Life Cycle Assessment of Paperboard Packaging Produced in Thailand

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Abstract

This paper presents the results obtained from the life cycle assessment of a paperboard box produced from virgin pulp and old corrugated box in Thailand. All materials and resources use, energy use, and emissions to environment of each processes in the life cycle were identified and analysed. In impact assessment, contributions to five environmental impact potentials were analysed i.e. global warming, acidification, eutrophication, photochemical ozone formation (smog formation), and solid waste generation. The result showed that the most important process with respect to environmental impacts was landfilling of the corrugated box after use. For energy use, drying processes in paperboard factory were the major contribution. For solid waste generation, board and box production was the major sources. A number of modifications in the product's life cycle were analysed in order to identify more environmentally friendly solutions. Emissions from landfill could be reduced significantly by increasing recycling and implementing efficient landfill gas collection and treatment system in landfills in Thailand. Reduction of electricity consumption in factories, re-design of the container for lower weight and increased reuse reduced impacts significantly throughout the life cycle.

Introduction

Paperboard plays an important role in packing because of its strength, cheap price, and flexible properties. Due to an increasing trend of paperboard consumption in Thailand [1] and increasing environmental awareness, many people and organizations have a close look on the environmental properties of the product. The purpose of this study is assessing the environmental impacts arising throughout the life cycle of paperboard packaging produced, used, and disposed in Thailand and further identifying improvement options to reduce environmental impacts by using Life Cycle Assessment (LCA[1]). A paperboard box produced in medium-sized factories in Thailand served as model product. The shape and dimensions of the paperboard box (corrugated box) is shown in Figure 1. The weight is 655 g.

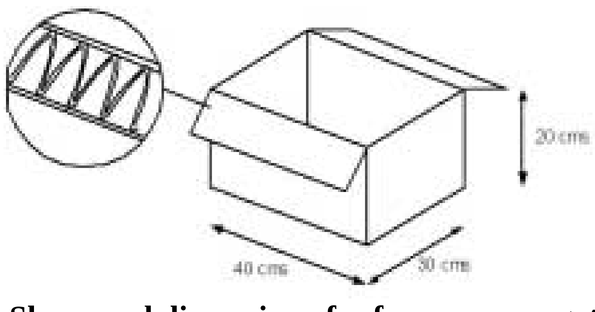

Fig. 1 Shape and dimension of reference corrugated box

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[1] Life Cycle Assessment (LCA) is an environmental management tool that is used to evaluate the environmental impacts associated with products and systems. The focus of LCA is on the entire life cycle of the product, from the extraction of raw materials through production of materials, manufacturing, transportation, use, and final disposal including possible recycling.

Methodology

The study was conducted by using LCA as the analysis method. The first step was to identify the life cycle of the box and define the system boundaries. Secondly, identify and quantify inputs and outputs of each unit process in the life cycle (raw material use, energy use, resources use as well as solid waste generation, emissions to air and water) as shown in Figure 2 [2] and [3].

