一般論文～～～～～～～～～～～～～～～～～～～～～～～～～～～～～～～～～～～～～

Establishment of Sustainability Indicator for Cushioning Packaging

Lijiang HUO*, Katsuhiko SAITO** and Yukiomi NAKAGAWA***

An integrated approach to sustainability assessment for cushioning packaging based on Life Cycle Assessment (LCA) has been developed to meet challenges within the context of packaging. The approach measures the performance of the cushioning packaging with regard to social, economic and environmental aspects and produces quantitative results as a monetary unit, and integrates the results into a sustainability indicator (SI) for directly indicating the overall benefits of the cushioning packaging. Two types of cushioning packaging made from molded pulp and corrugated board respectively for packaging a gas appliance were assessed in this study as a case study demonstration. The results show that the main environmental impacts of the two cushioning packaging are global warming and acidification caused by the atmospheric emissions during production processes for the cushioning packaging materials and products. The molded pulp material with associated advanced component structure was found to be the scheme in the two cushioning packaging designs for achieving sustainability although it has somewhat higher physical costs than that of the corrugated board cushioning. The optimum for the two cases is indentified by calculating the newly developed SI.

Keywords： sustainability indicator; cushioning packaging; LCA; molded pulp; corrugated board

1. Introduction

The molded pulp material and corrugated boards which are made from waste paper, are recognized for their potential to replace plastic cushioning packaging based on fossil fuels and therefore contribute to the conservation of natural resources.[1-4] Researchers have concentrated on innovation in technical performance of the cushioning packaging using the paper materials.[4-7] However, the cushioning packaging in practice is affected by a number of impact factors, involving social, economic and environmental aspects, simultaneously. Multiple metrics and indicators must be employed to ascertain the consequences and trade-offs implicit in technology adoptions for implementing sustainability.[8] On this view, we established the SI approach to quantitatively measure the various performance and the overall benefits of the cushioning packaging for identifying potential improvements and implementing sustainability in the domain of packaging industry.

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2. Methodological approach

Based on LCA thinking, the cushioning packaging has its own life cycle including raw materials acquisition, cushioning material manufacture, cushioning packaging manufacture, packaging/contained contents distribution and cushioning packaging disposal.[9] According to the concept of the life cycle, the basic input-output logic regarding the cushioning packaging itself can be set up and diagramed in Fig.1.

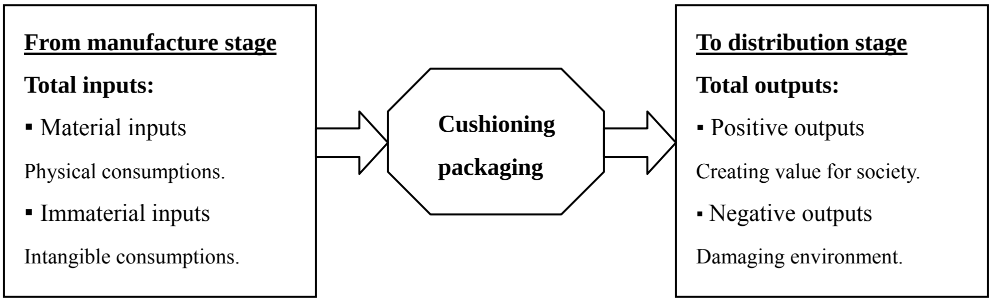


Fig. 1 Basic input-output logic of cushioning packaging

The total inputs within the input-output flows involve material inputs (e.g. materials, natural resources, energy.) and immaterial inputs (e.g. techniques, human resources.). The total inputs are quantified by means of a technical and economical analysis of the cushioning packaging production. The material inputs are physical usage in the processes of the cushioning packaging production. The amount of the physical usage can be measured according to the first law of thermodynamics (the law of the conservation of mass). By definition the material inputs must equal to the outputs plus net accumulation of materials in the system. The measurement outcomes are subsequently converted into a monetary unit. The immaterial inputs are regarded as intangible consumptions but represent a cost to the production of the cushioning packaging. The total inputs are presented by the direct costs of consumed inputs (DCC). The DCC is expressed as Equation (1).

$$DCC = C_{materials} + C_{resource} + C_{energy} + C_{other} \qquad (1)$$

where $C_{materials}$ represents costs of materials needed during the cushioning packaging production;

$C_{resourcer}$ represents costs of consumed natural resource during the cushioning packaging production;

C_{energy} represents costs of consumed energy during the cushioning packaging production;

C_{other} represents costs of equipment depreciation, maintenance, salary and taxes related to the cushioning packaging production.

