# LCA of new communicative devices: constraints and opportunities

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**ABSTRACT**

In current times, sustainability is being considered on the whole life cycle (life cycle thinking) and supported on three main pillars: Environmental, economic and social. Therefore, these pillars become of rising importance on defining sustainability of packaging.

On the one hand a methodology like life cycle assessment (LCA) provides information about the environmental impacts within the life cycle of a product. On the other hand the methodology of life cycle costing (LCC) allows estimating the economic impact in terms of cost also during the life cycle of the packaging.

Additionally social aspect reaches high relevance in sustainability of a product due to consumer acceptance may drive to the success of product on the market.

In this context, new communicative devices show a new challenge to determine their impact over the environment. They have been introduced during the last decades and, as far as technological developments come up, they represent new challenges to researchers.

One of these devices is relative humidity (RH) indicator. It can be incorporated on packaging to provide information about humidity changes by means of visual colour changes. It is still under development and represents a new opportunity to packaging store control but it also presents new constraints to the currently used end of life treatment.

This paper shows how to evaluate opportunities and constraints in order to estimate the environmental and economic sustainability of new communicative devices, applied specifically to a RH indicator used for red vine tomatoes export. The combination of this type of indicator and tomatoes is only an example.

**Introduction**
Nowadays millions of thousands of perishable goods are moving along the worldwide logistic supply chain. In many cases such goods are transported on boats (containers) covering wide distances from a continent to each other. These are special containers designed to control the climate during transportation and thus avoid product quality decay. However, as result of logistics operations, shrinkage and quality losses for these products can occur. Therefore minimization of shrinkage of perishable goods is an important item in intercontinental trade operations. Communicative devices (i.e.: RH indicators) affixed to packaging can help logistic operators in this challenge, keeping quality of products, saving costs as well as reducing shrinkage.

**RH indicators**
RH indicators are devices composed by two kinds of inks whose colour varies according to the presence of humidity in the atmosphere. If the relative humidity exceeds a certain limit the colour change of the indicator takes place (Figure 1).


Figure. 1. Example of RH indicator [1]

Such indicators can be used in the supply chain management in order to guarantee the quality of products, i.e.: fruit and vegetables, meat, bread, etc.

**The case study**

The case study considered within this paper covers the transport of tomatoes from The Netherlands to the USA in a corrugated board box, which include~~,~~ a relative humidity indicator (RH). The RH indicator represents the new communicative device. A life cycle assessment of both box and RH indicators is made, according to standard ISO 14040. Thus the two components to be studied are:

A) Corrugated board box: The case study considers a corrugated board box that acts as the support material for the communicative device. This box contains tomatoes and it is distributed from The Netherlands to the USA. This will lead to the characterization of the effect of the communicative tag on this scenario.

B) Relative humidity (RH) indicators: As stated above, RH indicators will play an active role in controlling the perishable goods quality more accurately. RH indicators analyzed are based on a two to three layer model [2]. These layers have been nominated in the study as: Layer 1, Layer 2, and Layer 3. These layers are printed over a printing substrate that acts as support surface.

The LCA was carried out separately for corrugated board box and for RH indicator The main reason for that is because of the minimum weight of the RH indicator is not comparable with the overall impact produced by the box.

**Life cycle assessment**

*Goal and scope*

The purpose of this life cycle assessment (LCA) consists of comparing the environmental impact caused by the incorporation of communicative devices in packaging with a packaging without them (RH indicators). The functional unit considered in the study is a corrugated board box with 0.304 kg of weight and 400 x 300 x 145 mm size. This box has an RH indicator incorporated.