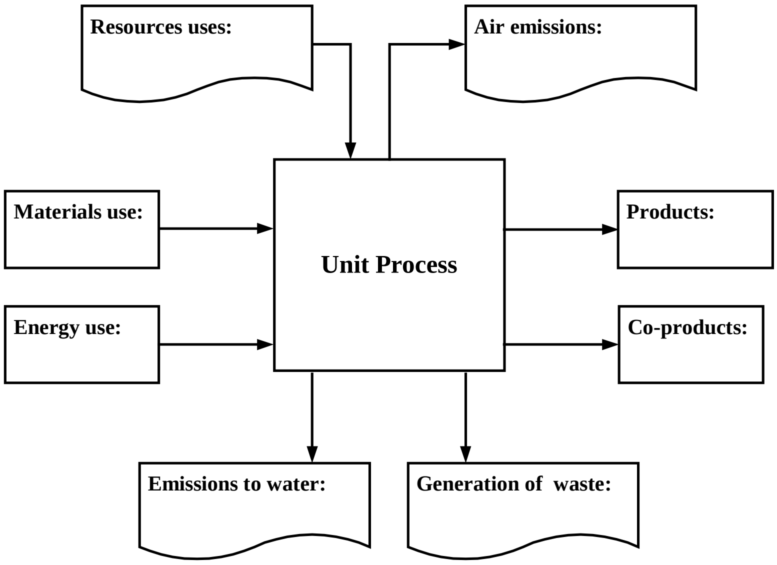

Fig. 2 Unit process

The most important data related to paperboard production were collected at a detailed level in a medium sized Thai factory (16 individual processes) primarily by measurements and laboratory analysis. Other data from processes such as tree growing and cutting, kraft pulp production, box production, transportation, electricity generation, recycling, and landfilling were obtained from other sources such as literature, databases, and interviews. SimaPro 5[2] was used as the data processing tool to summarize and recalculate all resources use and emissions to the environment into the environmental impact potentials per corrugated box. Figure 3 shows the processes, which are included in this study.

[2] SimaPro 5 is an LCA software used in the study, for more details see http://www.pre.nl.

