this. Additionally, while the home appliances industry can design products that incorporate either recovered or recoverable material, this good practice can flounder if product development has not also considered the issues of disassembly and sorting. To achieve greater eco-efficiency, product development considerations should include disassembly and sorting as well as the use of recovered and recoverable resources, while still managing economic considerations.

The equation for new resources and discarded resources is shown below. Figure 3 shows the concept of Resource efficiency.

\[
\text{new resources + discarded resources} = (\text{supplied resources} - \text{reused or recycled resources}) + (\text{supplied resources} - \text{reusable or recyclable resources})
\]

(11)

This indicator is able to evaluate the overall efforts to utilize resources using the so-called 3R’s: Reduce, Reuse, and Recycle. Efforts to reduce resources can be assessed in terms of the amount of supplied resources and the life span. Strategies to reduce resources include not only resource conservation by reducing the product size or weight but also longer usability by designing products with longer life spans, easier maintenance and upgrading. These can all be evaluated by taking the life span into account. Efforts to reuse or recycle resources can be evaluated in terms of reused or recycled resources and reusable or recyclable resources. In this way, it can bring together the 3R strategies. It is an indicator that is able to foster technological innovations leading to the establishment of a sound material-cycle society. No other indicator premised on the concepts of circulation brings together the circulating use of resources in this way. It must be noted that the issues relating to the quality of the resources are addressed in the assessment of specific substances.

Since product design and recycling technology are the two sides of a coin, a well-thought-out 3Rs design that is in balance with economics is important. The use of the Resource Factor X proposed here, which evaluates both design technology and recycling technology, leads to well-balanced product development encompassing both design technology and recycling technology, thereby avoiding excessive reuse/recycling designs that neglect the current state of the art, or in contrast, product designs that are solely dependent on the reuse/recycling effort.

For many electric products, resources that comprise the main body of the product have a large impact, but there are also products for which the materials consumed in the use of the product (consumables) have a greater impact than the body itself. In the case of devices, the impact during the production stage is sometimes great, and efforts at the design stage can lead to a reduction in the manufacturing yield.

In the same way as with the GHG Factor X (GHG efficiency), evaluating a product according to its eco-efficiency over its life cycle can promote technological progress in line with product features.

### 3.2.2 Resource coefficient

It is necessary to not simply sum up the wide variety of resources but to consider the resource coefficient, such as Hidden Material Flow (HMF, also called Ecological Rucksack). The equation is presented below.

\[
\sum RC \times R_{dlc}
\]

(12)

RC: Resource coefficient such as HMF (Hidden Material Flow)

Currently available data does not sufficiently cover material types for electric and electronic products. In consideration of the development stage of the concept, the data will be updated as it is developed and collected, but at the moment, it is assumed to be 1.21)  

### 3.3 Specific substances

Resource Factor X (Resource efficiency) evaluates resource quantity, but it is also necessary to evaluate the quality of the resources. However, a supply chain management system for identifying the quantities of substances contained in purchased components and materials is still under development, and identifying the types and quantities of small amounts of substances, which is critical for assessing the quality of the resources, is currently extremely difficult. Since risk assessment of substances is also still under
development, the quality of the resources cannot at the present time be reliably assessed. For the time being, the appropriate course is to work towards abolishing the use of toxic materials based on such laws as the “Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) Directive” that has been passed by the European Parliament and European Council. This will be revised as progress is made in substance risk assessment and in the development of supply chain management.

3.4 Integration

Although the three elements—GHG Factor X, Resource Factor X, and specific substances—are to be considered equal in importance, they need to be integrated because some elements have a tradeoff relationship. A simple and integrated expression also makes the assessment result easier to understand. As a means of integrating assessment indicators, the results of a study by Japan’s LCA national project on life cycle impact assessments are being considered. A study report on the Japanese version of the Lifecycle Impact Assessment Method based on Endpoint Modeling (LIME) was made by the LCA project in 2003 as a life cycle impact assessment. Due to the remaining issues in the exhaustive level and reliability of the study, research has continued since 2003 as the “Technology Development for Product Life Cycle Carbon Dioxide Emission Assessment and Verification” (LCA Project Phase II). Because the assessment is still undergoing research and is not ready to be applied to design and development operations, further reviews are planned when a report on LCA Project Phase II becomes available in 2006.

