Henryk Manteuffel Szoege[1]
Agnieszka Sobolewska[2]
Chair of Agricultural Economics and International Economic Relations
Warsaw University of Life Sciences
Warsaw

Life cycle analysis with regard to environmental impact of apple wholesale packaging

Abstract. A comparison between cardboard and plastic boxes for apple packaging in the wholesale and retail trade has been drawn using the SimaPro programme for life cycle analysis. The environmental impact of using plastic cases was estimated much lower, mainly thanks to their repeated use.

Key words: plastic box, cardboard box, life cycle assessment, enviornmental impact.

Introduction

Inserting a new subject called ‘Ecologistics’ into the syllabus of logistics sudies in the Economic Sciences Faculty in our school has created a need for preparing a case study for student exercises. When working on this the authors got conviction that some results of their efforts are worth publishing.

Poland is a world power in apple growing and exporting. The market chain between the orchard farm and the consumer means also a logistic chain. The commodity traded needs packaging. Apples are picked into big pallet cases holding ca 350 kg of apple and then are repacked into small retail boxes of various dimensions. In the export trade and the supermarket retail trade the most popular are boxes with dimensions of 60x40x17 cm. They are made of either plastic or cardboard. The differences in the environmental impact of using either type of boxes has been studied over their whole economic life, which is commonly called Life Cycle Assessment. The calculations have been made by means of the SimaPro computer programme and databases attached to it [Introduction… 2008]. A similar analysis was made by Zarębska and Graczyk for white tin and aluminium beverage cans [Zarębska & Graczyk 2004]. There exists a special international journal totally sacrified to life cycle assessment and food packaging is quite frequently analysed in the papers published there [Humbert et al. 2009].

[1] Prof., email: henryk_manteuffel@sggw.pl
[2] PhD, email: agnieszka_sobolewska@sggw.pl

The tool

The life cycle within the SimaPro methodology is divided into three phases The first one meaning the creation of the subject of analysis (in the programme nomenclature ‘product’) is called ‘assembly’, the second meaning the use of it or the operation is called simply ‘LCA’, the third called ‘disposal scenario’ means the way the post-use waste is finally disposed of (besides disassembly and reuse are possible). This scenario after defining its characteristics is then included back, as well as the ‘assembly’ phase, into the second phase ‘LCA’.

Materials and technological processes used should be defined in each phase. The programme calculates environmental impacts of producing the materials (including the impacts of producing the necessary fixed assets, the energy spent on production, the impact of technological processes of production and necessary transportation) in four categories called ‘compartments’, which are extraction of natural raw materials from the environment and emissions to air, water and soil.

In order to do this the programme user has to choose for each material or process one of databases attached to the programme and then a method of aggregating the results which is called ‘methodology’. They have been composed by various research institutions and contain data concerning mostly some countries in the Western Europe or the United States of America.

Besides the materials, the user has to define the technology of producing the analysed subject. This means decomposing the production process into a mix of some primary processes included in the databases provided with the programme.

The LCA phase also needs defining the materials and processes analogously to the assembly phase.

The same applies to the disposal scenario which should also contain data on the allocation of the final waste to the different disposal processes foreseen by the programme.

The programme then aggregates the particular environmental impacts into some more general impacts called ‘damage categories’ or, more technically, ‘midpoints’ and finally synthesizes them into most general areas of impact called ‘endpoints’. In the most popular Eco-indicator 99 methodology they are ‘human health’ (a sum of damage categories ‘carcinogens’, ’respiratory organics’, ‘respiratory inorganics’, ‘climate change’, ‘radiation’ and ‘ozone layer’[3]), ‘ecosystem quality’ (a sum of damage categories ‘ecotoxicity’, ‘acidification/eutrophication’ and ‘land use’[4]) and ‘resources’ (a sum of damage categories ‘minerals’ and ‘fossil fuels’[5]). Two or more analysed subjects can be compared with respect to those three levels of generalization.

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[3] They can be added up since they are all expressed in the same units with an acronym ‘DALY’ which stands for ‘disutility adjusted life years’.