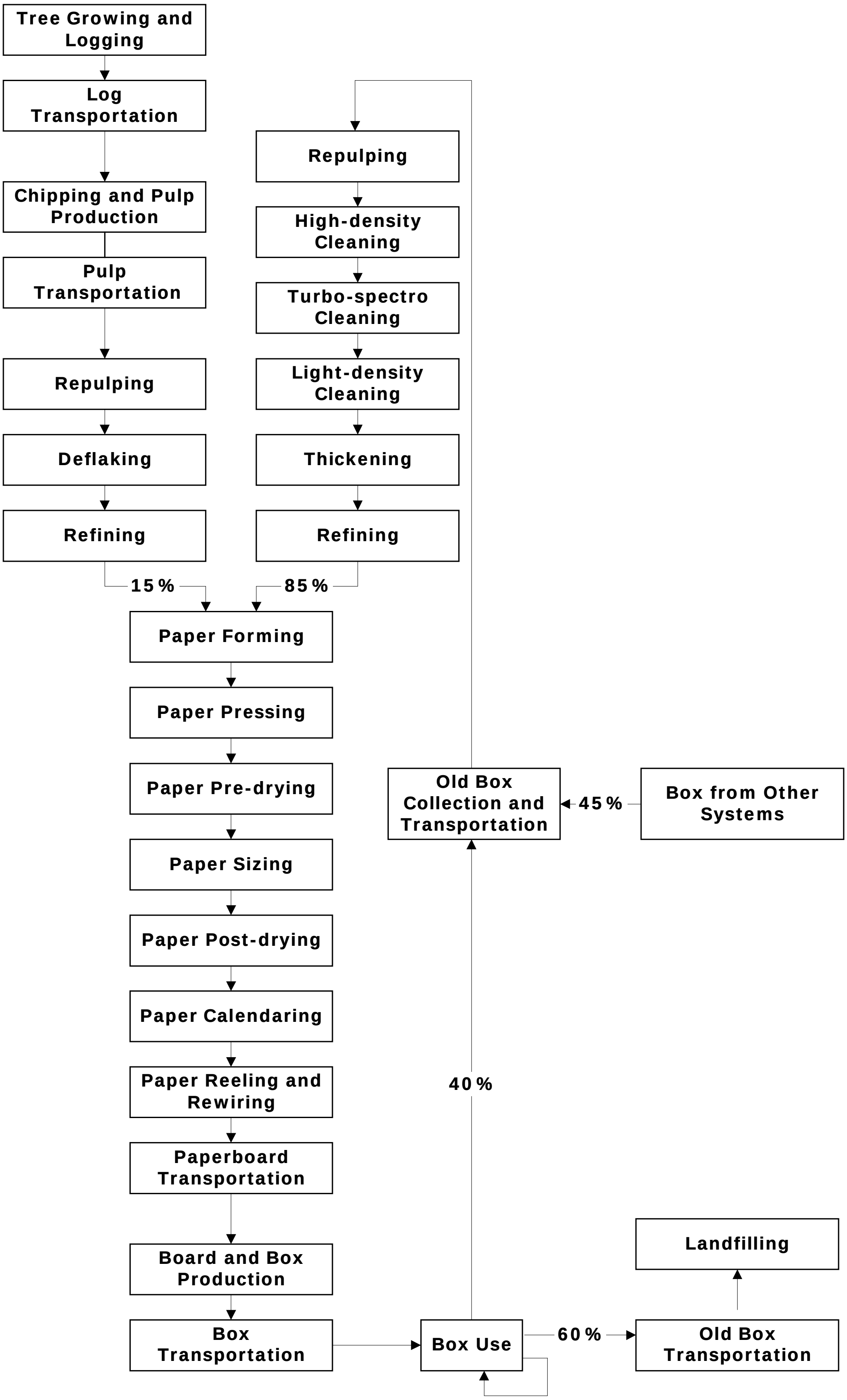

Fig. 3 System boundaries of the LCA study of the reference corrugated box

Some details about the most important processes and assumptions in the product life cycle are provided below:

- Paperboard was produced from 15% virgin kraft pulp and 85% old corrugated container.
- Steam used in paperboard factory is derived from combustion of heavy fuel oil.
- It is assumed that the user uses the box only once before it is disposed.
- Thailand's electricity mix (app. 20% coal, 2% oil, 73% natural gas, and 5% hydro power) has been applied for all significant processes [4].
- 60% of corrugated box is disposed to landfill and the other 40% is recycled [5].
- Landfills are assumed to have no gas collection and treatment system, and all gases generated from the box are assumed to be emitted to the atmosphere.
- Old corrugated box is imported from other systems (see Fig. 3) in order to fulfill the needs for recycled material in paperboard factory. Exchanges from virgin pulp production for boxes from other systems are included in the study [6].

Further details about all processes in life cycle of paperboard box can be found in reference [7] and [8].

Inventory

The inventory of resource uses and emissions to environment in the entire life cycle of one corrugated box is shown in Table 1.

Table 1 Inventory of selected resource uses and emissions to environment per one reference corrugated box (655 g)

Substances	Amount	Unit
Resources use		
Aluminium hydroxide	7.54	g
Coal	4.33	g
Crude oil	0.18	kg
Glue	0.73	g
Ink	1.12	g
Land use for eucalyptus	27.2	cm^2 in one year
Lignite	79.50	g
Limestone	3.36	g
Lubricating oil	0.6	g
Natural gas	6.56	g
Starch (potatoes)	1.21	g
Water	4.47	kg
Wood (Eucalyptus)	0.18	kg
Emission to air		
CO	1.16	g
CO_2	0.51	kg
CO_2 (non-fossil)	0.31	kg
H_2S	4.16	mg
CH_4	22.4	g

Substances	Amount	Unit
NH_3	1.44	g
NO_x	3.09	g
SO_x	1.57	g
VOCs	20.50	mg
Emission to water		
AOX	6.28	mg
BOD	13.4	g
Chloride	1.15	g
COD	56.1	g
Fats and oils	56.0	mg
Nitrate	0.11	g
Phosphorus	56.1	mg
Sulfate	0.18	g
Suspended solids	33.7	g
TOC	0.12	g
Solid waste generation		
Plastics packaging	5.25	g
Process waste	58.60	g
Steel and metal scrap	15.12	g

The total energy use in the box's life cycle is 16.3 MJ .

Impact Assessment

In the study, contributions to five environmental impacts were analysed; global warming potential, acidification potential, eutrophication potential, photochemical ozone formation potential (smog formation potential), and solid waste generation. For more details about environmental impacts, see [9]. Figure 4 shows the main sources of environmental impacts and energy use. These results were used as reference in the study of modifications below.