4. Simulation Model on Factor X of home Appliances in a Household

GHG Factor X and Resource Factor X, both of which allow quantitative assessment, were used to simulate of the Factor X of home appliances in a household from the year 2003 based on references from the year 1990. How Factor X of home appliances in a household was evaluated in this simulation will be explained first. To simulate Factor X of home appliances in a household, a lifestyle model (family and home) was first established. The home appliances were selected according to the lifestyle model.

4.1 How Factor X of home appliances in a household was evaluated for this simulation

4.1.1 How was Factor X of a product group evaluated

This indicator is defined by the life cycle amount including numerator and denominator. In other words, it considers life span. Although life span varies by individual product, by converting it to a unit life span, eco-efficiency and Factor X of product groups and product systems having different life spans can be evaluated (cf. 2.2.1 (2) life span).

When functional performance and environmental impacts can be evaluated using the same unit respectively, eco-efficiency and Factor X of a product group are described by the following equations.

\[
\text{eco-efficiency of a product group} = \frac{\sum P_k L_k \times L_s}{\sum E_{lc} L_s} = \frac{\sum P_d \times L_s}{\sum E_{dlc} L_s} \tag{13}
\]

\[
\text{Factor X of a product group} = \frac{\text{eco-efficiency of the evaluated product group}}{\text{eco-efficiency of the reference product group}} \tag{14}
\]

4.1.2 GHG and Resource Factor X of home appliances in a household for this simulation

Environmental impacts can be evaluated using the same unit respectively and are calculated from the aggregate, as GHG efficiency is evaluated with GHG emissions (kg–CO₂eq), and resource efficiency with new resources and discarded resources (kg). However, functional performance has different units in each product as a washing machine’s unit is washing capacity (kg) and a refrigerator’s unit being storage capacity (mL), and therefore, functional performance cannot be calculated from the aggregate at present. When eco-efficiency and Factor X for each product are evaluated, they can be done by an evaluation method of functional performance that differs from product to product. However, when eco-efficiency and Factor X of product groups or product systems are evaluated, functional performance must be evaluated based on the same unit. For example, make it dimensionless based on the ratio and add weight to it, or calculate it converting each function value to monetary value. In this way, if functional performance can be evaluated based on the same unit, a comparison between different products can become possible as in an eco-efficiency comparison between washing machines and refrigerators.

However, since studies on the evaluation methods of this functional performance have just begun, this simulation evaluates on the basis that each product provides equal functional performance which is 1. \(\sum P_d\) in eq. (13) is presented below for this simulation. Evaluation methods for functional performance shall be our subjects for further study.

\[
\sum P_d \approx \sum_{i=1}^{N} P_d(n) = 1 \times N = N \tag{15}
\]

N: Number of home appliances

Because the life span of a home appliance generally use years, the unit life span is assumed to be one year in this simulation. Then, eco-efficiency and Factor X of home appliances in a household are described below.
Factor X of home appliances in a household = \frac{\text{eco-efficiency of the evaluated home appliances in a household (2003)}}{\text{eco-efficiency of the reference home appliances in a household (1990)}}

In particular, GHG efficiency and GHG Factor X of home appliances in a household can be showed as:

GHG efficiency of home appliances in a household = \frac{\sum N}{\sum \frac{G_{\text{dic}}}{L_s(\text{year})}}

GHG Factor X of home appliances in a household = \frac{\text{GHG efficiency of the evaluated home appliances in a household (2003)}}{\text{GHG efficiency of the reference home appliances in a household (1990)}}

In the same way, Resource efficiency and Resource Factor X of home appliances in a household can be showed as:

Resource efficiency of home appliances in a household = \frac{\sum N}{\sum \frac{R_{\text{dic}}}{L_s(\text{year})}}

Resource Factor X of home appliances in a household = \frac{\text{Resource efficiency of the evaluated home appliances in a household (2003)}}{\text{Resource efficiency of the reference home appliances in a household (1990)}}

### 4.2 Lifestyle model

A lifestyle model was established as a four-member, three-generation household with a grandmother (70), a father (40), a mother (37), and a child (10). The family was assumed to live in a two-story, single-family home in the suburbs with three bedrooms, a living room, dining room, kitchen, and Japanese-style room, with a total area of 1,369 m² (average for Japan).