[4] They can be added up since they are all expressed in the same units with an acronym ‘PDF*m^2*year’ which stands for ‘potentially disappeared fraction of plant species’.

[5] They can be added up since they are all expressed in the same units with an acronym ‘MJ surplus energy’ which stands for ‘MJ of additional energy requirement to compensate lower future ore grade’.

The three aggregate categories can be subjected to what the programme authors call 'normalisation'. This means dividing the results by an average impact a West European is experiencing (and, conversely, producing) in a year.

Table 1. Materials and processes in the three phases of the retail boxes LCA

Characteristics	Plastic box.	Cardboard box
Weight	1.5 kg	0.62 kg * 48
Assembly phase		
Materials		* 48 (counterpart to 1 plastic box)
box	polypropylene injection moulding E, 1.5 kg (isotactive propylene)	Kraftliner brown A B250, 0.57 kg (corrugated cardboard) Alkyd varnish ETHU, 0.01 kg (paint varnish) vinyl chloride ETHU (by default), 0.04 kg (glue)
trays	polypropylene injection moulding E, 2.88 kg (0.06 kg * 48) (isotactive propylene)	polypropylene injection moulding E, 0.06 kg (isotactive propylene)
packing foil	PET ETHU, 0.7 kg (once empty + 48 times laden box)	PET ETHU, 0.028571429 kg (1 empty + 1 laden box) PET ETHU, 0.001733193 kg (for 1 punched cardboard sheet)
Processes		
production, box	injection moulding I (PP, polypropylene)	production cardboard box I
production, trays	injection moulding I (PP, polypropylene)	injection moulding I (PP, polypropylene)
production, packing foil	foil extrusion B250	foil extrusion B250
Exploitation phase		
Transport		
boxes	truck 28t ETHU, 1.4229744 tkm (empty boxes and trays) truck 28t ETHU, 125.76 tkm (laden boxes) electricity from coal B250, 0.525533184 kWh (for charging fork lift batteries)	truck 16t ETHU, 3.627552 tkm (punched cardboard sheets) truck 16t ETHU, 0.26784 tkm (empty boxes producer – wholesaler) truck 16t ETHU, 0.936 tkm (trays) truck 28t ETHU, 121.728 tkm (laden boxes) electricity from coal B250, 0.525533184 kWh (for charging fork lift batteries)
packing foil	truck 16t ETHU, 0.0044516571 tkm (producer – wholesaler) truck 16t ETHU, 0.004641143 tkm (boxes producer – wholesaler) truck 16t ETHU, 0.1371428571 tkm (wholesaler – logistic platform – supermarket)	truck 16t ETHU, 0.14243521 tkm (foil producer – cardboard punching) truck 16t ETHU, 0. 010840084 tkm (cardboard punching – boxes producer) truck 16t ETHU, 0.040628571 tkm (foil producer – boxes producer) truck 16t ETHU, 0.06171429 tkm (boxes producer – wholesaler) truck 28t ETHU, 0.137142857 tkm (wholesaler – logistic platform – supermarket)
Disposal phase		
boxes and trays	recycling only B250 avoided, 98% household waste NL B250 avoided, 1% landfill B250, 1%	recycling only B250 avoided, 90% household waste NL B250 avoided, 5% landfill B250 (98), 5%
packing foil	recycling only B250 avoided, 100%	recycling only B250 avoided, 100%

The normalised results can be summed up into a single indicator. For doing this some weighing of various impacts is performed. In the more advanced versions of the programme the weigthts can be modified by the user. The weights adopted by the Eco indicator 99 method version Europe E/E used in this study were 500 for 'human health', 300 for 'ecosystem quality' and 200 for 'resources', but divided by 1000.

The model

A plastic box has its life time estimated at 3 years, during which it circulates 3*16=48 times between the apple packaging wholesale company, the logistic platform and the supermarket. Therefore a cardboard box counterpart to it, which circulates only once, had to be multiplied 48 times for proper comparison.