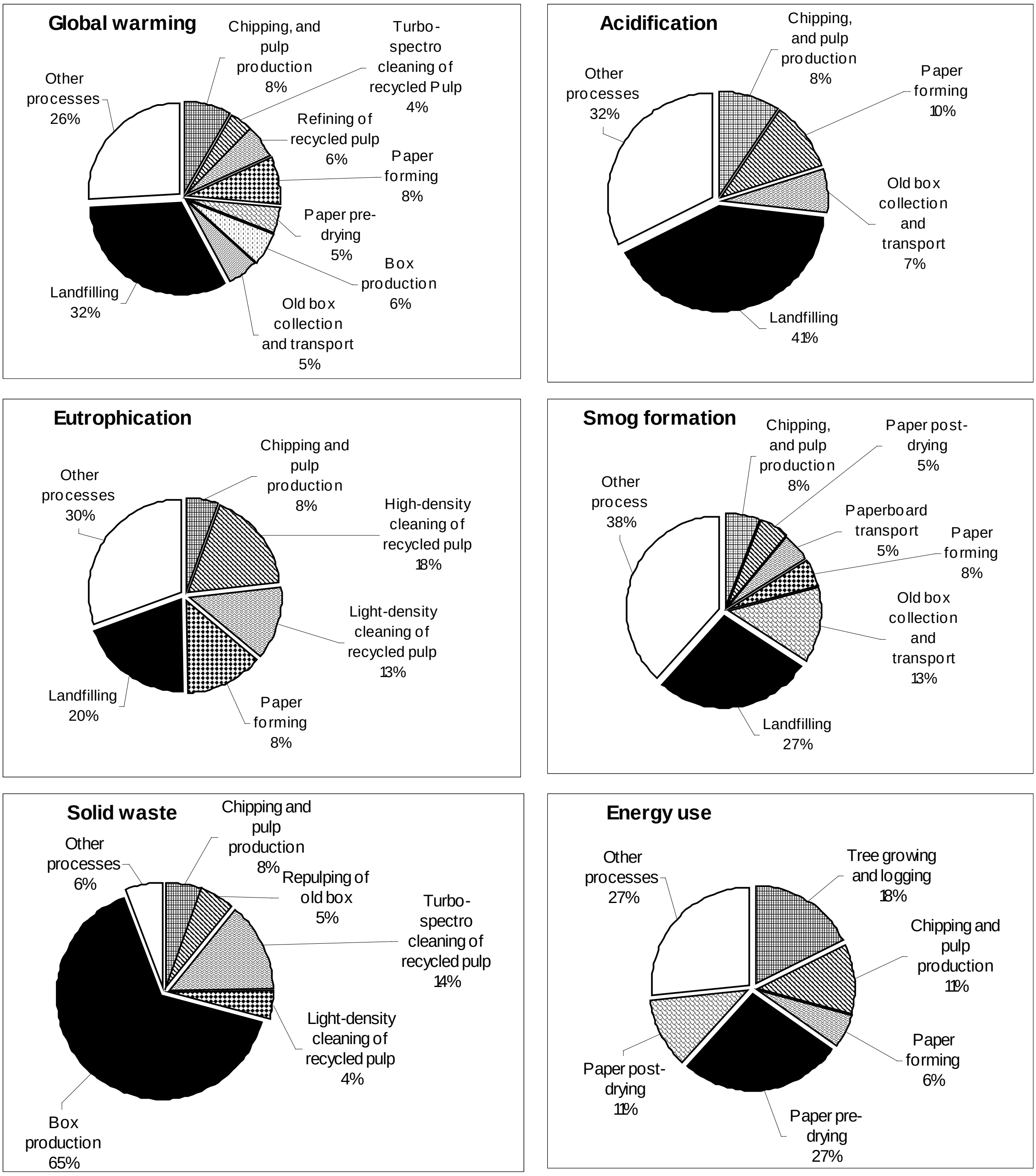

Fig. 4 Main sources of environmental impacts and energy use for the life cycle of the reference corrugated box

Table 2 shows the total amount of environmental impact potentials and energy use in the life cycle of one corrugated box (0.655 kg).

Table 2 Environmental impact potentials and energy use per one corrugated box

Categories	Amount	Unit
Global warming	0.75	kg CO_2-eq
Acidification	6.42	g SO_2-eq
Eutrophication	2.37	g PO_4-eq
Smog formation	0.557	g C_2H_4-eq
Solid waste generation	89.8	g
Energy use	16.3	MJ

The results showed that the most important process with respect to environmental impacts is landfilling of the box. It is responsible for about one third of contributions to global warming and acidification and about one fourth of the contribution to smog formation. The contributions to these impacts are due to air emissions of CH_4 and NH_3 generated during anaerobic decomposition of the corrugated box.

- The main source of **global warming** is CH_4 emissions from the landfill. CH_4's contribution to global warming potential is about 25 times of CO_2's contribution. The remaining contributions are primarily due to CO_2 emission from steam and electricity production based on fossil fuel (coal, oil and natural gas).