### 4.3 Home appliances

For 1990, the home appliances were assumed to be the latest models of products with high penetration rates. For 2003, to reflect social changes, the home appliances were assumed to be the latest models manufactured and recommended by Matsushita Group regardless of their penetration level. Additionally, the simulation reflects the increasing number and size of products in use.

### 5. Evaluation on Factor X of Home Appliances in a Household

#### 5.1 Functional performance

This research evaluates on the basis that each product has equal functions, meaning that it equals the number of products as mentioned previously.

Newly added products included PCs, mobile phones, a dishwasher/drier, an alkali ion water purifier, an electronic health monitor, and a garbage processor.

#### 5.2 GHG (greenhouse gas) emissions

The GHG emissions figures take into account life cycle stages, from materials manufacture to product disposal. These were calculated by the Matsushita Product Assessment Support System using inventory data from the JEMAI-LCA software and internally developed LCA data from electronic component manufacturing.

The environmental impact of the product usage was calculated from the power consumption and the materials consumed during product use. Power consumption during product use was calculated for operation and standby modes. The materials consumed during product use included the water used by the washing machine, dishwasher, and water heater, the detergent used by the washing machine and dishwasher, and batteries used by remote controls. The energy used in the production and recycling stages was calculated from the total energy consumed by the factory divided by the number of units produced. Because different products have different life spans, the volume of GHG emissions over the life cycle of each home appliance was divided by the life span; the sum of the values represents the GHG emissions per year of home appliances in a household.

#### 5.3 New resources and discarded resources

New resources and discarded resources take into account life cycle stages, during procurement, production and product use. New and discarded resources at the procurement/production stages were calculated for the basic structural material of the product’s main unit, accessories, packaging, and operating instruction manuals. In the product usage stage, the water consumed by the washing machine, dishwasher, and water heater, the detergent consumed by the
washing machine and dishwasher, and batteries used by remote controls, etc., were calculated as resources. Since the resources consumed for power generation are assessed as GHG emissions, they are excluded from the Resource Factor X. Reusable or recycled resources included only the content weight. Reusable or recyclable resources included the four product categories (TVs, washing machines, air-conditioners, and refrigerators) subject to the “Law for Recycling of Specified Kinds of Home Appliances” enforced in 2001 in Japan along with water heaters and facsimile machines. The resources actually reused or recycled at the design stage of the assessed product or the resources, for which recycling technology and reuse applications were at least available, were counted in the calculation. The fiscal 2003 products were assessed by referencing the technology level at Matsushita Eco-technology Center, which is a recycling plant. The product collection rate or in-process yield was not considered. The economic advantage was examined from the viewpoint of the recycling business. Using the same method employed for GHG emissions, new resources and discarded resources over the life cycle of each home appliance were divided according to life span; the sum of these values represented the new resources and discarded resources per year of home appliances in a household.

6. Results on Factor X of Home Appliances in a Household

6.1 Functional performance

This research evaluates on the basis that each product has equal functions, meaning that it equals the number of products as mentioned previously.

The number of home appliances in a household rose from 65 in 1990 to 79 in 2003, an increase of 1.2 times.

6.2 GHG (greenhouse gas) emissions

As shown in Fig. 4, the GHG emissions per year were reduced by 3,073 kg–CO\(_2\)eq/year (0.64 times), from 8,456 kg–CO\(_2\)eq/year to 5,383 kg–CO\(_2\)eq/year, even as home appliances grew in number and size. This suggests that when consumers replace old home appliances with the latest home appliances, the home’s overall energy consumption is reduced, which plays a major role in preventing global warming. Products that particularly conserve energy include air conditioners, water heater, lights, stove, and refrigerator.

6.3 New resources and discarded resources

The amount of supplied resources increased by 15 kg/year (11%), from 130 to 145 kg/year, but since reused or recycled resources increased from 6.7 to 14.2 kg/year and reusable or recyclable resources increased from 23.2 to 47.4 kg/year, the amount of new resources and discarded resources per year fell from 231 to 228 kg/year, as shown in Fig. 5. This was due to the improvement in recycling capability for the 4 products subject to the Law for the Recycling of Specified Kinds of Home Appliances (TVs, washing machines, air conditioners, and refrigerators) and to the increase in reused or recycled and reusable or recyclable resources.