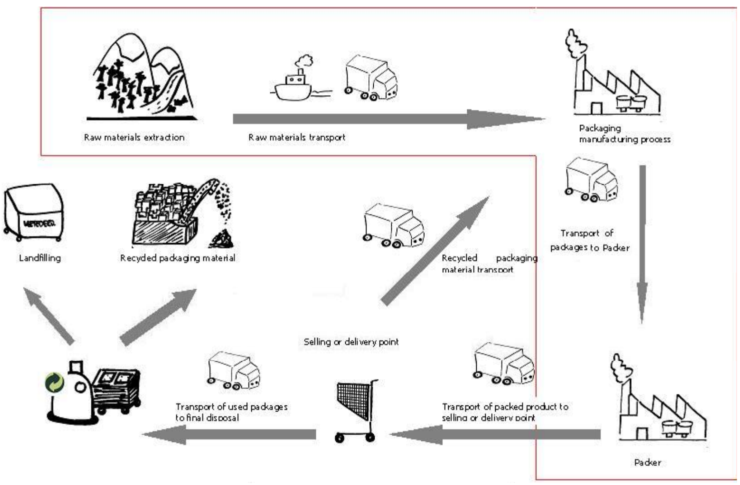



Figure 2: Flow diagram of the packaging life cycle

Two different scenarios are considered: first related to the LCA of the corrugated board box alone, and second the system consisting of corrugated board box and the RH indicator. In the first case, corrugated board box is analyzed from the raw materials extraction until disposal, according to the Figure 2. The whole pathway starts, then, with the raw materials extraction (mostly pulp), followed by the transport to the processing plant. Then it is moved into the packing plant where it is filled with the product. Following, transport and delivery stages are necessary in order to drive the packaging to its destination, the retailers. Finally, empty and used boxes are disposed, burned or recycled. If recycled, the loop starts over.

The use phase of the box has not been considered. This is due to its influence over the global impact is negligible, keeping in mind that distribution processes usually produce the maximum impact. On the other hand, RH indicators are still under development, so that there are processes like end-of-life treatments which are not defined. Therefore, the study includes only the raw materials extraction and assembly, not having information of distribution channels, delivery or use.

In addition for each communicative device used the system to analyzed must be previously defined. The system must include all processes and sub-products necessary to manufacture and use it.

*System boundaries, data quality requirements, geographical and temporal scope*
As stated in Figure 2 only raw material extraction and distribution phases have been analyzed. It is assumed (in a first approach) that these stages have the biggest influence over environmental impact of these devices. Others have not been considered because there are no available data, like use and end-of-life.

It is important to consider the quality of the data used in the study as well as the assumptions made in case of absence of data in order to get a good Life Cycle Assessment. Data sources and assumptions are summarized in Table 1:

Table 1: Data quality requirements (DQI) for the case study LCA

| OBJECT | ASPECT | DATA SOURCE | ASSUMPTIONS |
|---|---|---|---|
| Relative humidity indicator (RH) | Materials | EcoInvent databases | -- |
| | | Literature references [1, 2, 3, 4, 5, 6] | -- |
| | Processing | [2] | -- |
| Corrugated board boxes | Materials | FEFCO 2003 database | -- |
| | | BÜWAL 250 | -- |
| | | ETH-ESU 96 | -- |
| | Processing | FEFCO 2003 database | -- |
| Energy model | Energy consumption | UCPTE model | Specific model for The Netherlands in case of moulding of corrugated board boxes |
| | | BÜWAL 250 | Only for corrugated board manufacturing |
| Transportation model | Road | BÜWAL 250, Literature references [7] | Trucks, trugmaster |
| | Internal transport at warehouses | BÜWAL 250, UCPTE Literature references [7] | Wheelbarrows |
| | Ship | BÜWAL 132 Literature references [7, 8] | Container ship |
| | Palletisation | Literature references [9, 10] | Palletisation model |
| | Containerisation | Literature references [11] | Containerisation model |

In the stages considered for the LCA, raw materials extraction and production are covered at European range, while transportation may include consumption data for North America.

*Impact assessment method selection*
In the study the impact assessment method selector developed by PRé Consultants [12] has been applied being selected the Eco-indicator 99 I/I v 2.1.

It should be taken into account that this study was just a preliminary study without comparison between different existing devices. Therefore, no critical review is carried out.

*Life cycle inventory*

The life cycle inventory was built considering up-to-date information about RH indicators as well as corrugated board boxes typically used for tomatoes storage and transport. Due to the scope of this study, Table 2 summarizes all the life cycle invetory used to carry out the life cycle assessment.

Table 2: Life cycle inventory

| Product | Component | Raw & ancillary materials | Energy | Transport | Size & weight |
|---|---|---|---|---|---|
| Corrugated board box | Kraftliner sheet | Kraftliner (22% recycled fibre) | Included in raw and and ancillary materials | USA/Scandinavia: maritime & road 40 t diesel truck (4471 km + 65 km) | |
| | Wellenstoff sheet | Wellenstoff (100% recycled fibre) | | The Netherlands: Road 40 t diesel truck (25 km) | |
| | Corrugated board box | 63.15% Kraftliner + 35.39% Wellenstoff + 1,45% glue | Corrugated board sheet manufacturing + assembly at greenhouses | Supply to greenhouses: The Netherlands: Road 40 t diesel truck (75 km)<br>Internal transport at greenhouses | 0.304 kg of weight and 400 x 300 x 145 mm size |
| Transport of vine tomatoes from The Netherlands to USA | | | | Greenhouses/Port Rotterdam (NL): Road 40 t diesel truck (65 km) | |
| | | | | Port Rotterdam (NL)/Port New York (USA): Maritime (4471 km) | |
| RH indicator | Layer 1 | Confidential | | Negligigle | 100 µg of weight and 1 $cm^2$ size |
| | Layer 2 | | | | |
| | Layer 3 | | | | |
| | Printing substrate | | Printing of the indicator | | |

*Impact assessment*

In this section the results of the LCA for the functional unit selected are showed (Figure 3), comparing such systems that comprise a RH device and those which the RH device is not used.