- The main source of **acidification** is NH_3 emission from the landfill. NH_3 can be converted into acids (HNO_3) in the atmosphere and spread into land and water. One kg of NH_3 equals to 1.8 kg SO_2-equivalent. Other important sources are NO_x and SO_2 emissions from steam and electricity production.

- **Eutrophication** mostly comes from the substances containing nitrogen and phosphorus remaining in the paperboard. During landfilling, nitrogen and phosphorous is released from the old corrugated box as ammonia and phosphate and contaminating surrounding water and land. Another major contribution is due to pulp losses during cleaning processes in paperboard factory.

- **Smog formation** is primarily due to CH_4 emissions produced in the landfill. One kg of CH_4 equals to 0.4 kg C_2H_4-equivalent. The remaining contributions are mostly due to emissions of CO and volatile organic compounds (VOCs) generated during transportation processes and steam and electricity production.

- **Solid waste generation** is primarily due to board and box production. The contribution is about 65% of total. Cleaning steps in paperboard making is responsible for about 20% of total solid waste generation.

- **Energy** Drying processes consume large amounts of steam and are the major sources of energy consumption. Paper pre-drying process is responsible for one fourth of total and paper post-drying process is responsible for about 10% of total.

The observed environmental impacts are to a large extend determined by the degree of landfilling of the corrugated box. However, the information about rates of landfilling is quite uncertain. Based on own observations, most of the disposed corrugated is collected for recycling along the way to landfills and in the landfills hence not degraded anaerobically in the waste. So, the obtained impacts of the reference system (landfilling of 60% old corrugated box) are maybe not reflecting the situation in Thailand properly. In order to analyse the results sensitivity to landfilling rate a number of different landfilling rates have been tested. Figure 5 shows environmental impacts coming from the life cycle of corrugated box at 20, 50, 60 and 70% landfilling. In all four cases the amount of corrugated box from other system is adjusted accordingly in the LCA models.

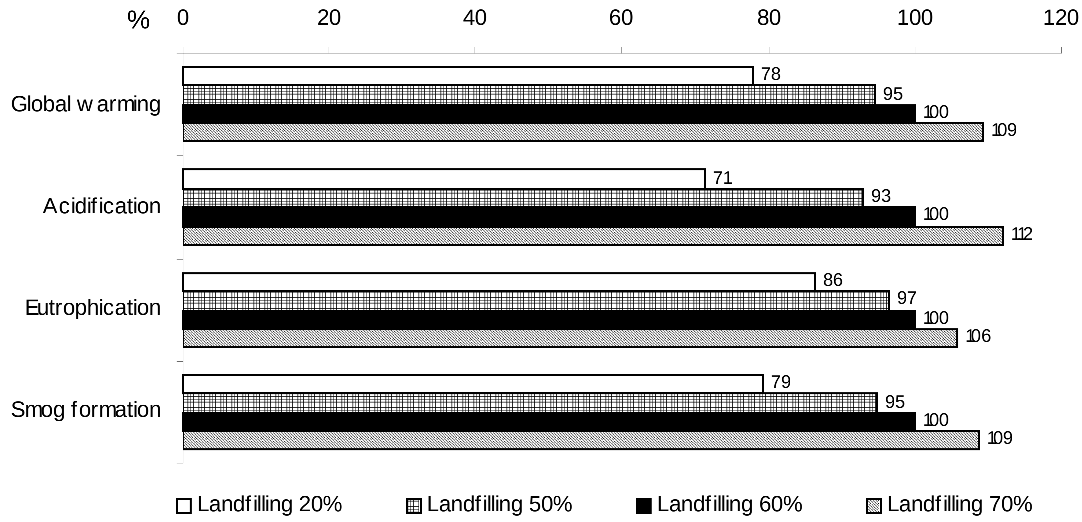

Fig. 5 Comparison of environmental impacts at variable landfilling rates

Figure 5 shows that the total environmental impacts are varying significantly with varying landfilling rate. When landfilling of corrugated box is 20%, the total impacts are reduced by 15 to 30% compared with the reference and processes in the landfill turn out to be of less importance. This result shows that with the present input data about landfilling rate, the results of this study are quite uncertain but it also demonstrates that landfilling is not a suitable disposal technique for paperboard unless landfill gasses are carefully managed; see below.