The life cycle model for two compared subjects has been defined as in Table 1. The materials and processes are called by the names used by SimaPro which also indicate the database chosen for estimation of the environmental impact. Additional explanations are added in brackets. For proper comparison the cardboard box must have been multiplied 48 times. The packaging foil is used to wrap the cardboard sheets, empty and full boxes in order to hold them together on a pallet.

The databases mainly apply to the West European conditions and therefore represent for us a certain underestimation with regard to the environmental impact, because one can safely assume that much more attention is paid to the environmental issues there than in our country. This remark however does not apply to the fruit wholesale trade company the specific data have been drawn from for this study. This company strictly complies to the EU rules of fruit handling. It is annually audited with regard to the environmental and sanitary behaviour and approved.

Results

The results of the comparison are presented in figures 1 through 8.

Figure 1 displays proportions between impacts of the two types of commercial apple box with respect to various damage categories, the bigger value taken as 100%. The cardboard boxes have bigger environmental impact in every case, though the scores are quite close except for the ozone layer depletion, the respiratory organics emissions and the radiation. The big differences in these impacts are undoubtly due to much bigger transportation needs for cardboard boxes, which when new are transported as new 48 times more than the plastic box which survives for 48 turnovers.

Normalisation applied in Figure 2 means that impacts are measured as a fraction of average impact of the kind, experienced (and caused) by a West European per year. The high scores for fossil fuels extraction and respiratory organics emissions reflect the big transportation needs in apple trading[6].

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[6] It should be recalled that this analysis covers 3 years of a plastic box life and the equivalent of 48 cardboard boxes.

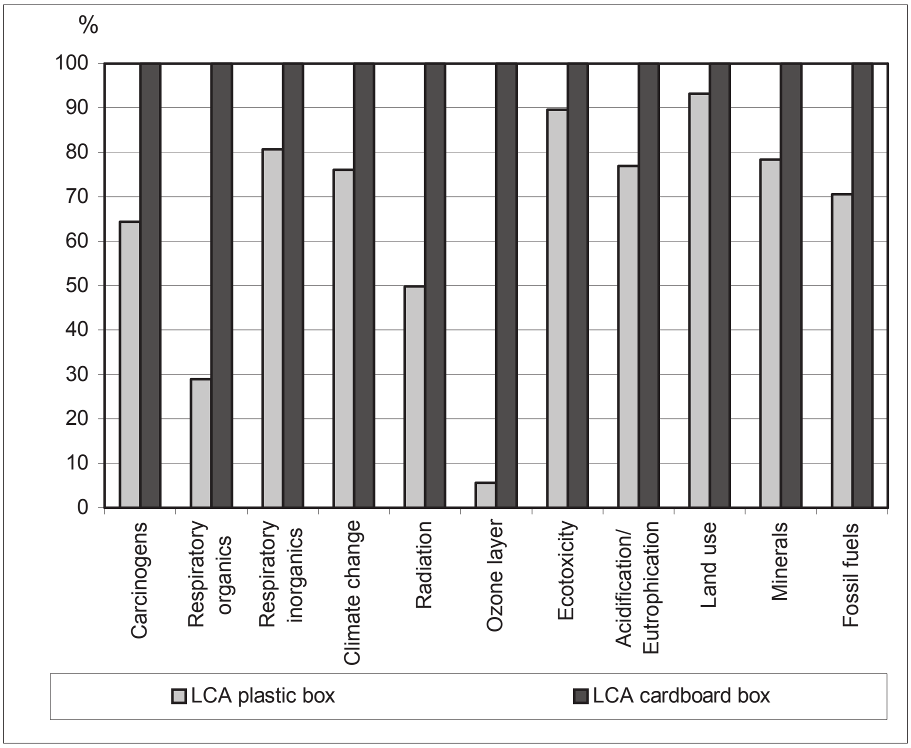

Fig. 1. Comparison per damage category, by summation of individual impacts, the higher impact set equal to 100, Ecoindicator 99 Europe E/E methodology

Weighing the normalised impacts according to the Ecoindicator 99 Europe E/E methodology in Figure 3 has somewhat flattened the relative importance of different impacts and levelled up the scores for the two analysed subjects when compared to Figure 2.

