Korean Journal of LCA
Vol. 2, No. 2, 2000, pp. 9~18

위험기능을 적용한 인간건강의 잠재위험도 평가

- 전기기구 연구사례 -

이쯔보 노리히로*, 이나바 이쯔시**

(일본 JEMAI*, 국립자원환경연구소**)

Assessment of the Potential Damage of Human Health Applying Damage Functions

- Case Study for Electric Appliances -

Norihiro Itsubo*, Atsushi Inaba**

(Japan Environmental Management Association for Industry*, National Institute for Resources and Environment**)

ABSTRACT

LCA has been recognized as a useful quantitative assessment tool to construct environmental management system for industry. The quality of LCIA methodology has been improved considerably as a result of continuous discussions internationally. In Japan, the researches including the weighting across impact categories have been attracted and performed comparatively to meet the requirements for easier decision making. Subjective judgment will be involved in weighting. All of the weighting methodologies proposed in Japan compare the priorities between impact categories such as greenhouse effects and acidification. They have to compare several environmental problems based on the results of midpoint level such as radiative forcing and proton release. However, a lot of category endpoints are involved in one impact category and then, the information for the receptor might be hidden in previous methods. From these backgrounds, endpoint approaches that assess total single index based on physical damages of category endpoints have been paid attention. Several methodologies have already been considered in Europe. Impact passways are dependent on substances, emission route and receptors. Consequently to develop this type of methodology, considerable researches are required. Impact assessment committee in LCA National Project of Japan started to develop the impact assessment system based on endpoint t approach. We have already developed several damage functions related with human health such as the marginal increase of thermal stress and malaria due to the emission of carbon dioxide. We can integrate damages of category endpoints reasonably with the application of years of life lost or DALY (Disability Adjusted Life Years). This paper provides the case study for electric appliance to demonstrate the effectiveness of the application of damage functions. According to the comparison between several endpoint methodologies, they showed many similar points. Those similarities cannot be obtained from the comparison between midpoint approaches. The results proved the validity of the application of endpoint approach.

Keyword: Damage Functions, Life Cycle Impact Assessment, Human Health, DALY

요 약 문

LCA는 산업을 위한 환경관리 시스템을 고안하기 위해 정량적인 평가도구로 유용하게 인식되어왔다. 질적인 면에서 LCAI 방법론은 국제적으로 계속된 토론으로 말미아마 상당히 향상되었다. 일본에서 가중치의 교차와 영향범주를 포함한

연구는 좀더 쉬운 의사결정의 요건을 충족시키기 위해 수행되어졌으며, 여기에서 가중치는 주관적인 판단을 포함하게 된다. 일본에서 제안된 모든 가중치 방법론은 산성화와 온실효과와 같은 영향범주 사이에서 우선적으로 비교되었다. 이러한 것들은 방사능과 양성자 유출과 같은 중간수준의 결과를 기초로 한 몇몇의 환경적 문제와 비교해야 할 것이다. 그러나 많은 최종단계 범주는 한가지의 영향범주를 포함하는 수용자로서 정보가 이전의 방법론에 의해서 감춰져 왔을 것이다. 이러한 경험들로부터 최종단계 범주는 물리적인 손해에 기인한 총단일지수 평가가 주의하는 것에 다다르게 된다. 이런 점에서 몇몇의 방법론은 이미 유럽에서 중요시되고 있다. Impact Passways는 물질, 방출되어지는 방법과 수용체에 의존한다. 일반적으로 이러한 형태의 방법론을 발전시키기 위해서는 상당한 연구가 요구되어 진다. 일본은 LCA국가 사업에서 영향평가위원회로 하여금 최종단계의 접근에 의한 영향 평가 시스템을 개발하도록 하였다. 그들은 약간의 열적 스트레스와, 이산화탄소 방출에 기인하는 말라리아와 같이 인간 건강에 관여하는 몇몇 손실 작용에 대한 개발을 완료했다고 밝히고 있다. 우리는 최종단계를 적용해서 손실을 표현할 수 있으며 그것은 DALY or years-life-lost의 적용에 의한 것이다. 이 보고서는 손실작용의 적용에 관한 효과를 증명하기 위해 전기설비의 연구 사례를 제공하였다. 몇몇의 최종단계[방법론의 비교에 따르면 그것들은 많은 유사점을 보이고 있다. 이러한 유사점은 중간수준접근 사이에서의 비교는 포함되지는 않는다. 그 결과 최종단계 접근응용 효과를 향상 시켰다.

