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Life cycle assessment applied to egg packaging made from polystyrene and recycled paper

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Abstract

In the present study, the application of life cycle assessment (LCA) for the comparison of two egg packages, from polystyrene and recycled paper, is presented. The input and output streams of mass and energy are examined and the environmental impacts associated with the two systems are analyzed. The application of LCA by using EcoIndicator 95 has made possible the comparison of the environmental impacts of two egg packages. The results of this LCA study are discussed and reveal that the PS packages contribute more to acidification potential, winter and summer smog, while recycled paper egg packages contribute more to heavy metal and carcinogenic substances impact. Nevertheless, it seems that paper eggcups have less environmental impact than the polystyrene ones with the assumption that the accuracy of the results is confined by the credibility of European databases used for primary data.

Keywords: LCA; Egg packages; Recycled paper; Polystyrene

1. Introduction

Industry is realizing that the impact their products have on the environment does not start and end with the manufacture of the product. The impact a product has on the world starts with the design and ends at the ultimate disposal of the product after its useful life. Therefore, it is important to have not only a means of determining the environmental impacts of the manufacturing process, but what impact the product will have on the environment and also to quantify these impacts. In this aspect, the concept of a life cycle means that the inputs to the 'cycle' (energy, materials, etc.) and outputs (products, energy, waste materials, etc.) are evaluated for each step of a product life or process [8,10,24,27,30].

During and after the Second World War, rapid expansion, especially, in the offer of the prepackaged food to the final consumer was dictated by reasons such as the conservation of the food's freshness and quality, consumer's attraction, storage and distribution convenience etc. However, planning the package of a product is a serious and complicated procedure, since different requirements, often contradictory to each other, should be taken into account. Protection is on the top of these requirements. When a package fails, then the results could be costly and dangerous. The right planning of the packaging system and its production procedure can bring energy and raw material saving along with less environmental impacts, [20].

Polystyrene, as a package material, is used in the manufacture of plastic cups for dairy products such as ice cream or yogurt cups, cups for marmalade, dry foods and other food products. Polystyrene is also used in foamed or expanded form for the production of eggcups and trays, which are used in the package of meat, fish or vegetables. It is also widely used as a package material in home delivery restaurants, because of the good heat-insulating properties [3,4,11,16,20,29]. According to the US Environmental Protection Energy (EPA), about 0.6% of solid wastes in the USA is polystyrene packaging—including both food service packaging (cups, plates, bowls, trays, clamshells, meat trays, egg cartons, yogurt and cottage cheese containers and

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Nomenclature

AOXs	Chlorinated organic compounds
AP	Acidification potential
B&G	Bureau Brand-en Grondstoffen [Office of Fuels and Raw Materials]
B[a]p	Benzo[a]pyrene
BOD_5	Biological oxygen demand
B–T–X	Benzene–tolene–xylenes
Buwal	Bundesamt für Umwelt, Wald und Landschaft [Swiss Federal Ministry for Environment, Forestry and Agriculture]
CFCs	Chlorofluorocarbons
CML	Centrum voor Milieukunde Leiden [Centre for Environmental Science, Leiden]
CO2	Carbon dioxide
COD	Chemical oxygen demand
CS	Carcinogenic substances
DAF	Dissolved air flotation
EPA	Environmental Protection Agency
EPS	Environmental Priority System, developed by the IVL in Sweden and used by Volvo Sweden.
GNP	Greenhouse warming potential
HM	Heavy metals
LCA	Life cycle asessment
LCANET	Strategic Life-Cycle Assessment European Network
NP	Nutrient enrichment
ODP	Ozone depletion potential
PAHs	Polycyclic aromatic hydrocarbons
PC	Polycarbonate
POCP	Photochemical ozone creation potential
PS	Polystyrene
RIVM	Rijksinstituut voor Volksgezondheid en Milieuhygiëne [National Institute for Public Health and Environmental Hygiene]
SETAC	Society of Environmental Toxicology and Chemistry
SPM	Suspended particle matter
SS	Summer smog
TNO	Nederlandse Organisatie voor Toegepast Wetenschappelijk Onderzoek [Dutch Organisation for Applied Scientific Research]
TSSs	Total suspended solids
VOC	Volatile organic compounds
VROM	(Ministerie van) Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer [(Ministry of) Housing, Spacial Planning a Environment]
WS	Winter smog

cutlery) and protective packaging (shaped and pieces used to ship electronic goods and loose fill 'peanuts'). Polystyrene food packaging is considered as sanitary and protects food against bacteria and spoilage. However, concerns have been expressed about styrene penetration into the edible part of the egg [15,16].