Since they have a bigger impact in each damage category, no wonder the cardboard boxes have it bigger also in each of the endpoint categories. The biggest difference between the two types of boxes in the 'resources' aggregate category arises from a distinct difference in fuel consumption, which in turn makes a major part of the 'resources' aggregate.

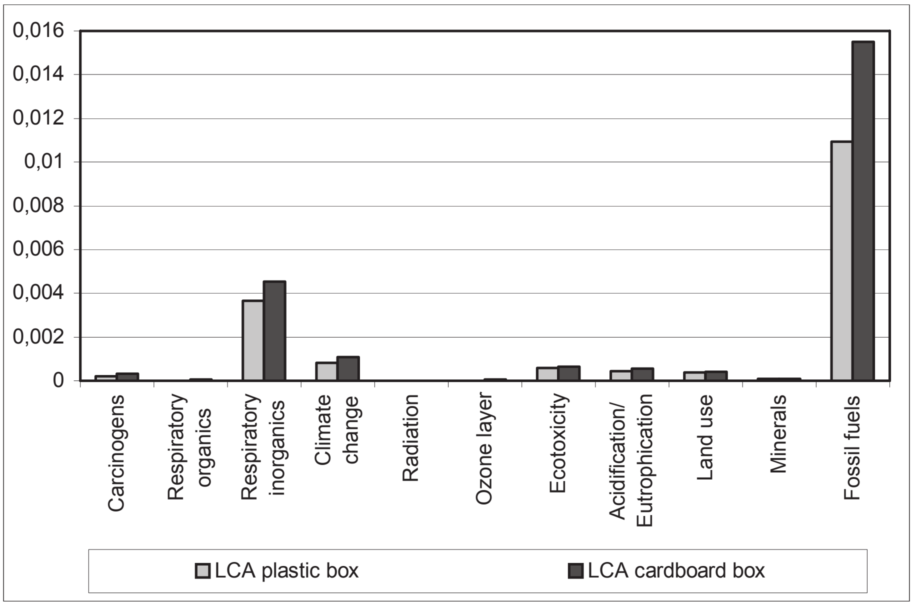

Fig 2. Comparison per impact category, normalisation of individual impacts, Ecoindicator 99 Europe E/E methodology

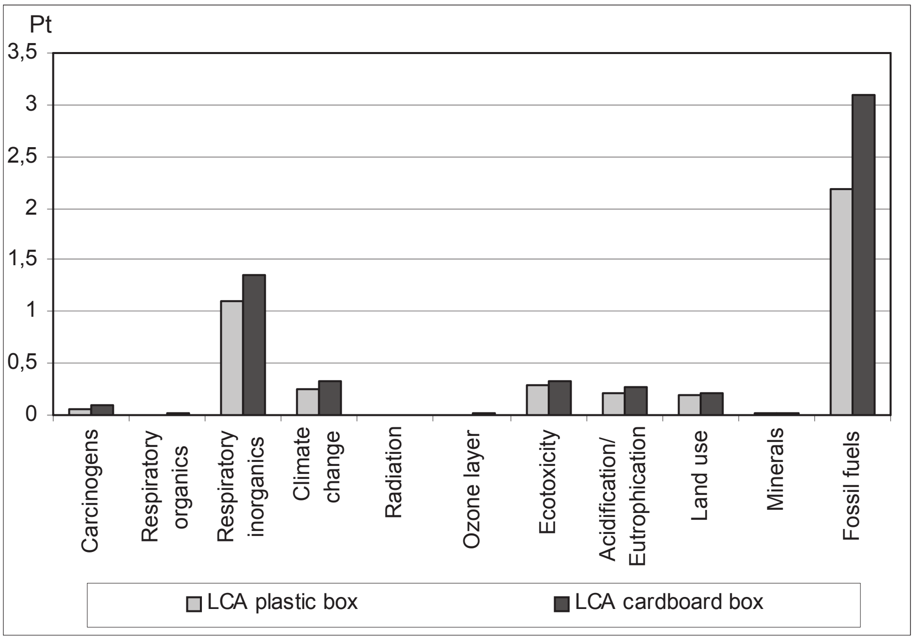

Fig 3. Comparison per impact category after weighing, Ecoindicator 99 Europe E/E methodology