I. Endpoint Approach and Damage Functions

LCIA (Life Cycle Impact Assessment) aims to examine the product system from an environmental perspective using impact categories and resource issues for one or more product system[1]. In characterization phase, we have to select characterization factors to convert the assigned LCI results to common units. In most cases, these characterization factors relate LCI with the category midpoints such as infrared radiative forcing and proton release not with category endpoints like the decrease of forest.

These indicators for midpoint level are useful to evaluate the potential impacts of corresponding impact category. From the viewpoint of weighting across the impact categories, the indicators that estimate the damage of endpoint level are very significant. Several category endpoints are involved in one impact category. If we integrate the impact categories expressed in midpoint level into single index, we have to establish the priority without any information for receptors and the quantified damages of them. In Japan, however, all of methods proposed previously focus on the comparison between results of characterization or normalization expressed in midpoint levels based on certain criteria. These criteria are quite depending on the methods. Fig. (1) compares the results of impact assessment for copier machine by the methodologies proposed in Japan previously. We can see from this Fig. that the compositions of impact categories are quite different between methods, even if same inventory table has been applied. It is difficult to establish the appropriate criteria between the impact categories fairly without any enough information for weighting. Weighting process will involve value choice unavoidably. To include the value choice reasonably, subjective judgment should be made in endpoint level not midpoint level to improve the transparency.

Impact assessment committee in LCA National Project of Japan has started to develop the impact assessment system based on the damage of endpoint level. This system will provide not only the single index by weighting but also potential damages of safeguard subjects to meet various types of practitioner's aim. The process of this system can be divided into 2 phases, natural science based and social science based. The latter one focuses on the comparison between the category endpoints or safeguard subjects with reasonable approach from the economic and social points of view. The former

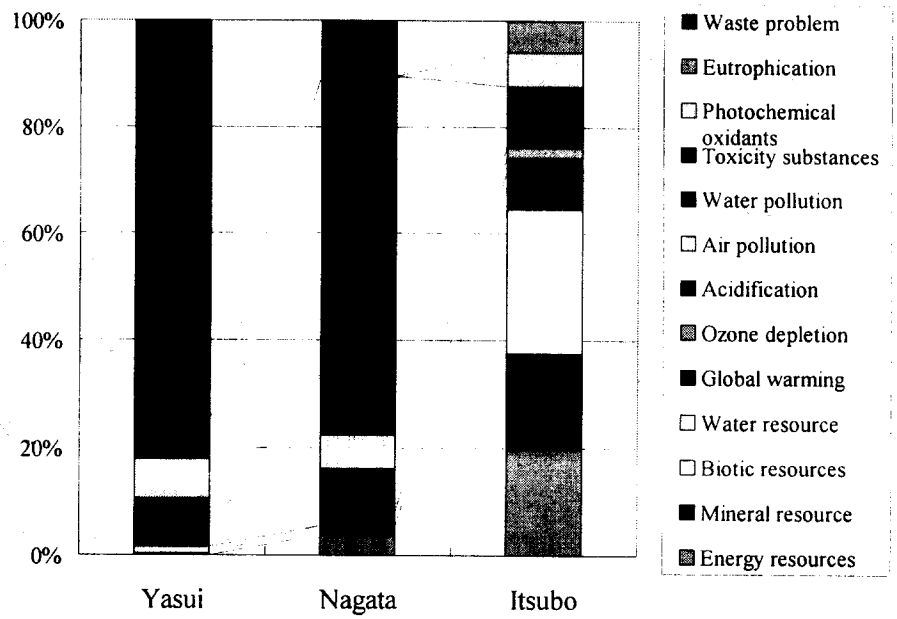

Fig. 1. Comparison between the results of impact assessment for photocopier machine by Japanese weighting methodologies proposed previously. Compositions of impact categories are quite dependent on methodologies.