Modifications

A number of modifications in the product's life cycle were analysed and compared with the reference in order to identify more environmentally friendly solutions. Figure 6 shows the results of four examples of modifications.

- **Landfill gas management** The landfilling gases are managed by applying soil cover at the top of landfill waste and/or by setting up efficient landfill gas collection and treatment system in landfills. These techniques could reduce air emission by for instance 50% [10]. The environmental consequences of landfill gas management are shown in Figure 6(a).

- **Reuse of the box** The reference box is used only once before it is disposed. However, many boxes can be used more than once and are in fact used many times. If the box use is doubled, the production of one new box can be avoided and impacts from almost all processes in the box lifecycle can be avoided. The environmental consequences of reusing the box once are shown in Figure 6(b).

- **Electricity saving technology** Thailand's factories are very often not using the most efficient technology in their production process and energy management is often at a quite low level. If the present machines were replaced with more efficient ones and cleaner technology programs were implemented in all factories in the life cycle the electricity consumption could probably be reduced by 40 to 60% of total [11]. The environmental consequences of 50% electricity saving are shown in Figure 6(c).

- **Reshape the box** The present box is not cubic (see Fig. 1) and hence not optimal with respect to paperboard consumption [12]. If the box was re-designed to cubic shape, the paperboard requirement could be reduced by 4% while keeping the same volume. The environmental consequences of reshaping the box are shown in Figure 6(d).