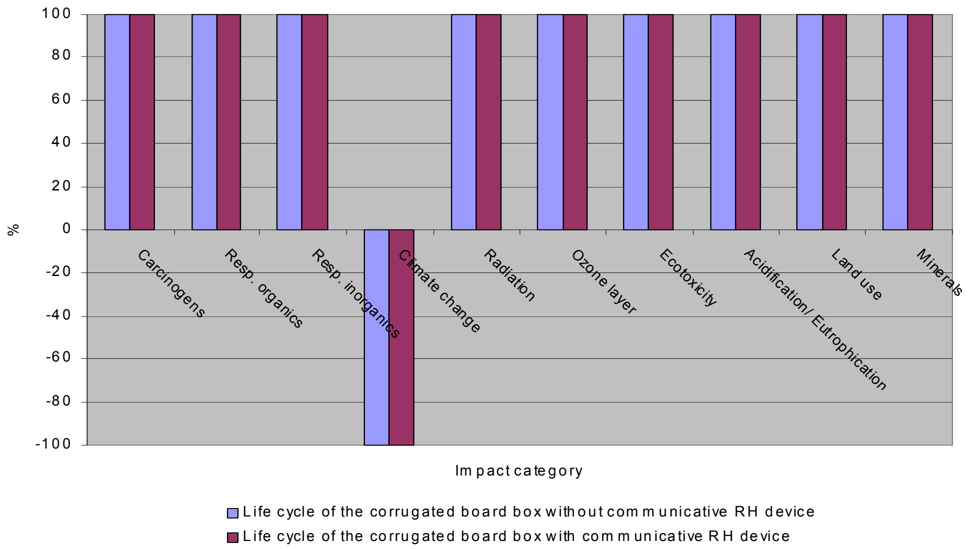
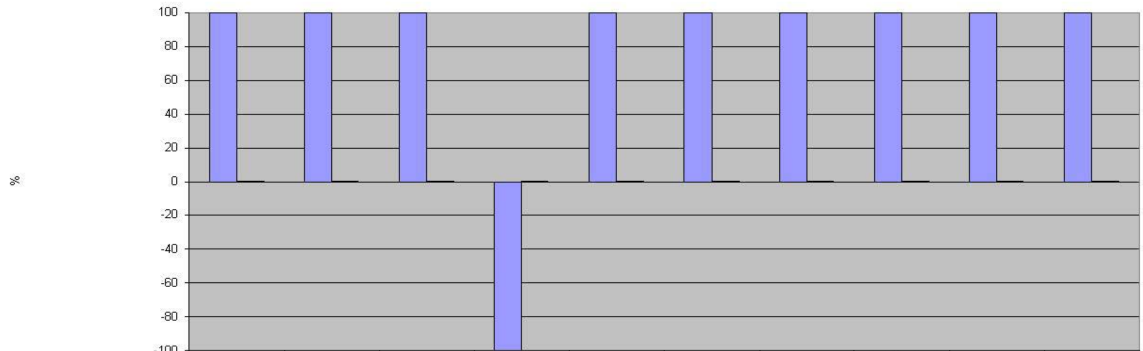



Figure 3: Characterisation of the life cycle for corrugated board boxes with and without communicative RH indicator.

Figures 3 and 4 demostrates that the impact caused by the RH device is negligible compared to the environmental impact of the box. Such affirmation makes sense since the corrugated board box weigths 304 g opposite to $10^{-4}$ g of the RH device. As result of that the environmental impact made by corrugated board boxes with and without communicative packaging devices is the same.




| | Carcinogens | Resp. organics | Resp. inorganics | Climate change | Radiation | Ozone layer | Ecotoxicity | Acidification/ Eutrophication | Land use | Minerals |
|---|---|---|---|---|---|---|---|---|---|---|
| Corrugated board box | 100 | 100 | 100 | -100 | 100 | 100 | 100 | 100 | 100 | 100 |
| RH communicative device | 5,51985E-05 | 5,70492E-05 | 7,76102E-05 | 6,90698E-05 | 1,93265E-05 | 6,53922E-06 | 3,75439E-05 | 2,00877E-05 | 7,77778E-05 | 7,18519E-05 |

Figure 4: Characterisation comparison of the life cycle for corrugated board boxes without communicative RH indicator and RH communicative device.