one concentrates on the assessment for the damage of receptor due to the emission of environmental loading substances with the considerations of the dispersion, concentration of media, exposure and damage of receptor. This former one can be recognized as one of the most difficult and essential point of this system. We call this phase as "damage functions", and develop to apply into total system in damage function sub-committee under impact assessment committee[2]. The mechanisms of environmental impact are depending on the impact categories and receptor, damage function will be established in each of category endpoint.

Fig. 2 describes the differences of the range in assessment between the general type of characterization in LCIA and damage function. Damage functions quantify the physical damage of category endpoint due to the emission of substances or consumption of resources (ex. increased numbers of death by heat stress through the emission of carbon dioxide). The result by damage functions can be aggregated into the potential damage of safeguard subject like the loss of life expectancy, although this aggregation will use some of subjectivity like the comparison of the seriousness of disability. This subjectivity, however, can be interpreted to possess the reliability and representativeness, because DALY, for example, has already been examined internationally and authorized by international body[3].

Safeguard subjects determined in impact assessment committee are 'Human health', 'Social welfare', 'Primary productivity', and 'Biodiversity'[4]. Practitioner can obtain the single index with the consideration of the priority of these items. In case of midpoint approaches, we have to compare between impact categories like 'Climate change' that exist more than 10 items. The number of subjects that will be compared should be smaller to reflect the

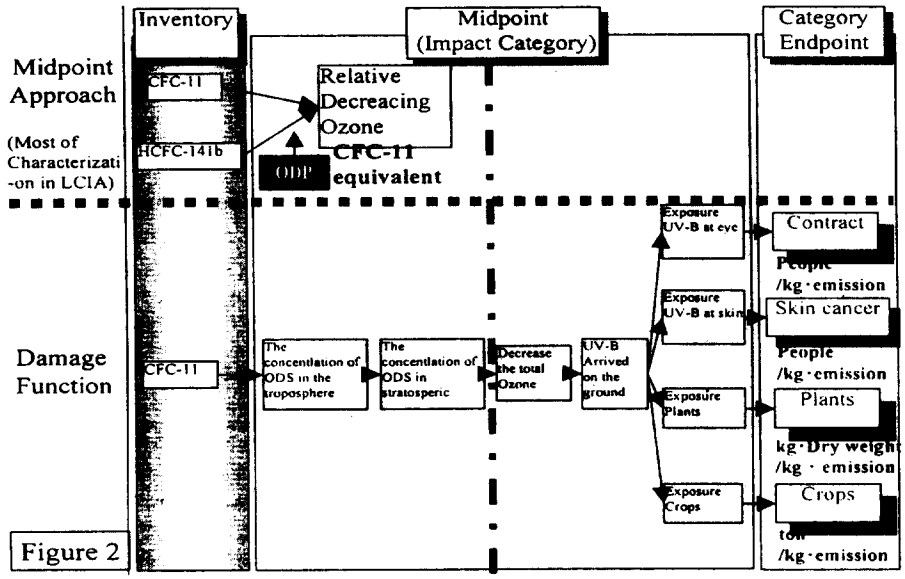

Fig. 2. The range of damage functions: Damage function focus on the estimation of actual damage of category endpoint such as the increased number of skin cancer due to the emission of substance whereas midpoint approach will provide the indirect effect with relative value like CFC-11 equivalent.

thoughts of practitioners. The consideration of the priority of safeguard subjects is suitable to compare in logical. Eco-indicator'99 [5] compares 3 types of damage categories (human health, ecosystem and resources) with the introduction of cultural theory. Damage functions provide the basis of the assessment for potential damages of safeguard subjects and the damage oriented total impact assessment system.