To the contrary, paper does not protect from moisture, spoilage and can damage its shape as well. Recycled paper for packaging is a lightweight material, but its wet strength is so low that it cannot qualify for many food-packaging applications unless it is reinforced and water-proofed [21]. Plastics' ability to provide light weighted packages is probably the largest single driving force behind the penetration of plastics in the market for food container [16]. Paper recycling industry quotes for typical energy savings from producing recycled paper range from about 28 to 70% [25]. The amount of energy saved will depend on paper grade, processing, mill operation and proximity to a waste paper source and markets. A key issue in paper recycling is the impact of energy use in manufacturing, which is usually derived from oil or coal. The benefit of paper recycling is generally assumed to be desirable and necessary and waste management policy in many countries considers, in its hierarchy, reuse and recycling to be preferable for energy recovery, and superior to landfill. The disposal and recycling of the already recycled paper in the form of paper egg packages (degree of recycling), which depends on fiber quality, is another key research issue in paper recycling [19]. Collection of waste paper requires energy in the form of diesel fuel and electricity and emissions have to be taken into consideration [25]. Concerns about disposal of plastic and paper packages have led to two different societal trends: the first one concerning plastics is that they occupy so much space in landfills that they should be disposed of in some other way, the second is about biodegradability of paper in contrast with plastics. It seems that Europeans are mainly concerned with the potential health hazard of dioxins formed when plastics are burned [2,15,20,29].

LCA and its application for comparative assessment of products, although it has not reached its full potential in environmental decision-making, can be considered as a useful tool for many applications, ranging from product development, through eco-labeling, to environmental policy and priority setting and to comparative environmental assessment, as is the case of the present study. In many cases LCA has already made a clear contribution in these areas. Some of the barriers for its broader applicability are: methodological gaps, including software and databases, confusion concerning the applicability of LCA (where and under what conditions), omitted involvement of stakeholders and the fact that the tool is often regarded as too complicated [7,9,30].

The purpose of this study is to evaluate, via the tool of LCA, the environmental burdens associated with the egg packaging products, polystyrene and recycled paper, by identifying and quantifying energy and material uses and releases; a second objective is to assess their impacts on the environment throughout the entire life of the product including extracting and processing raw materials, manufacturing, transportation and distribution, use, re-use, maintenance, recycling and final disposal. The expectation is to have a first approach by using the LCA tool, already knowing that the role of LCA is aiding and supplementary; the final decision is political [5,6,12,13].

2. Methodology

2.1. Boundary of the system

One of the most important elements in a life cycle study is a clear statement of the specification of the system's function and, derived from that, the functional unit for the study [8,26,27]. In comparative studies, it is essential that the systems be compared on the basis of equivalent function. In the present study, the functional unit was considered to be the quantity of 300 000 eggs which need 50 000 eggcups of six eggs each, as packages, in order to be supplied to the market. Closed eggcups have been considered, containing six eggs each. The weight of a PS eggcup and recycled paper one was measured and found to be 15 and 22 g, respectively. Fifty thousand eggcups require for their production a quantity of 0.75 tn of PS and 1.1 tn recycled paper, respectively.

The Life Cycle stages evaluated in this study do not include the transportation, distribution and utilization stages of the product of both systems, although transportation costs might be different, because of difficulties met in the collection of data. It is assumed that both egg-packaged products are disposed of in landfills even thought the waste treatment stage was taken into account because of the different behavior of the two materials in the landfill. The capital equipment and minor ancillary materials have been excluded from the life cycle inventory although their estimation could be useful for the assessment [19,8]. Also, the depicting of mechanical injures and maintenance has not been considered [7].

The two systems studied are geographically localized in Greece. Data concerning polystyrene manufacturing are derived from other European Countries and not from Greece, since PS is imported to Greece. The specification of the geographical localization is also important for the utilization of a set of homogenous parameters for the energy production model. Due to lack of data, in the present study, an energy model that represents European situation has been used [28].

2.2. Data collection

A LCA starts with a systematic inventory, which includes and quantifies material and energy use and wastes throughout the product life cycle. For each egg-package the following environmental impact indicators were calculated [25]:

- Energy demands: electric power and heat;
- Non-renewable fuel demand: coals, fuels, natural gas;
- Raw materials demands: common raw materials;
- Consumption of primary energy sources: coal seam, crude oil, hydropower, nuclear fuel, crude natural gas, and biomass of trees;
- Air emissions: CH_4, SO_2, NO_x, CO and CO_2;
- Water emissions: total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), and chlorinated organic compounds (AOXs);
- Solid emissions: municipal wastes from life cycle and in landfills.