The total outputs within the input-output flows are considered as positive outputs (creating value added for society) and negative outputs (resulting in environmental damage). The value added (VA) produced by the positive outputs is presented by economic gains of the cushioning packaging related to market and expressed as Equation (2).

$$VA = (SV_{contained\ contents} - C_{contained\ contents}) \times \frac{C_{cushioning\ packaging}}{C_{contained\ contents}} \tag{2}$$

where $SV_{contained\ contents}$ represents sale value of contained contents using the cushioning packaging;
$C_{contained\ contents}$ represents costs of contained contents using the cushioning packaging;
$C_{cushioning\ packaging}$ represents costs of the cushioning packaging.

The $C_{\text{cushioning packaging}}$ equals to the DCC if manufacturers who make the contained contents produce the cushioning packaging by themselves. Otherwise, the $C_{\text{cushioning packaging}}$ equals to the DCC plus the profits of the cushioning packaging production. The VA is created by technical functions of the cushioning packaging within the framework of related social laws and regulations. It represents social responsibility undertaken by the cushioning packaging. The negative outputs resulting in environmental damage are considered to be hidden costs of consumed inputs (HCC). The HCC can be calculated by the LCA methodology. In this study, life-cycle impact assessment method based on endpoint modeling (LIME) [10)] is mainly adopted and Eo-indicator’ 95 model [10)] is also used for validating the results.

The social, economical and environmental aspects of the cushioning packaging are integrated into the SI based on an efficiency ratio, which is expressed through a formula of more-is-better elements as opposed to less-is-better elements.[11)] The SI is expressed as Equation (3) and Equation (4). The bigger the SI, the better the overall benefits the cushioning packaging.

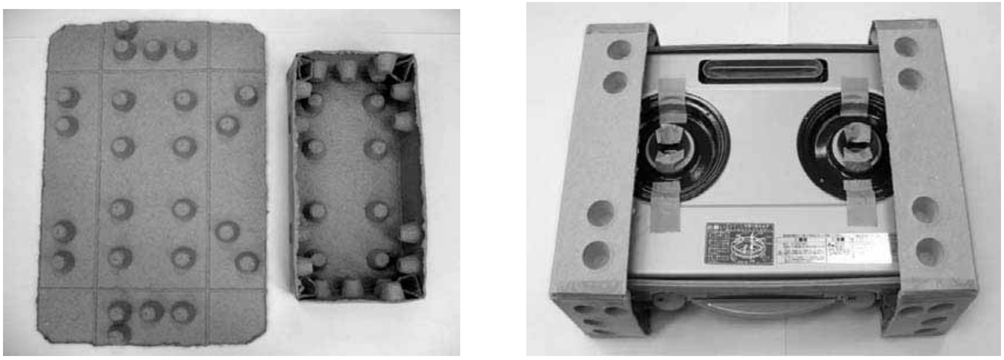
$$SI = \frac{f(Positive\ outputs)}{f(Inputs, Negative\ outputs)} \tag{3}$$

$$SI = \frac{f(VA)}{f(DCC, HCC)} \tag{4}$$

3. Case studies

Conventionally comparing to the corrugated board cushioning packaging, the molded pulp cushioning packaging has not been extensively used in paper cushioning category due to high cost and some technical problems. [1-2)] However, a new molded pulp cushioning design associated with new type of mold tool have been developed.[2) 4)] For further identifying potential improvements in the paper cushioning packaging, we carried out the overall evaluation on the basis of the new molded pulp cushioning packaging design and corrugated board cushioning packaging design in this study.