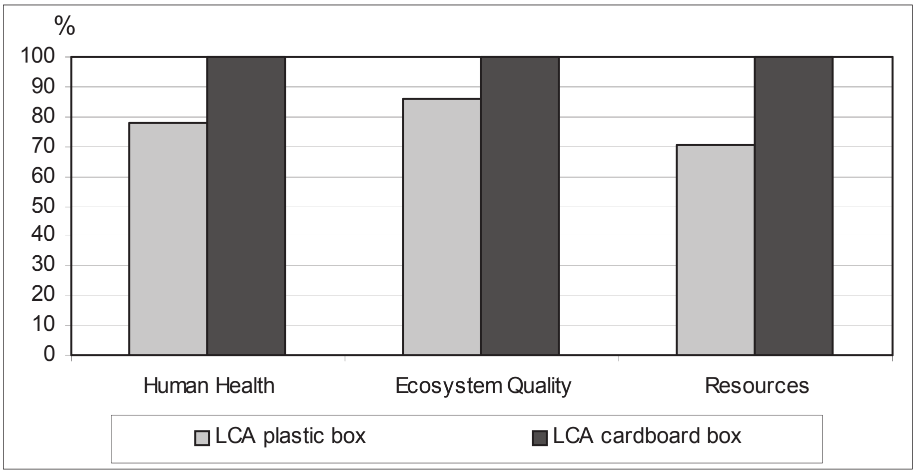

Fig. 4. Comparison per endpoint impact category, by summation of individual impacts, the higher endpoint impact set equal to 100, Ecoindicator 99 Europe E/E methodology

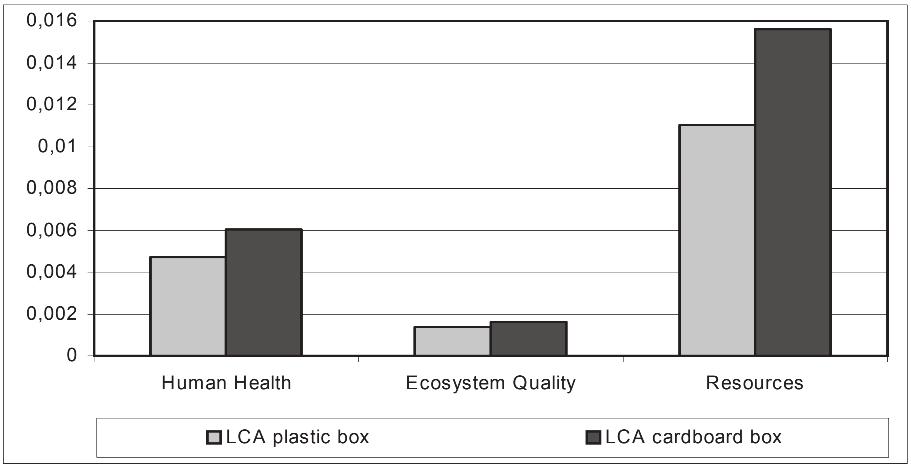

Fig. 5. Endpoint comparison after normalisation, Ecoindicator 99 Europe E/E methodology