II. Case Study Applying Damage Functions

We describe the results of case study for electric appliance, refrigerators, with the application of damage functions related with human health. The modeled life cycle steps of the system include the demand of materials and energy for the manufacturing of the product, the manufacturing process of the components, the final assembly of the product, the use phase and finally the end of life phase without recycling aspects whereas the product is landfilled after shredding. Transportation that connects every phase is also included. Domestic transportations are assumed to use diesel truck with 10 capacity. The distance for carrying product and wasted one and the loading rate are assumed as 30 km and 100%, respectively. For oversea transportation, we estimated the emissions considering the distances of the exported countries and Japan for every resource. In disposal and waste phases, we assumed that the used product are broken into pieces by shredder and about the half weight of product will be landfilled according to the reference[6]. We assessed the differences of the damages of human health between the refrigerators used CFCs and avoided CFCs. The former one, the

older version, use CFC-11 and CFC-12 as coolants and sparkling matter. The latter version, the new version, converted CFCs into HCFC and HFC to suppress the ozonelayer depletion.

We used the LCA software to perform LCI, 'JEMAI-LCA ver.1', that enable to consider the emitted area such as Kanto-region of Japan. Table 1 shows the inventory table for 10 substances related with both of refrigerators. These substances affect human health through greenhouse effects, ozonelayer depletion and photochemical oxidant creation. According to this table, the emissions through the life cycle of product avoided CFCs are higher than that of used CFCs except for CFCs, HCFC and CFC. Because we adopted the energy scenario that the product used CFCs consume 5 percentages higher than that of the avoided one[6].

Concerning impact assessment, we considered the damage through greenhouse effects, ozonelayer depletion, and photochemical oxidant creation. Category endpoints involved in this study are acute death by thermal stress, malaria, skin cancer, cataract, respiratory disorder by the exposure of oxidant. We took acute effects, restricted the action and in hospital into account as respiratory effects. Consequently, 7 types of damage functions are applied in this study. Especially for the phenomena of photochemical oxidant creation are discussed as a local impact. Consequently, this effect should not be treated as average impact of Japan, we applied the model for Kanto-region[7].

All of the damage functions used in this study

Table 1. Inventory table for the refrigerator (used CFCs, avoided CFCs)

	Used CFCs (kg)	Avoided CFCs (kg)
CH_4	0.080	0.080
CO_2	3.61 E+3	3.64 E+3
CFC-11	0.84	-----
CFC-12	0.20	-----
HCFC-141b	-----	0.69
HFC-134a	-----	0.18
N_2O	0.158	0.164
NOx	2.90	2.96
CxHy	0.0354	0.0379
NMVOC	0.1947	0.1948

Table 2. Potential damages of human health by the emissions of substances (unit: DALY/ kg-emission): GE: Greenhouse Effect, OD: Ozonelayer Depletion, PO: Photochemical Oxidant Creation, TS: Thermal Stress, MA: Malaria, DF: Dengue Fever, SC: Skin Cancer, CA: Cataract, AE: Acute effects, AR: Act Restricted, HO: In hospital

Impact category	GE		OD		PO		
Category endpoint	TS	MA	SC	CA	AE	AR	HO
CH_4	-6.7E-7	9.0E-6	-----	-----	-----	-----	-----
CO_2	-3.2E-8	4.3E-7	-----	-----	-----	-----	-----
CFC-11	-1.3E-4	1.7E-3	8.42E-5	6.18E-4	-----	-----	-----
CFC-12	-2.7E-4	3.7E-3	8.97E-5	6.48E-4	-----	-----	-----
HCFC-141b	-2.0E-5	2.7E-4	7.61E-6	5.53E-5	-----	-----	-----
HFC-134a	-4.7E-7	6.3E-6	-----	-----	-----	-----	-----
N_2O	-9.9E-6	1.3E-4	-----	-----	-----	-----	-----
NOx	-----	-----	-----	-----	1.89E-6	5.00E-6	1.15E-7
CxHy	-----	-----	-----	-----	5.70E-7	1.51E-6	3.47E-8
NMVOC	-----	-----	-----	-----	4.88E-7	1.29E-6	2.97E-8