Because of lack of data, in the present study, an energy model that represents the European situation has been used [28]. Concerning the energy consumption the following components have been considered:

1. The energy demands for the production of the raw

materials in the case of PS have been borrowed from the data bases BUWAL 250 (1996) and ETH Energy version 2 (1994), existed in SIMAPRO 4.0, [28].
2. The energy demands for the transportation of raw materials to Greece have been calculated by taking into account that: the raw materials are transported from countries of Europe, a mean distance of 3000 miles, and that the marine transportation cost is 0.75 MJ/tn-mile (this cost component has been estimated based on data of Koumoutsos et al. [18]).
3. The energy demands for paper production have been taken from Greek Industry [22].
4. The energy demands for transportation of empty eggcups to egg producers and afterwards transportation of the products to the consumers and the relative cost has been estimated by taking in account road transportation and that trucks capacity is of 28 tn (22 MJ/truck-km) [18].
5. Quantities of gas emissions and liquid and solid wastes have been borrowed from BUWAL 250 and ETH Energy version 2, [28].
6. Electrical energy in Greece comes from three different sources: lignite, fuel, and hydropower energy. The contributions of them are 50, 20 and 30%, respectively.

As far as polystyrene production is concerned, data have been acquired from the software tool SIMAPRO 4.0 (demo version) databases, developed by Pré consultants [28] and consequently these data are subjected to the uncertainty of open data. Data concerning recycled paper were obtained from the Greek company 'Hercules Packaging Company S.A', a subsidiary of Greek cement company A.G.E.T HERACLES, [21]. Hercules Packaging Company S.A is a firm founded in 1979, employs 19 people and is located in the Central Macedonia region. The company manufactures packages from paper pulp: egg cups and paper trays. The raw materials used are derived from collected waste newspapers and cardboards from the city of Thessaloniki. The products of the company are distributed in the Greek market and are exported in Europe and Mediterranean countries. A packaging company of PS Ovoplast Company S.A in Thessaloniki has provided data of energy demand for PS reforming to packaging materials, [23]. Data for the waste treatment stage, such as emissions of the paper biodegradability, are based on the study carried out by Hunt [14].

2.3. *Impact Assessment*

The Impact Assessment in LCA consists of the following three steps; classification- characterization; normalization; and evaluation [8]. In the present study the Eco-Indicator'95 method has been used for the Impact Assessment step [26], because it was for us the more available method when the study started. The Eco-Indicator'95, a weighting method for environmental effects that damage ecosystems or human health on a European scale, was developed under the Dutch NOH program by Pré consultants in a joint project with Philips Consumer Electronics, NedCar (Volvo/Mitsubishi), Océ Copiers, Schuurink, University of Leiden, (CML), Technical University of Delft (TU-Delft), TNO Product Center, Center for Energy Conservation and Environmental Technology Delft, University of Amsterdam (IDES, Environmental Research) and Ministry of Housing, Spatial Planning and the Environment (VROM).

2.3.1. *Classification and characterization*

Classification is the step in which the data from the inventory analysis are grouped together into a number of impact categories. This grouping is done in such a way that one entry from the inventory table may well be included in more than one category (e.g. NO_x having both an acidifying and an eutrophication impact) [8]. The impact categories considered in the present study are reported in Table 1 and in Fig. 1. The substances are aggregated within each category to produce an impact score. It is not sufficient just to add up the quantities of substances involved without applying weightings. Some substances may have a more intense impact than others. This problem is dealt with by applying weighting factors to the different substances. This step is referred to as the characterization step [8,26–28].

2.3.2. *Normalization*

A further development of the characterization step is to normalize the aggregated data per impact category in relation to the actual magnitude of the impacts within this category in some given area. The reason for doing this is to increase the comparability of the data from the different impact categories and thus provide a basis for the next step, the evaluation [8]. Therefore, each impact calculated for the life cycle of a product is benchmarked against the known total effect for this impact category. For example, the Eco-indicator'95 is normalized with the impacts caused by the average European during a year

Table 1
Environmental impact categories: normalization coefficients, evaluation and weighing factors

Impact category	Normalization coefficients	Weighting factor
GWP (kg CO_2 eq.)	7.65×10^{-5}	2.5
ODP (kg CFC_{11} eq.)	1.24	100
AP (kg SO_2 eq.)	8.88×10^{-3}	10
NP (kg PO_4^{3-} eq.)	2.62×10^{-2}	5
SS POCP(kg C_2H_4 eq.)	5.07×10^{-2}	2.5
WS SPM (kg of SO_2 and SPM eq.)	1.06×10^{-2}	5
CS (kg B(a)p eq.)	106	10
HMs (kg Pb eq.)	17.8	5