6.4 Factor X of home appliances in a household

Table 1 shows Factor X of home appliances in a household, GHG Factor X is 1.9 and Resource Factor X is 1.2.

The results on Factor X of home appliances in a household quantitatively show the potential to improve the function (as counted by the number of home appliances) while at the same time reducing the environmental impact (as evidenced by GHG emissions and the new resources and discarded resources). These results also show that Resource Factor X is more difficult to improve than GHG Factor X.

7. Discussing Factor X (Eco-efficiency) Indicator

In order to obtain objective evaluation results of eco-efficiency and Factor X, the product or service value and environmental impacts must be objectively defined respectively. With regard to environmental impacts, the integration methods are still undergoing research and discussions on establishing system boundaries are still in progress at even the most promising LCA. Therefore, we can say that they are still in the development stage. Research on product and service value has just begun.
As was mentioned at the outset, although many researches on eco-efficiency are in progress, the most of academic papers already delivered discuss concept, and only a few of them present case studies. Among those few case studies, few of them deal with quantitative evaluation of products and services, and none of them might deal with quantitative evaluation of electric and electronic products. While on the other hand, initiatives are being taken by the industry, and therefore, it is becoming increasingly difficult to secure objective evaluation results. We should accept this situation seriously and accelerate establishing objective evaluation methods.

The indicator proposed in this paper arbitrarily sets product and service value and environmental impact respectively, but it leaves much for further discussions and issues to be identified. For instance, it is necessary to consider the Resource Coefficient (RC), such as Hidden Material Flow for Resource Factor X. However currently available data does not sufficiently cover material types for electric and electronic products. It is also necessary to evaluate the quality of the resources. However, risk assessment of substances is also still under development. A means of integrating assessment methods is still undergoing research. It is expected that this paper will help contribute to the development and deepening of academic discussions.

8. Discussing Factor X of Home Appliances in a Household

The results on Factor X of home appliances in a household show Resource Factor X is more difficult to improve than GHG Factor X. So why GHG Factor X improved more than Resource Factor X and the problems in improving Resource Factor X will be discussed.

8.1 Comparison of two kinds of Factor X

The improvement in GHG Factor X (reduction in GHG emissions) was due to the reduction in energy consumed during the use of the appliances, as shown Fig. 4. This reduction in energy consumed during use also reduced usage costs and entailed direct, short-term benefits for the users. Thus, due to consumer demand, substantial progress was made in developing technology relating to power consumption during use, such as for achieving greater efficiency. On the other hand, improvements to Resource Factor X—the utilization of reused or recycled and reusable or recyclable resources—offer users neither direct nor short-term benefits, so there is a lack of demand, and the development and commercialization of such technology is not readily reflected in corporate profits. This is why GHG Factor X improved more than Resource Factor X.

8.2 Improving Resource Factor X

Figure 6 shows the breakdown by material of the supplied resources per year over the life cycle of home appliances. Based on an analysis of the materials listed in Fig. 4, the following five scenarios were simulated to find ways to improve Resource Factor X. The results are shown in Table 2. The results suggest that Resource Factor X can be improved by a factor of 2.0.

(a) When 100% of metals (steel, copper, and aluminum) are recycled
(b) When 100% of thermoplastic resins are recycled
(c) When 100% of recycled metals (steel, copper, and aluminum) are used
(d) When 50% of recycled thermoplastic resins are used
(e) When all of the above scenarios are applied

Since the use of reusable or recyclable resources can be improved through the development of product design and recycling technology, the improvements can be achieved

Table 2 Possibility of improving Resource Factor X.

<table>
<thead>
<tr>
<th>Scenario a)</th>
<th>Scenario b)</th>
<th>Scenario c)</th>
<th>Scenario d)</th>
<th>Scenario e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource Factor X</td>
<td>1.3</td>
<td>1.3</td>
<td>1.5</td>
<td>1.3</td>
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through the efforts of companies, including those involved in related industries. Furthermore, under the influence of the “Law for Recycling of Specified Kinds of Home Appliances” in Japan and the Directive of the European Parliament and European Council on Waste Electric and Electronic Equipment (WEEE), the steady implementation of recycling can be anticipated.