are related with human health. Through these functions, we can obtain the marginal occurrence of the death or disability for each type of health damage. If we convert them into the loss of the life expectancy, we can aggregate these many types of health damage into one index. This index can be interpreted as an indicator of potential damage of human health as one of the safeguard subject. Damage functions applied in this study are the results through the discussion in impact assessment committee of LCA National Project of Japan. These are published in International Eco-balance conference in Tsukuba[7)~11)]. The potential damages of human health by the emission of specific substances were summarized as Table 2.

Fig. 3 shows the aggregated potential damages of human health applying the damage functions to LCI. According to this Fig., we can see that the conversion of CFCs contributes to reduce the damage considerably. The damage through the greenhouse effects accounts for more than 80 percentages for both of the products. The effects due to ozonelayer depletion occupy about 10 percentages of total impact. The damage by photochemical oxidant creation is not serious relatively. Concerning the effects by the emission of NOx, the impacts by the exposure of secondary substance, ozone, are only involved in this study. If we include the impact by the direct exposure of NOx itself, the contribution of NOx might be larger.

Fig. 4 describes the contributions of category endpoints to the total damage of the refrigerator. The loss of life expectancy by malaria is the largest in both products. The risk occurrence of malaria and that of thermal effects per 1kg emission of carbon dioxide are 9.5E-9 and 1.7E-8 (person/kg-CO_2), respectively. The risk of melanoma and other skin cancer per 1 kg of CFC-11 are 1.6E-6 and 2.3E-5 (person/kg-CFC-11). Consequently, the risk of malaria is not large than the other category endpoints. However, most of cases of malaria has happened in young ages, acute stress by thermal stress is seen in advanced ages. In case of skin cancer,

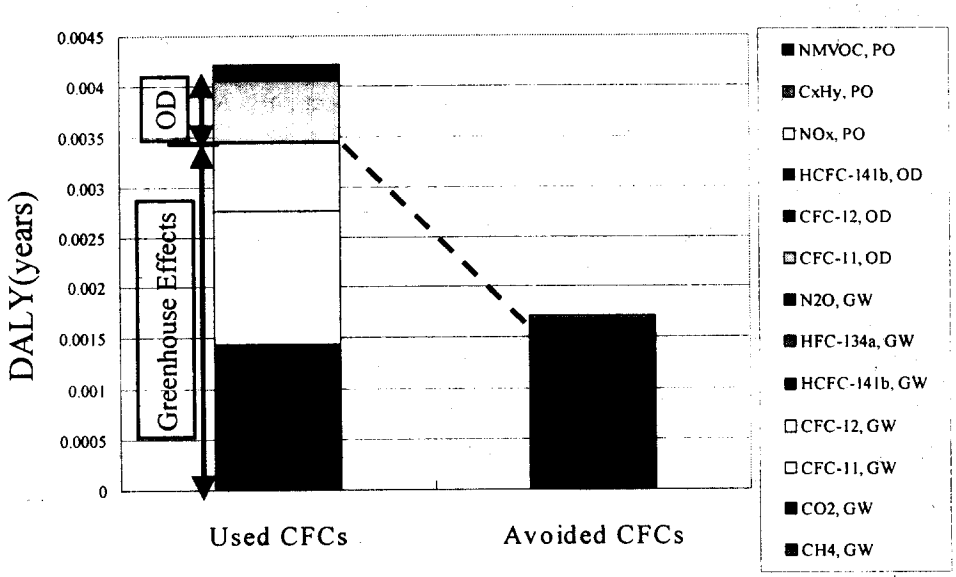

Fig. 3. Aggregated damages of human health for refrigerators applying the damage functions. The results can be expressed as disability adjusted years of life lost.