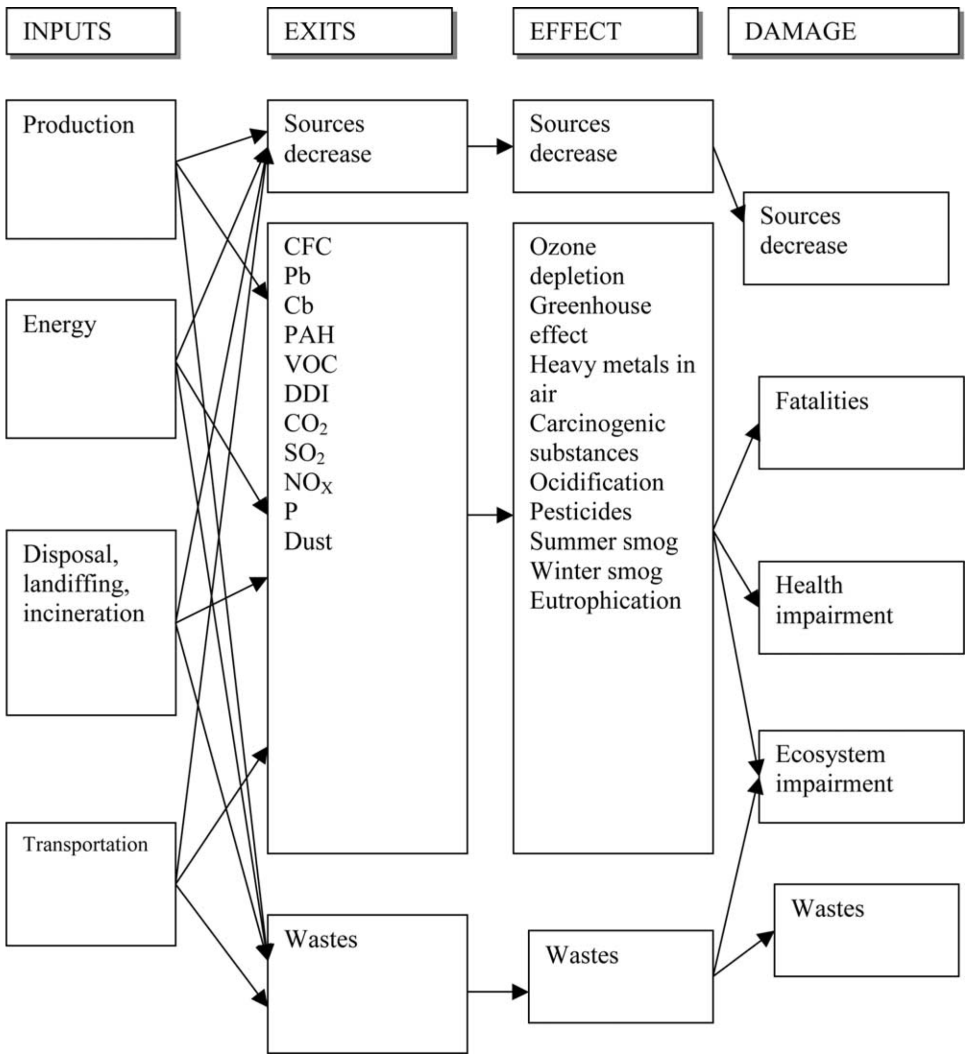


Fig. 1. Schematic representation of environmental impacts.

[26]. Of course it is possible to choose another basis for normalization. By normalization the relative contribution from the material production to each already existing environmental impact category can be estimated. The normalization and other coefficients used in this study are reported in Table 1.

2.3.3. Evaluation

The normalization reveals which effects are larger or smaller in relative terms. Evaluation is the step in which the contributions from the different specific impact categories are weighted so that they can be compared among themselves. The importance of the impact categories in relation to each other is a value-bound procedure based on assessment of the relative environmental harm. This assessment therefore reflects social values and preferences [8]. In the evaluation phase the normalized impact scores are multiplied by a weighting factor representing the relative importance of the effect.

In the Eco-indicator'95 method, [26], the distance-to-target principle is used to calculate evaluation values. The basic assumption is that the seriousness of an impact can be judged by the difference between current and target levels. The target level is derived from real environmental data for Europe (excluding the former USSR), compiled by the RIVM. The targets are set according to the following criteria:

- At target level the effect will cause 1 excess death per million per year.
- At target level the effect will disrupt less than 5% of the ecosystem in Europe.
- At target level the occurrence of smog periods is extremely unlikely.

3. Description of the processes

3.1. Production of polystyrene egg cups

The process flow-chart of polystyrene egg cup production is illustrated in Fig. 2, [17].