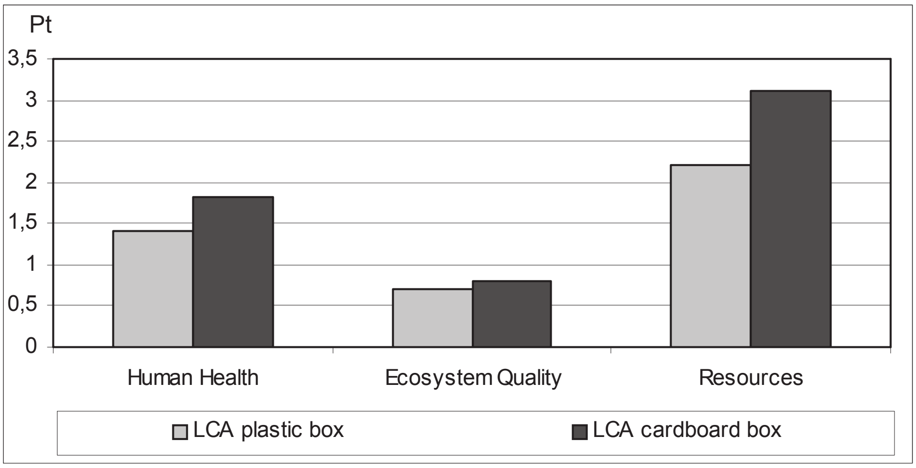

Fig. 6. Endpoint comparison after weighing, Ecoindicator 99 Europe E/E methodology

Resources depletion clearly has the highest relative aggregated impact of the three (Fig. 5) when it is judged after normalisation. The difference between the two types of boxes is also most conspicuous in this case.

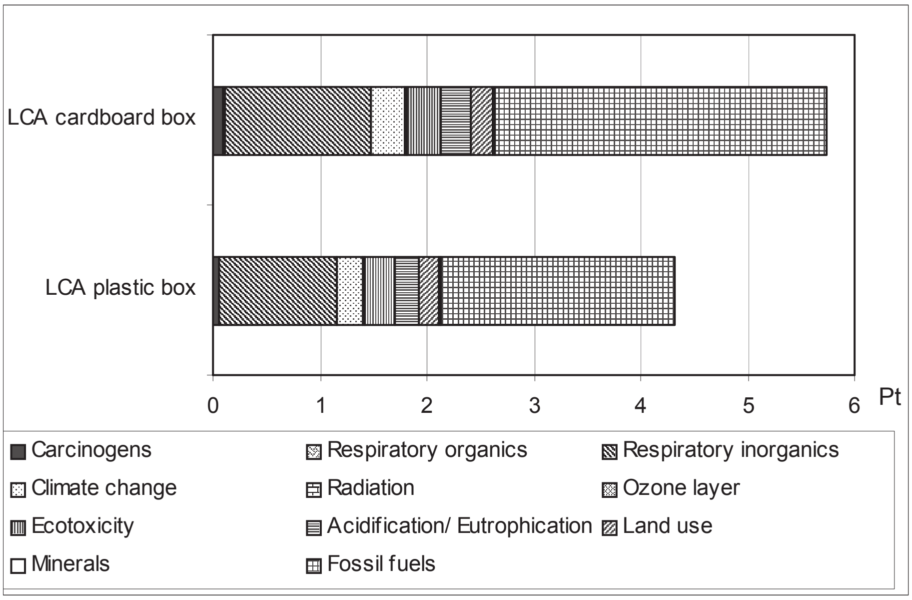

Fig. 7. Single score comparison by impact category, Ecoindicator 99 Europe E/E methodology

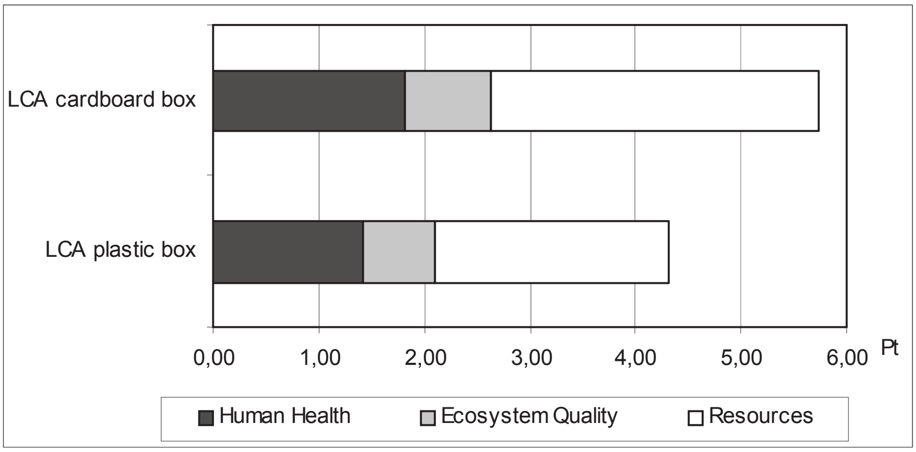

Fig. 8. Single score comparison by endpoint impacts, Ecoindicator 99 Europe E/E methodology