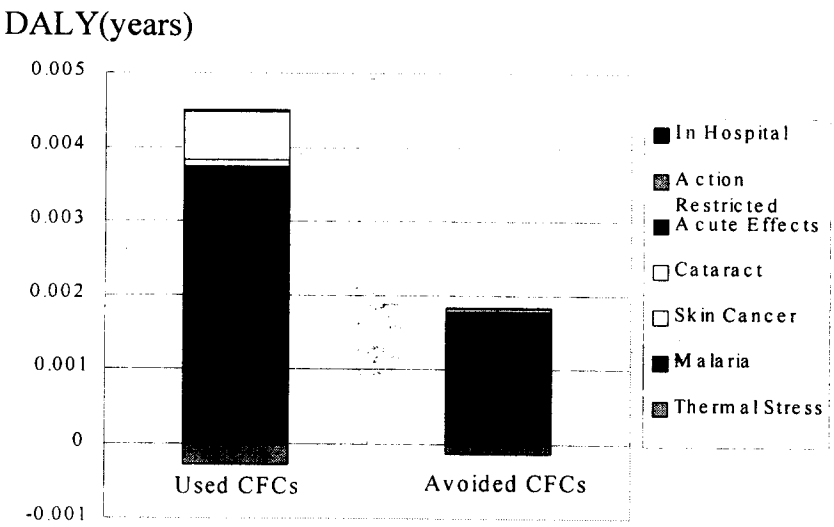

Fig. 4. The contributions of category endpoints to the total damages of the refrigerators. The effects of malaria and cataract are significant.

the rate of death is not large. We assumed years of life lost for one case of malaria as 45 years, this is 10 times larger than that of skin cancer and thermal stress. Furthermore the emission of CO_2 is 4 orders larger than that of CFCs. Plenty of CO_2 emission contributes the large damage. This is the reason of the contributions of category endpoints described in Fig. 4.

The results of impact assessment applied Eco-indicator'99 to the common inventory table (Table 1) are shown in Fig. 5. Both of Fig. 3 and 5 express the damage of human health as the loss of life expectancy, we can compare the values itself. We can point out the following similarities.

(1) Conversion of CFCs into HCFC and HFC enable to reduce less than the half of the total damage of human health.
(2) The exponents of total damage values for both of products.
(3) CO_2 and CFCs are important substances for the refrigerator used CFCs, CO_2 is considered as significant for the refrigerator avoided CFCs
(4) The contributions of greenhouse effects and ozonelayer depletion are large, and that of photochemical oxidant creation is not as serious.

We can also describe the different point as the followings.

(1) The total impact of product life cycle by our approach is estimated larger than the case of Eco-indicator'99.
(2) The impacts by the photochemical oxidant creation are estimated smaller than the result of Eco-indicator'99.

These differences above are owing to the adapted model and the involved category endpoints. Concerning photochemical oxidant creation, the direct exposure of NOx and asthma are excluded in this study, whereas Eco-indicator'99 includes them. On the other hand, we included skin cancer and cataract for the damages through ozonelayer depletion, but Eco-indicator'99 considers only skin cancer. According to our group's research, the potential

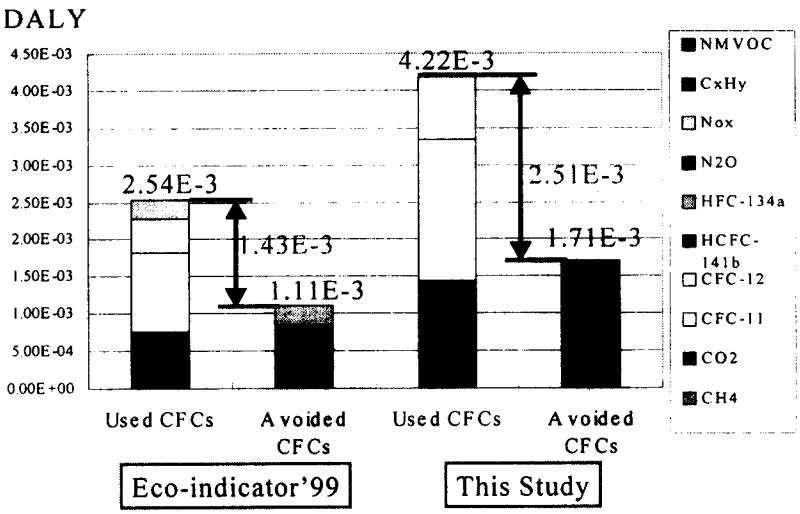

Fig. 5. The results of impact assessment for the damage of human health by Eco-indicator'99