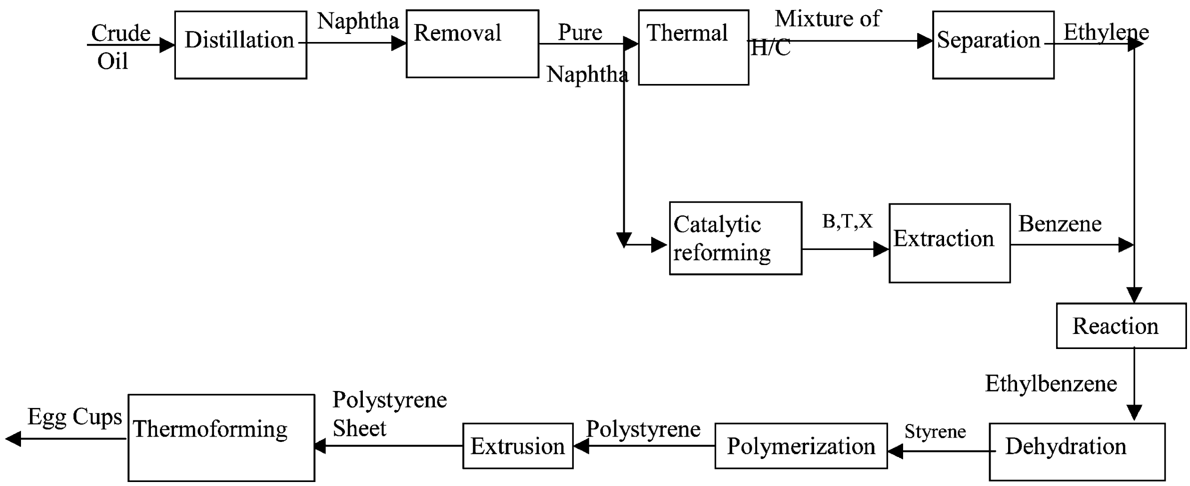


Fig. 2. Process flow-chart for the production of polystyrene egg cups.

3.1.1. Ethylene production

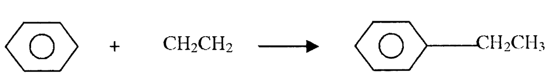
Distillation of crude oil leads to the production of the naphtha side fraction, which then is treated with hydrogen in the desulfurization unit for the removal of existed sulfur, hydrogen and nitrogen. Then the fraction is treated in the thermal cracking unit where heavy hydrocarbons is cracked into lighter alkane and alkenes molecules. Eventually ethylene is obtained from various separation processes.

3.1.2. Benzene production

The naphtha fraction, produced by the distillation of crude oil, is treated with hydrogen in the desulfurization unit for the removal of existed sulfur, hydrogen and nitrogen. The mixture is mixed with hydrogen, is preheated at 495–525°C and 25–35 atm and then is fed to the catalytic reforming reactor (Pt–Al catalyst). The product of the previous stage contains hydrogen in excess, benzene, toluene and xylene (‘B–T–X’ mixture). Benzene is recovered from the mixture via extraction.

3.1.3. Styrene production

Styrene is manufactured by reacting benzene with ethylene. The reaction takes place in two stages, via formation of ethyl benzene over a synthetic zeolite catalyst.



The dehydrogenation of the ethyl benzene to styrene takes place on a promoted iron oxide-potassium oxide catalyst in a fixed bad reactor at the 550–680°C temperature range, in the presence of steam.

3.1.4. Polymerization of styrene

Free-radical polymerization of styrene systems, primarily in solution, is used commercially in the manufacture of polystyrene.

3.1.5. Extrusion

Extrusion of polystyrene is one of the most convenient and least expensive fabrication methods, particularly for obtaining sheets.

3.1.6. Thermoforming

The polymer sheet is heated above its glass-transition temperature so that it can be formed into the final desirable shape of the eggcup.

3.2. Production of recycled paper egg cups

Unlike polystyrene case, the production sequence of the recycled paper has not been traced back to the extraction of raw materials from the earth. Wastepaper, newspaper and cardboard specifically, are regarded as the raw materials used for the production of the eggcups in this case [21]. The process for the production of recycled paper eggcup is illustrated in Fig. 3.

3.2.1. Pulping

The first of the recycling process is pulping. Pulping disintegrates paper into individual fibers dispersed in water. The process described in the present study does not involve ink detachment from cellulose fibers during pulping. Mild pulping conditions are preferable to preserve stickiness, as relatively large particles permit their later removal by screens and mechanical cleaners. For example, wax is a common contaminant in mills recycling old corrugated containers. Pulping at temperatures less than 12°F keeps the wax from melting, making it