Two cushioning packaging designs for packaging a gas appliance (570×440×150 mm, 10kg) were assessed in this study. They are nominated as 1st and 2nd cushioning packaging hereafter. Both of them are able to standardize the cushioning design by some structure factors. The two evaluated targets show technical variations as follows:



(a) Molded pulp cushioning packaging

(b) New mold tool

Fig. 2　1st cushioning packaging

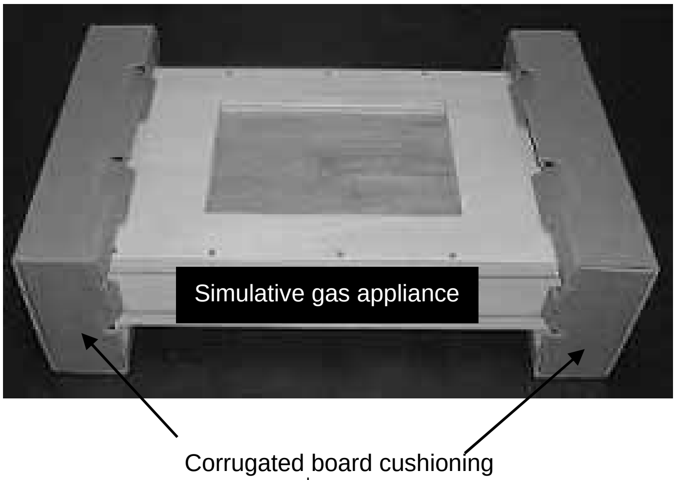


Fig. 3　2nd cushioning packaging

▪ The 1st cushioning packaging is molded pulp product made from used cardboard and newspaper (6:4 mixing ratio by weight) and adopt the new structure design with components, [4] as shown in Fig. 2 (a). The new structure of the molded pulp cushioning packaging is formed by the new mold tool, [4] as shown in Fig.2 (b). The new mold tool is made from aluminum alloy. The weight of the 1st cushioning packaging itself and its mold tool are approx 1.0 kg and 20 kg respectively.

▪ The 2nd cushioning packaging is corrugated board (K180/SCP160/K180, B/F) product made from used paper. Its structure is able to fit the shape of the gas appliance, as shown in Fig.3. The corrugated board is processed by die-cutting machine and is then folded along the pressed marks. The weight of the 2nd cushioning packaging is approx 1.5 kg.