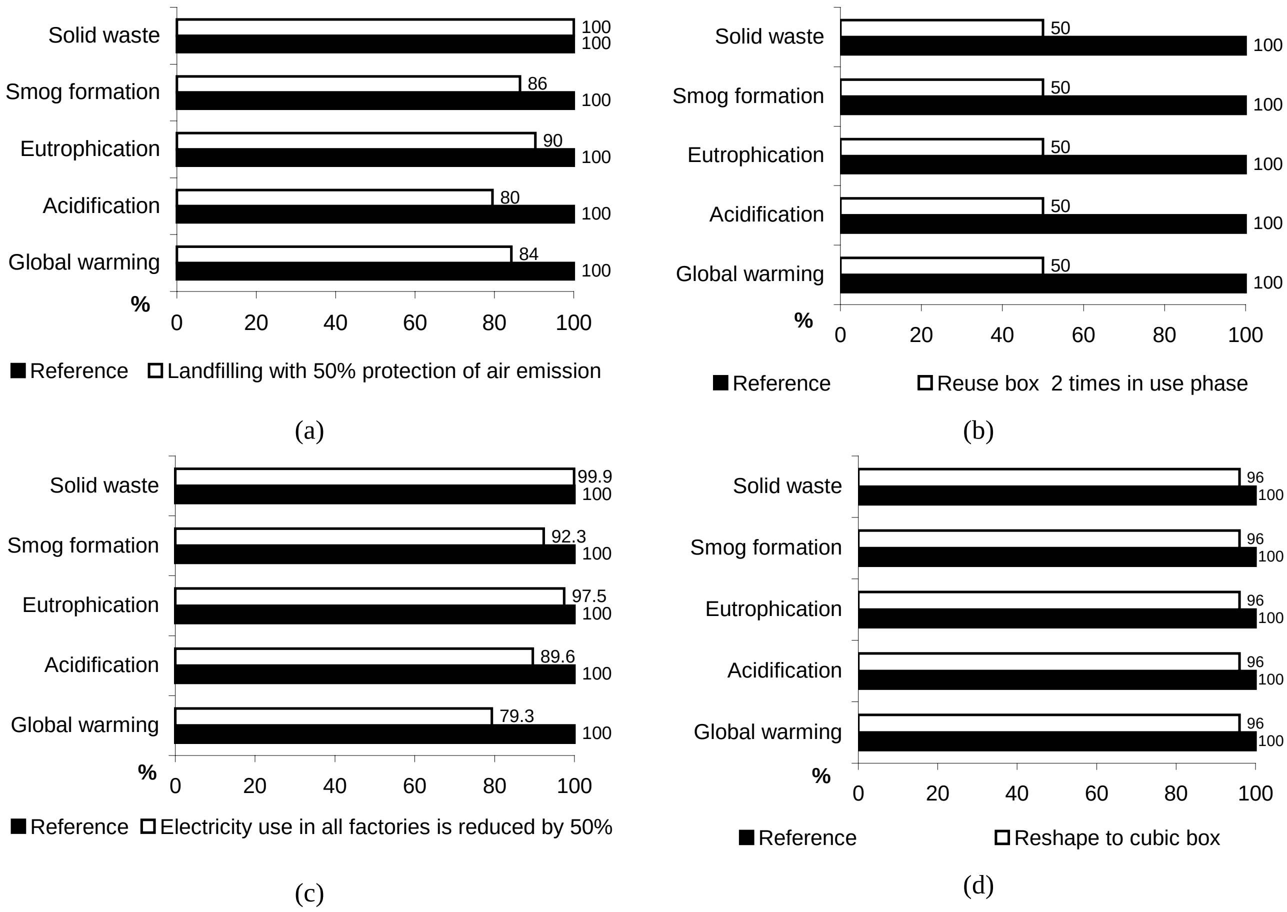

Fig. 6 Comparison of environmental impacts between the reference and four improvement options

a) Implementing efficient landfill gas collection and treatment system in landfills could reduce most of environmental impact potentials by 10 to 20 %.
b) If reuse of the box was doubled; all environmental impact potentials could be reduced by about 50% compared with the reference. If the box was reused e.g. ten times, all environmental impacts could be reduced by 90%.
c) If electricity use in all factories is reduced by 50%, most of environmental impact potentials could be reduced. However, the reductions in the life cycle perspective are only about 20% for global warming and 10% for smog formation and acidification.

d) Re-design of the box into cubic shape could reduce all environmental impact potentials by 4% compared with the reference box due to corrugated board saving. The degree of impacts reduction is not so high because the present box is already quite close to cubic shape. However, for other boxes with less cubic shapes, the paperboard savings can be larger and the reduction of environmental impacts could be more significant.

Conclusions and recommendations

This study shows that the life cycle of paperboard consists of many processes and that sources of environmental impacts are numerous. The main sources of environmental impacts are landfilling, drying processes and other electricity consuming processes, board and box production

- **Landfilling** The total environmental impacts vary significantly with varying landfilling/recycling rate. If the degree of landfilling is high (e.g. 60%), landfilling is the main source of most environmental impacts and it is responsible for about one third of contributions to global warming and acidification and about one fourth of the contribution to smog formation. On the other hand, if the degree of landfilling is low or the landfill is equipped with the gas collection and treatment systems, the landfilling of the box turns out to be less important process in a life cycle perspective.

- **Drying processes and other electricity consuming processes** are the main sources of energy use because they consume high amount of steam and electricity for operation. Paper-drying processes in paperboard factory are responsible for about one third of total energy consumption and other processes such as paper forming and pulp making are responsible for about 45% of energy consumption. Most energy is produced from combustion of fossil fuels and the energy use is responsible for significant contributions to global warming, acidification and smog formation.

- **Board and box production** is the main source of solid waste generation due to high amount of solid wastes generated during production processes. Its contribution is about 65% of total.

To reduce the extend of these impacts, a number of improvement options have been suggested; decreasing impacts from landfills, reuse and reshape of the box, and applying cleaner technology together with electricity saving techniques.

- **Decreasing impacts from landfills** Landfilling is not a suitable disposal technique for paperboard and the box should be recycled to largest possible extend. To avoid impacts from landfilled paperboard landfills should be equipped with proper landfill gas collection and treatment systems.

- **Reuse and reshape of the box** In practical, the box can be used more than once and if the box use is doubled, the production of new box can be avoided and environmental impacts from almost all processes in the life cycle of box can be avoided. The double use of box could reduce most environmental impacts by 50% compared with the reference. Moreover, the increasing of reuse time (e.g. ten times), most environmental impacts would be much less at about 10% of reference. Reshape of the box is another mean to reduce most of environmental impacts. If the box was reshaped to cubic, the paperboard requirement could be reduced by 4% and all environmental impacts could be reduced accordingly.

- **Applying cleaner technology together with electricity saving techniques** in all factories can save the electricity consumption and also reduce most environmental impacts as advantages. If electricity use in all factories is reduced to a realistic level of for instance 50%, environmental impact potentials can be reduced by 20% for global warming and 10% for smog formation and acidification.

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