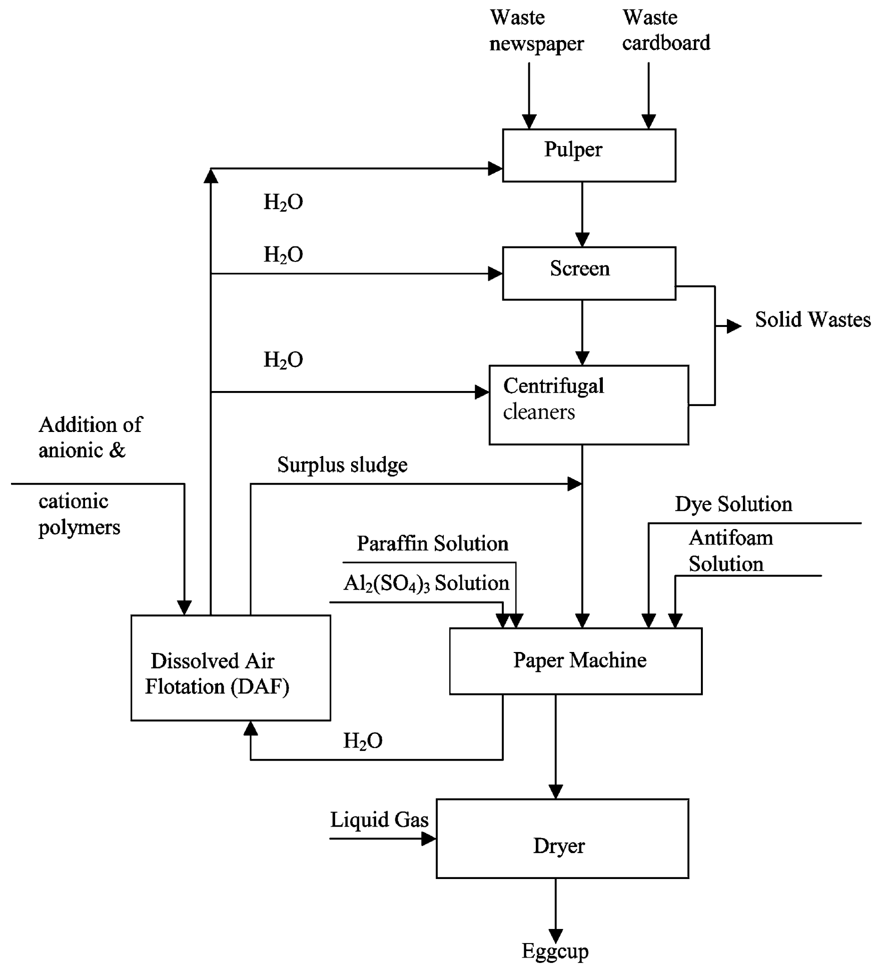


Fig. 3. Process flow-chart for the production of recycled paper egg cups.

easier to remove using fine screens and mechanical cleaners. Another technique to reduce the problems caused by sticker is to use additives to reduce the tackiness of these particles. These additives are added either in the pulp or in the paper machine.

3.2.2. Screening and cleaning

The objective of both screening and cleaning is the removal of non-fibrous contaminants with minimal loses of useful fibber.

3.2.3. Pulp formation into the final product

Pulp formation is taken place in the paper machine where is added $Al_2(SO_4)_3$, antifoam, paraffin and dye solution.

3.2.4. Drying

The removal of the humidity is taken place in indirect rotary dryer.

3.2.5. Water clarification

Process water needs to be clarified as it contains different dissolved chemicals and suspended solids. The water clarification is implemented through dissolved air flotation process (DAF).

4. Results

The results of the LCA procedure applied to both systems are presented in this section. These results can be used for determining which of the two products has lower environmental impacts. Table 2 presents the raw materials needed for the production of both packages. Table 3 depicts the energy requirements for both packages, during their life cycle and Table 4 shows the gas, liquid and solid wastes produced during the life cycle of both packages. Fig. 4 shows the environmental impacts of each package and makes their comparative assessment. The relative contribution from the polystyrene and recycled paper eggcup to each already existing environmental impact in Europe is illustrated in Fig. 4.

However, no final judgments can be made as not all impacts are considered to be of equal importance. It is necessary, therefore, to set a hierarchy of relative importance of the different impacts. After the characterization

Table 2
Comparative presentation of raw materials for the production of eggcups from polystyrene and recycled paper. Calculation basis 300 000 eggs; 50 000 eggcups; 1.1 tn recycled paper, 0.75 tn PS

Raw materials	Eggcups packages	
	Polystyrene	Recycled paper
Fuel	718 m^3	358 m^3
Natural gas	715 m^3	18.5 m^3
Waste paper	—	1500 kg
Iron mines	0.45 kg	—
$CaCO_3$	0.22 kg	—
Bauxite	1.6 kg	—
Mine salt	12 kg	—
$Al_2(SO_4)_3$•$14H_2O$		315 kg
Wax (emulsion)	—	20 kg
Dye	—	0–0.8 kg
Anti foaming	—	0.4 kg
Polyelectrolyte	—	0.3 kg