damage of cataract is larger than that of skin cancer, these differences of involved items contribute the gap of total impact. Because the results through greenhouse effects are dependent on GCM (General Circulation Model), the sensitivity to the total impact by the selection of GCM should be assessed. The damage caused by the emission depends on the background such as the exposed population, the annual emission of substances, and climate especially for local impact like photochemical oxidant. In fate and exposure analysis incorporate these above data, and provide results considering this information. Eco-indicator'99 and our approach treat whole of Europe and Kanto-region of Japan. The change of concentration of environmental media like air, water and soil is dependent on emitted area and adopted model, even though common emission data were applied. We have to note that the initial data such as temperature and wind speed are different between the both of approaches. Both of results revealed that the global damage for global impacts such as greenhouse effects and ozonelayer depletion is dominant in this case study. Therefore the total values revealed similar.

The result applied EPS to common inventory table is shown in Fig. 6. EPS is also well known as endpoint approach. This method has revised in last year, and published the version of 2000[12]. The unit of damage differs to the former results, because the damage is expressed as cost by EPS. Steen assumed 85,000 ECU per one year of life lost (YLL). We converted the unit into the years of life lost with the above relationship. According to this result, the values by EPS estimated 2 or 3 times of our results. The results of Fig. 4 incorporate many types of damages such as crops, starvation, and extinct species not included in above methods. However, there are many similar points between the results like the contributions of substances and the differences between the refrigerators.

Ⅲ. Conclusions

In Japan, LCIA especially for weighting has been attracted that enable to avoid trade-off relationship, and many of methodologies have

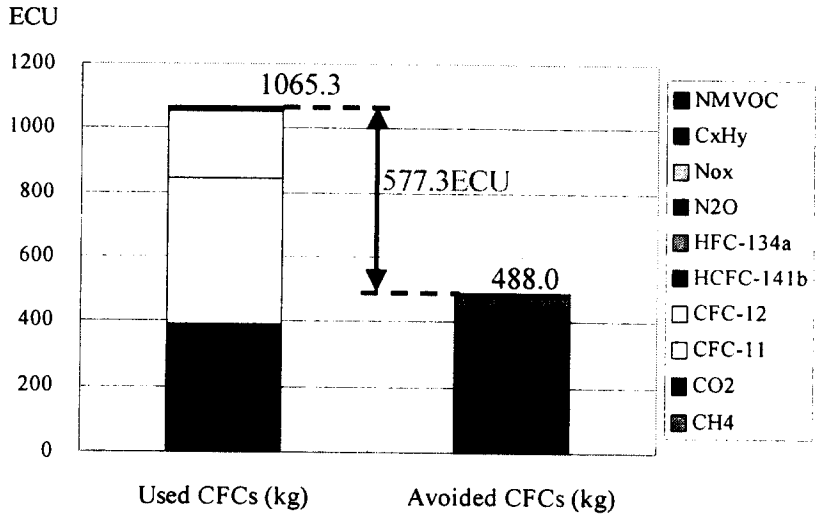

Fig. 6. The results of impact assessment by EPS version 2000

been proposed. These methods compare the priorities between impact categories. This comparison is based on the indirect effects such as potential of ozone depletion. This means that there is no information as to what will be affected and to what degree of that damage is in previous methods. There are many types of effects even in one impact category like greenhouse effects. It seems impossible to understand the magnitude of many types of impact categories correctly without any data regarding damages. There is little similarity between the results applied several methodologies proposed previously to common inventory data[13]. To perform weighting across impact categories fairly, the information related with endpoints must be required.