3.1 Functional unit and system boundary

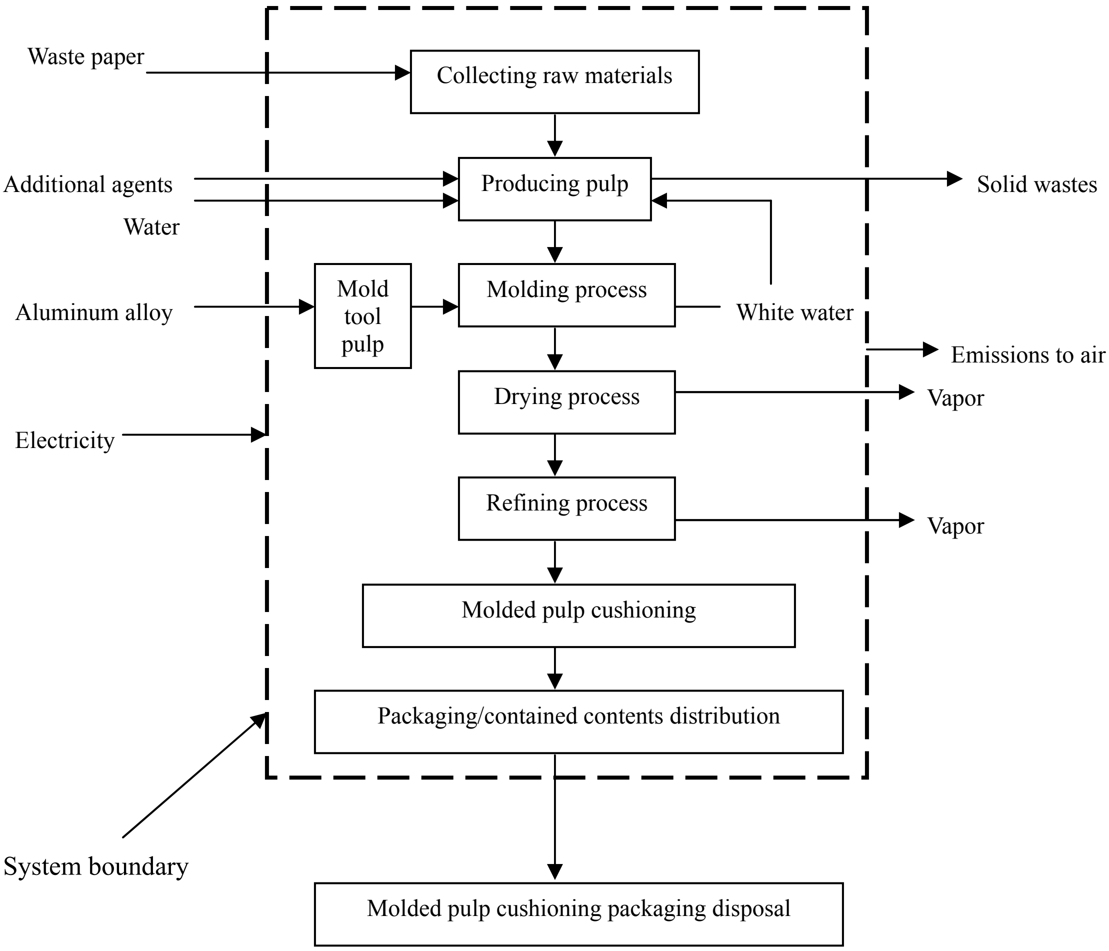


Fig. 4 System boundary of molded pulp cushioning packaging based on life cycle

For this study, the functional unit (FU) was defined as a set of cushioning package for the gas appliance ready for dispatch. The system boundary on basis of the life cycle commenced with collecting the raw materials and ended with ready cushioning packaging/contained contents for distribution. The study did not include transportation of raw materials, product and distribution, nor the disposal of the cushioning packaging. The system boundaries with indication of the inputs and outputs of the molded pulp cushioning packaging and the corrugated board cushioning packaging were presented in Fig.4 and Fig.5 respectively.