Table 3
Comparative presentation of energy consumption for the production of eggcups from polystyrene and recycled paper. Calculation basis 300'000 eggs; 50'000 eggcups; 1.1 tn recycled paper, 0.75 tn PS

Energy feedstock	Eggcups packages	
	Polystyrene	Recycled paper
Fuel	570.5 kg (26 243 MJ)	358 kg (16 468 MJ)
Natural gas	535 m^3 (29 746 MJ)	18.5m^3 (1029 MJ)
Lignite	1102 kg (13 224 MJ)	596 kg (7152 MJ)
Coal	40 kg (1400 MJ)	4.4 kg (154 MJ)
Hydro electrical energy	685 MJ	285 MJ
Diesel (container ship)	2250 MJ	
Diesel (truck)	11 000 MJ	13 200 MJ

step for the eggcup, in order to gain a better understanding of the relative size of an impact, a normalization step is required. The characterized impact scores are multiplied by the normalization coefficients. In the evaluation phase the normalized effect scores were multiplied by a weighting factor, representing the relative importance of the impact category. The length of the columns actually represents the seriousness of the impacts (Fig. 4). After evaluation it becomes clear that the polystyrene eggcup throughout its life cycle contributes mainly to the following environmental impact categories: Greenhouse effect (GWP), Acidification (AP), Winter smog (WS) and Summer smog (SS).

Concerning the recycled paper eggcups, as can be seen from Fig. 4, they contribute mainly to the following environmental impact categories: Heavy metals (HM) and Winter smog (WS).

Concerning the raw materials needed for the production of both packages, no direct comparison can be made since they need different raw materials (Table 2). The comparison of energy demands of the two packages is presented in Table 3. It can be concluded that PS eggcups require more energy that the recycled paper ones. From Table 4 we can notice that the main air emission for both packages is CO_2. During PS eggcups life cycle more air and liquid waste are produced compared to that of paper eggcups with the exception of benzene, Zn, B[a]P, N-tot, Cl^-, Pb, Cu, Mo, Ni, Hg, phosphate, dissolved inorganics, which are presented in a higher degree in the case of recycled paper eggcups. In contrast, more solid wastes are produced during the life cycle of paper eggcups than those of PS.

5. Discussion and environmental comparison of the two processes

Evaluation results for the two products compared in the present study are illustrated in Fig. 4. The results show clearly that the polystyrene eggcup during its life cycle, has a higher environmental impact than the recycled paper one, i.e. the polystyrene eggcup is more polluting than the recycled paper one. The length of the columns actually represents the seriousness of the impact. Especially, polystyrene eggcups during their life cycle produce seven times more NO_x and 16 times more SO_x than paper eggcups. In contrast, recycled paper eggcups produce twice as much heavy metals, such as Pb, Cd, Cr, Cu. Mo, Ni, and solid wastes than PS ones (Table 4).

Nevertheless, it should be pointed out that a fundamental parameter of LCA is that products, PS and paper eggcups must become a waste and to choose the friendlier package of the two it is necessary to take into account their environmental impacts from 'cradle to grave'. This includes not only indirect inputs to the production and associated wastes and emissions, but also the future downstream of the product [1]. And of course, the future fate of the product is a subject of national or regional environmental policy. In our study, the disposal of both eggcups (PS and recycled paper) was considered to be landfill disposal, which is the actual disposal method in Greece. But, one cannot exclude the case of different disposal options that may modify the results of the present study.

Another fundamental difficulty contributing in the uncertainty of the results is related with the comparisons of materials and energy flows. These data are not readily available from producers or published sources and, consequently, information from open sources may not correspond to actual practice and trustworthy conclusions cannot be drawn. Therefore, the use of open source information, data and material and energy bal-

Table 4
Comparative presentation of air emissions, liquid and solid wastes during the life cycle of both packages. Calculation basis 300 000 eggs; 50 000 eggcups; 1.1 tn recycled paper, 0.75 tn PS