On the other hand, there are limits to what companies alone can accomplish in terms of the use of reused or recycled resources. In the area of household electronics, the use of reused or recycled resources has not made significant progress due to the following reasons. This has become a vicious circle.

(A) The use of reused/recycled resources (re-ed resources) requires many steps and strict management, and is disadvantageous in terms of cost.

(B) General consumers have concerns that such products are quickly to break down, or might be dirty, etc.

(C) As a result, demand is poor, and related companies do not actively develop the technology or build social infrastructure.

Due to the collection and/or recycling costs described in A) above, recycled products tend to cost more than new products. Many consumers, at least at the present time, are unwilling to pay more for recycled products simply for environmental reasons.

In order to overcome this problem and establish a sound material-cycle society, the industries associated with assembly, components, and materials should jointly promote the use of reused or recycled resources. The industries need to produce the products and services that can change the consumer mindset as well as make further efforts to enlighten consumers about the meaning of selecting ECPs through their sales activities.

The roles of public institutions and NGOs are also essential for materializing consumer desires. Also required is a mechanism for educating and enlightening consumers about the concept and criteria of ECPs and the meaning of selecting ECPs. When the demand for ECPs increases and the market size expands, technological development by the related industries will progress. Since the markets are global, establishing an international standard for such an education mechanism should be considered. Particularly in the case of Japan, the construction of a resource recycling system is crucial for connecting production and consumption sites.

The most powerful means for changing the market so that ECPs become advantageous is to reflect the environmental cost in the product prices, constructing such mechanism is also essential in for long run.

In addition, although new energy systems, such as solar power and fuel cells, are effective in responding to energy problems and preventing global warming (improving GHG Factor X), these require resources and may cause new environmental problems regarding resource utilization. Therefore, technological development that incorporates the circulating use of resources is essential.

9. Conclusions

(1) Practical eco-efficiency (Factor X) indicators were developed from the viewpoints of prevention of global warming, effective utilization of resources, and management of specific substances. This indicator was published in 2001 and was first applied in the Matsushita Group in 2002. Since 2003, a number of other companies have applied this indicator.

(2) However, the indicator proposed in this paper leaves much for further discussions and issues to be identified. For instance, there are the development of the Resource Coefficient for Resource Factor X and the risk assessment of substances. It expected that this paper will help contribute to the development and deepening of academic discussions.

(3) GHG and Resource Factor X of home appliances in a household from the year 2003 with respect to those from the year 1990 were simulated using the independently developed eco-efficiency (Factor X) indicators. The number of home appliances in a household increased by 1.2, from 65 to 79, but since the GHG emissions per year was 0.64 times the former amount, dropping from 8456 to 5383 kg–CO₂eq/year, and the new resource and discarded resources per year were 0.99 times the previous amount, dropping from 231 to 228 kg/year, GHG Factor X was 1.9 and Resource Factor X was 1.2.

(4) Although based on a restricted simulation model, these results quantitatively show the potential to improve functional performance (as counted by the number of home appliances) and at the same time reduce their environmental impact (as evidenced by GHG emissions and new resources and discarded resources).

(5) These results also show that Resource Factor X is more difficult to improve than GHG Factor X. Therefore, improving Resource Factor X and establishing a sound material-cycle society require not only technological innovation and reform of the social system, but also a significant change in people’s awareness.

10. Future Tasks

(1) The author intends to continuously improve the indicators in the process of utilizing them in daily operations. As described earlier, further studies on Resource Coefficient should be made in light of Resource Factor X. Studies on assessing the quality of the resources in specific substances should also be made, and the indicators integrated.

(2) The ‘value created by the functions of home appliances in a house’ is an objective assessment method for the future. Current thinking assesses value by weighting each product function and summing up the values. When evaluating a product system, the method should be based on the synergy effect of each function rather than the simple summation of the values. It is expected to help promote the transition to dematerialization (a post-material society, functional thinking, decoupling, etc.) through the development of such an assessment method.

(3) Although product improvement activities are simulated in this study, reducing energy consumption by air-
conditioners, for example, requires not only improving the energy-saving design of the air-conditioners themselves, but also the building designs to incorporate heat insulation, air-tightness, the use of daylight, etc. Future studies should expand the scope from product-centered activities to a combined effect with other installed equipment and building designs so that a house is viewed as a product system.

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