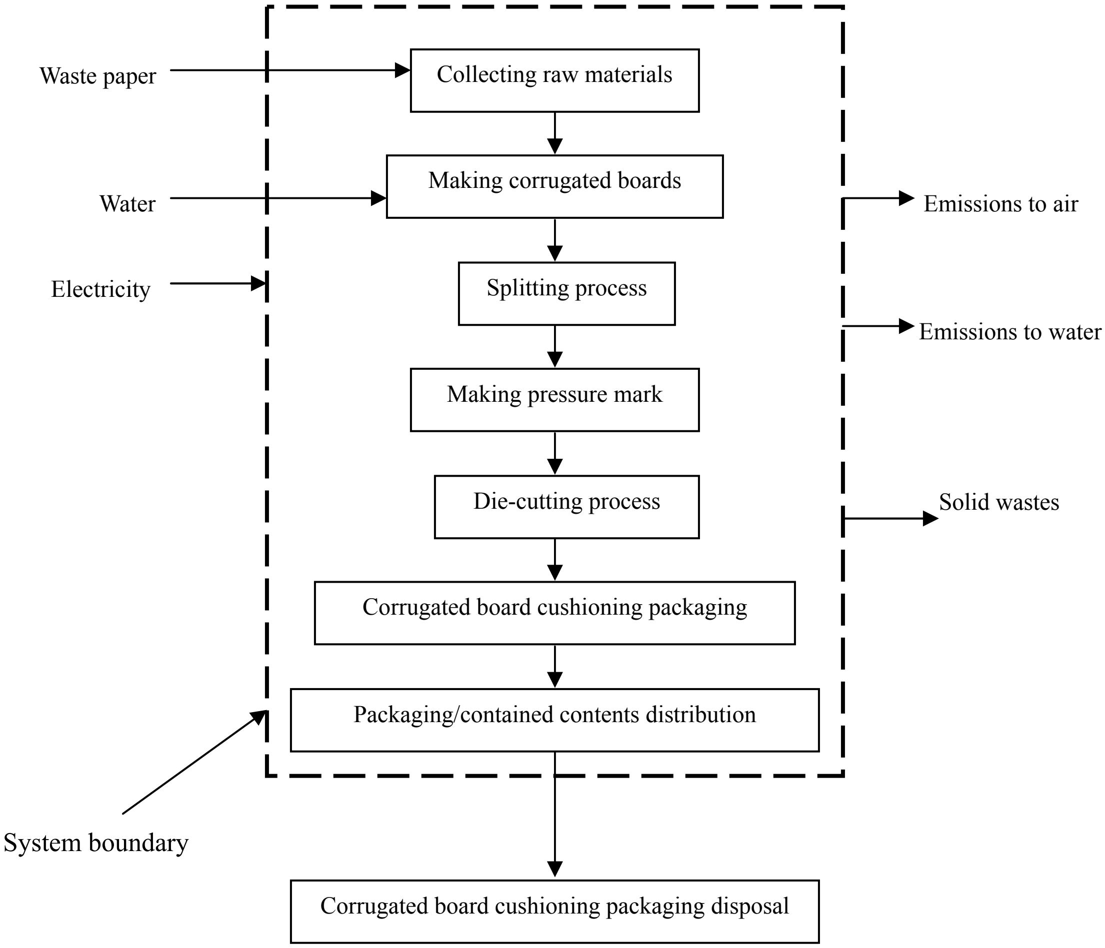


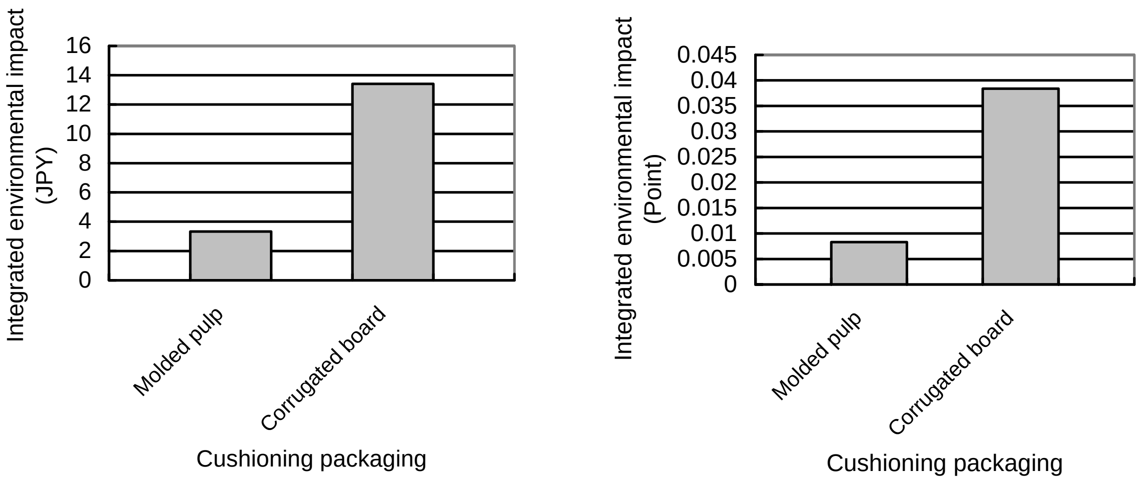
Fig. 5 System boundary of corrugated boards cushioning packaging based on life cycle

3.2 Input-output analysis

Data collection worked on the premise that the technical indicators of the two cushioning packaging meet requirements of users well. By means of investigative and calculative actions, the input-output flows of the two evaluation targets within the system boundaries were quantified based on the FU, and related life cycle inventories (LCI) were created. The LCI of the input-output flows for the evaluation targets in a monetary unit was shown in Table 1.

JEMAI-LCA Pro with associated databases, which is developed in accordance with the LIME model was used in the LCA. The LCI of emissions to environment of the two evaluation targets based on the FU and subsequent characterization result were shown in Table 2 and Table 3.
As some in-house data was not available, we applied comparable average data assuming a similar situation exists between the two evaluated targets in this study.

The environmental impacts of the two cushioning packaging were further assessed by the LIME model and Eco-indicator'95 model respectively, and the related results of integrated environmental impact were presented in Fig.6 (a) and (b), respectively.