Furthermore, results on LCA analysis applied to RH indicator showed that printing processes and the printing substrate have an higher significance over the life cycle of such device (Figure 5).

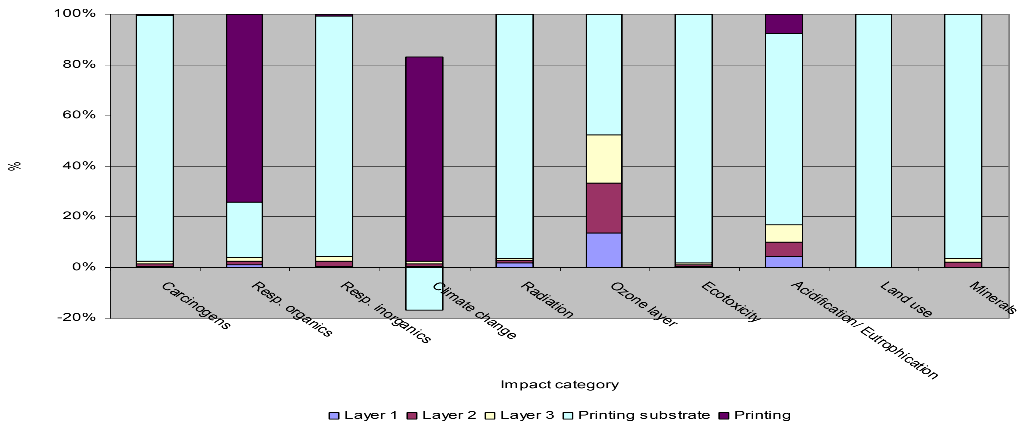



Figure 5: Characterisation of the life cycle of communicative RH indicator.

**Life cycle costing (LCC): an overview**

A preliminary LCC analysis was also carried out in order to introduce a guideline which provides an idea about the costs of the life cycle of such device. The main objective of LCC study is to assess and compare costs associated to the life cycle of the corrugated board box with and without communicative packaging device affixed.

In accordance with the already mentioned assumptions in the Life Cycle Assessment, the product is corrugated board box containing red vine tomatoes produced at a greenhouse in Delft (The Netherlands). These tomatoes are shipped to the USA following the model proposed by Kreft [13]. In this LCC analysis cost of raw materials, energy consumption, machinery and facilities repayment, salaries, indirect costs, etc., where included in the acquisition cost.

Results on LCC demonstrate that the cost of such RH indicators is very small in comparison with costs of transport and corrugated board box acquisition, having only 0.32% of the total life cycle cost. Thus, the influence of a RH communicative device over the cost of packaging is negligible in practice. Nevertheless it is possible to save costs as a result of shrinkage reduction with these new communicative devices [14]. However this costs (benefits) have not been considered in this preliminary study. So that the total LCC result could even decrease.

## Conclusions

In accordance with LCA and LCC results obtained, some points may be remarked:

(1) The impact of either corrugated board box and the RH indicator are not comparable.
(2) The corrugated board box, contributes to positive impact over the climate change, as result of $CO_2$ drain effect observed in forest growing and harvesting to produce pulp for paper.
(3) Processes with most impacts are corrugated board production and use followed at a distance by transportation processes. On the contrary the influence of box assembly processes is negligible.
(4) On considering RH indicator the most important impact is due to printing substrate production and use, contributing positively to climate change.
(5) Printing processes for RH indicator have a high significance over the climate change and resp. inorg categories, mainly due to electricity consumption of printing methods.
(6) The influence of a RH communicative device over the cost of packaging is negligible in practice. Specifically, in the selected case, only 0.32% of the total cost of the packaging system for vine tomatoes to exports is due to RH communicative device. Nevertheless costs can be saved as a result of the use of such devices, since less shrinkage over the product occurs.

Please note that the above mentioned results do represent just an approach to the real environmental behaviour, as RH indicators are in its early stage of development. It is also expected that development of the life cycle inventory of other communicative devices such as time-temperature loggers, intelligent inks, RFID tags, organic electronic displays, anti-counterfeiting devices will allow to compare the LCA of such devices. As result of that, the LCA will be a quantitative tool to take decisions for communicative packaging devices solutions. Manufacturers, packaging & logistic companies, consumers and researchers will be able to use this information and decide which are the most suitable solutions for packaging systems, contributing to quality, safety and sustainable packaging. Moreover, results from the LCC will provide feasible information to consumers on purchase decisions, allowing them to assess if communicative packaging devices represent advantages or disadvantages against economic cost of a product, even this challenge is already at a preliminary stage.

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