Weighing the impacts, as before, has had an effect of flattening the scores and diminishing the differences between the two subjects. The hierachy among the three aggregate impact categories has stayed untouched.

Single scores (Figures 7 and 8) confirm that a bigger overall environmental impact comes from the cardboard box. It results mainly from a much bigger longevity of a plastic box and the ensuing bigger transportation needs for new cardboard boxes. A plastic box is transported empty from the producer to the logistic chain only once, while a cardboard one 48 times. Though the distance between the punched cardboard sheets (a prefabricated element of a box) producer and the wholesaler in the studied case was much shorter than that between the plastic box producer and the wholesaler (139.3 km and 324.88 km respectively) the repeated cardboard boxes supplying course made the total distance much longer.

As a matter of fact a different location of the suppliers and receivers of deliveries might have given quite different results of resources depletion.

Table 2. Aggregate comparison results, Ecoindicator 99 Europe E/E methodology weighing, points

Model	Plastic box				Cardboard box			
	human health	environmental quality	resources	total	human health	environmental quality	resources	total
Basic run	1.41	0.696	2.21	4.32	1.81	0.808	3.12	5.74
Distances +10%	1.49	0.757	2.32	4.56	1.9	0.868	3.23	6.0
Distances -10%	1.33	0.636	2.1	4.07	1.73	0.747	3.01	5.49
Distances -50%	1.02	3.394	1.66	3.07	1.41	0.506	2.56	4.48

Since the transportation had such a big share in the total impact, a simple trial of a sensitivity analysis has been made. All distances have been either increased or decreased by

10% and, in order to sharply decrease the transportation influence, also decreased by 50%. The decisive influence of the distances to cover are clearly visible in Table 2.

Conclusions

The plastic boxes proved to exert much less environmental impact during their lifetime, mainly due to their much longer longevity. However, the final results depend heavily on distances covered in transportation, which means that different locations of various points in the logistic chain can give much different LCA appraisals. A similar conclusion was drawn by Humbert et al. [2009] when comparing retail packaging of baby food. The transportation processes impact influenced significantly the final result of comparison.

References

Cąderek T. [2008]: Opakowania warzyw i owoców. *Hasło ogrodnicze* 5.
Cąderek T. [2008]: Opakowania - ważny element marketingu. *Hasło ogrodnicze* 5.
Gadowski M. [2005]: Jakość opakowań kartonowych. *Hasło ogrodnicze* 6.
Gadowski M. [2005]: Maszyny do pakowania. *Hasło ogrodnicze* 6.
Humbert S., Rossi V., Margni M., Jolliet O., Loerincik Y. [2009]: Life cycle assessment of two baby food packaging alternatives: glass jars vs. plastic pots. *The International Journal of Life Cycle Assessment*, vol. 14, no. 2, pp. 95-100.
Introduction to LCA with SimaPro. [2008]. PRe product ecology consultants, Amsterdam.
Jąkowski Cz. [2005]: Opakowania dla owoców i warzyw. *Hasło ogrodnicze* 6.
Korzeniowski A., Skrzypek M. [2005]: Ekologistyka zużytych opakowań. ILM, Poznań.
Korzeń Z. [2001]: Ekologistyka. ILM, Poznań.
Śpiewak M. [2008]: Zmiany na rynku opakowań produktów ogrodniczych w Polsce. *Hasło ogrodnicze* 5.
Zarębska J., Graczyk M. [2004]: Analiza komparatywna bilansów ekologicznych dla puszek z białej blachy i aluminium. *Recykling* 11, pp. 26-27.

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