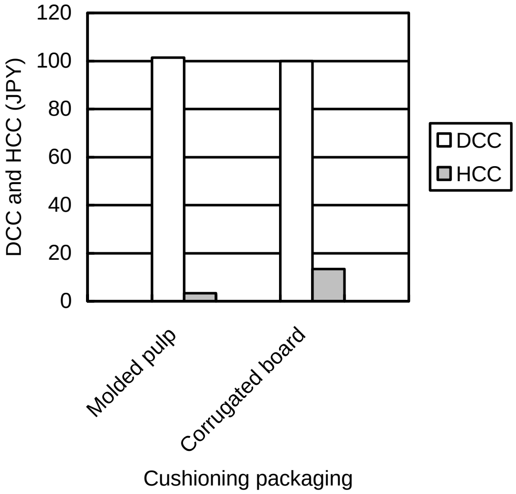


(a) By LIME (b) By Eco-indicator'95

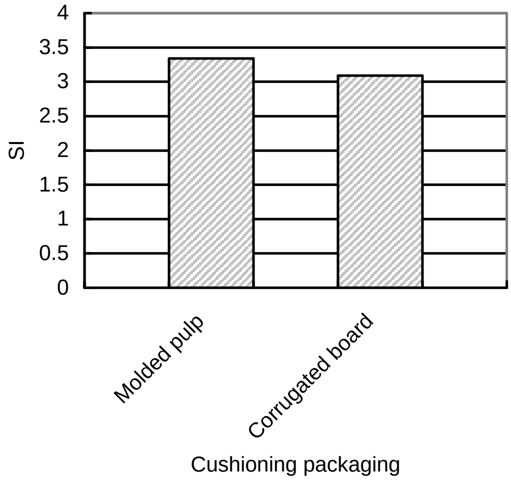
Fig. 6 Results of integrated environmental impact by LIME and Eco-indicator'95

3.3 Results and discussion

Through calculation, the HCC of the two evaluation targets based on the FU were 3.32 and 13.4 JPY respectively, as shown in Fig.7 (a). The SI of the two evaluation targets were 3.34 and 3.09 in the order given, as shown in Fig.7 (b).



(a) DCC and HCC



(b) SI

Fig.7 DCC, HCC and SI results of the assessment

The results of the input-output analysis show that, main environmental burdens of the two cushioning packaging are led to by the atmospheric emissions. They mainly result in global warming and acidification. According to the results assessed by the LIME model, the integrated environmental impact generated by the 2nd cushioning packaging is more than four times of that of the 1st cushioning packaging because of more solid waste and emissions to air during the production processes. The result produced by Eco-indicator'95 model also demonstrates the same situation.

The final results of the assessment show that the 1st cushioning packaging has advantage in overall benefits over the 2nd cushioning packaging due to the less HCC, although the 1st cushioning packaging has more DCC than that of the 2nd cushioning packaging because of the mold tool involved. The findings indicate that the molded pulp material with associated the component structure design should be the first option for achieving sustainability in the development of the gas appliance cushioning package. However, as the case study results rely partly on assumptions in the data, in-house data should be applied for more accurate results.

4. Conclusions

The SI integrating social and economic concern into LIME-based LCA, was utilized to assess the cushioning packaging. The input-output flows representing the performance of the cushioning packaging in social, economic and environmental perspective were indentified and quantified in a monetary unit. The newly developed SI was used to indicate overall benefits of the cushioning packaging so that the final results are direct and transparent to practitioners. The proposed SI approach can be used to assist in identifying potential improvements and enhancing the sustainability of the cushioning packaging.

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緩衝包装に対する持続可能性指標の開発

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革新的な包装システムを実現するために、ライフサイクルアセスメントに基づく緩衝包装に対する持続可能性評価への統合的手法を開発してきた。その手法では社会的・経済的そして環境適性を評価対象として、評価値を貨幣価値に換算することで緩衝包装の包括的な利得を示す持続可能性指標を導き出すものである。ケーススタディーとして、ここではガス調理器具の２種類（パルプモウルドと段ボール）の緩衝包装材を対象にする。検討の結果、緩衝材料とその形成品を生産する過程で生ずる環境へ及ぼすインパクトは主に地球温暖化と酸性化であることを示す。また、最近提案されたコンポーネント構造体で組み合わされたパルプモウルド緩衝体と段ボール製緩衝体について、持続可能性指標からその優劣を比較している。ここで提案した新しい指標によって、どちらが緩衝包装として総合的に優れているかを評価することができる。

キーワード： 持続可能性指標、緩衝包装、LCA、パルプモウルド、段ボール