To improve the transparency, the integration from the midpoint levels is not sufficient. It is required to develop the methodology that is based on endpoint approach involving the knowledge of detailed natural science. We described the application of several damage functions and integration into the level of safeguard subjects, human health through the case study. According to case study, we could find several similar points and prove to obtain the adequate results.

The assessments by endpoint approach provide what type of disease is significant and how serious quantified damages are. We can compare between the methodologies of endpoint approach in detailed level such as the simulation models, background data for calculations like population and even life style. Furthermore, concerning the integration the damages of category endpoints into safeguard subjects, we can apply the indicator that possess the reliability and transparency. WHO and UNEP, for example, authorized DALY. Then we can avoid personal subjective judgment as far as possible and obtain fair and adequate results with a satisfactory level.

The total impact assessment system that treats endpoint approach is now in developing stage. In future, it is required to construct damage functions for category endpoints recognized as important without omission and to develop the technique that integrate the results of damage functions into the safeguard level and

single index with comprehensiveness.

Acknowledgements

The authors would like to thank the New Energy and Industrial Technology Development Organization (NEDO) for their financial support.

References

1) ISO14042: Environmental management Life cycle assessment Life cycle assessment,
2) Itsubo N: Launch the damage function sub-committee in National LCA Project of Japan, Int. J. LCA, 5 (2) 2000.
3) MurrayC.J.L., Lopez A.D.: The Global Burden of Disease, Volume 1 of Global Burden of Disease and Injury Series, WHO/Harvard School of Public Health/ World Bank, Harvard University Press, Boston, 1996.
4) Itsubo N., Inaba A.: Definition of safeguard subjects for damage oriented methodology in Japan, Proceedings of The Fourth International Conference on EcoBalance, Tsukuba, Japan, pp.217-220, Oct. 31-Nov.2, 2000.
5) Goodkoop, M., Spriensma, R., (1999): The Eco-indicator 99 A damage oriented method for Life Cycle Impact Assessment, Methodology Report.
6) New Energy and Industrial Technology Development Organization, Japan Environmental Management Association for Industry: International Collaborative Project for Streamlining Energy Use, (1995).
7) Nagata Y., Ohara T., Fujii T., Itsubo N., Inaba A.: Life Cycle Impact Assessment of Photochemical Oxidant through Damage Function Approach (Valuation of Incremental Ozone Concentration Due to Emissions of Ozone Precursors), Proceedings of The Fourth International Conference on EcoBalance, Tsukuba, Japan, pp.245-248, Oct. 31-Nov.2, 2000.
8) Itaoka K., Uchida H., Itsubo N., Inaba A.: Life Cycle Impact Assessment of GHG Emission on Human Health, Proceedings of The Fourth International Conference on EcoBalance, Tsukuba, Japan, pp.225-228, Oct. 31-Nov.2, 2000.
9) Hayashi K., Itsubo N.,Inaba A.: Damage Function of Stratospheric Ozone Depletion for Life Cycle Impact Assessment, Proceedings of The Fourth International Conference on EcoBalance, Tsukuba, Japan, pp.237-240, Oct. 31-Nov.2, 2000.
10) Hayashi K., Itsubo N., Inaba A.: Development of Damage Function for Stratospheric Ozone Layer Depletion, Int. J. LCA 5 (5) 265-272 (2000).
11) Fujii T., Nagata Y., Itsubo N., Ohara T., Inaba A.: Life Cycle Impact Assessment of Photochemical Oxidant through Damage Function Approach (Valuation of Damage Due to Ozone Concentration), Proceedings of The Fourth International Conference on EcoBalance, Tsukuba, Japan, pp.241-244, Oct. 31-Nov.2, 2000.
12) Steen B.: EPS-Default Valuation of Environmental Impacts from Emission and Use of Resources Version 2000.
13) Itsubo N., Inaba A., Matsuno Y., Yasui I., Yamamoto R.: Current Status of Weighting Methodologies in Japan, Int. J. LCA 5 (1) 5-11.