Air emissions (g)	Polysterene eggcups	Recycled paper eggcups	Air emissions of PS/air emissions of recycled paper
Dust	4213.88	974.5	4.32
C_6H_6	4.263	32.4	0.13
PAHs	0.0199	0.021	0.95
C_xH_x(aromatic)	15.5421	20.37	0.76
Halon-1301	0.094	0.085	1.11
C_xH_y	0.000082	0.00004	2.05
CH_4	3443.8572	1554	2.22
NMVOC	11360.483	3248	3.50
CO_2	2952457.2	1788000	1.65
CO	1959.3	920	2.13
NH_3	0.6749	0.35	1.93
HF	12.4677	9.6	1.30
N_2O	11.483	16.284	0.70
HCl	101.096	92.2	1.10
NO_x	32669.28	4156.2	7.86
SO_x	94952.97	5847	16.24
Pb	0.1655	0.1355	1.22
Cd	0.033768	0.0262	1.29
Mn	0.05613	0.0413	1.36
Ni	1.47987	1.2	1.23
Hg	0.0441	0.0276	1.60
Zn	2.4696	36.7	0.07
B(a)P	0.000063	0.12	5.25E−04
H_2S	3.15	41	0.08
Liquid wastes (g)			
BOD	75.7134	1.233	61.40
COD	1703.016	35.42	48.10
AOX	0.07812	0.052	1.5
Fly ash	82.467	1025	0.08
Phenols	2.6951	2.33	1.27
Toluene	2.3789	2.12	1.12
PAHs	0.25326	0.234	1.08
C_xH_y (aromatic)	22.3146	15.27	95.36
C_xH_y	0.022365	0.016	1.40
Fat/oil	256.095	404	0.63
TOC	398.16	151	2.63
B(a)P	0.000063	0.12	5.25E−04
H_2S	3.15	41	0.08
N-tot	23.973	27.21	0.88
NH_4^+	254.5893	28.1	9.06
Nitrate	13.7655	9.35	1.47
As	0.116865	0.064	1.83
Cl^-	1458.7272	8400	0.17
Phosphate salt	1.42947	7.6	0.19
Sulfate salt	3082.9189	2334	1.32
Dissolved inorganic	3655.4112	8873	4.18
Al	49.959	7.5	6.67
Ba	52.6554	45.32	1.16
Pb	0.32319	0.717	0.45
Cd	0.02438	0.0336	0.72
Cr	0.69048	0.77	0.90
Fe	1138.18	956	1.19
Cu	0.2835	3	0.09
Mo	—	0.112	—
Ni	0.304	0.7	0.43
Hg	0.00136	0.01	0.14
Zn	0.6741	0.176	3.83
Solid wastes (g)			
TOTAL	15.6114	32	0.49

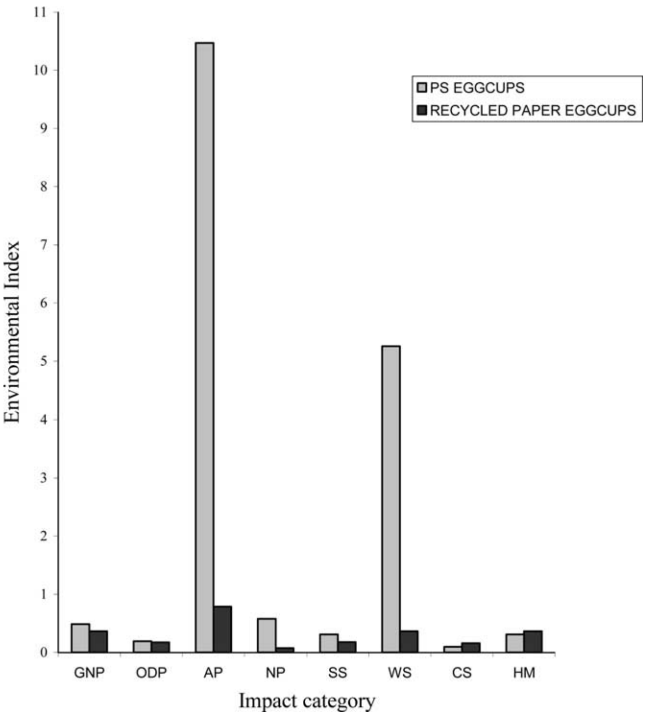


Fig. 4. PS and recycled paper eggcups evaluation results and comparison.

ances may be used with caution. In the present study, it was difficult to obtain field data, especially for polystyrene production and European databases have been used. It is obvious that the accuracy of the results of the present study is confined in a great degree by the credibility of data used. Publications on environmental process data are often incomplete or inaccurate. Despite the above-mentioned limitations, a case study for the implementation of LCA in packaging materials can be useful for making a gross evaluation of the two packages.

The use of American literature and practice, such as that of Hunt [14], in the assessment of paper egg packages in Greece, knowing that there are differences in practice in Europe versus the USA, was due to the fact that 'real' data about the pulp and paper industry are exceedingly difficult to find. This difficulty has also been pointed out by Ayres [1].

For the comparative assessment of the above polystyrene and recycled paper eggcups, no consideration has been taken of the sanitary aspects, appearance, durability, and impermeability to oxygen and water vapors, and strength (important features for packages), due to the lack of not yet defined appropriate parameters. In this study, a cost analysis has not been performed. Thus, such an analysis would complete the present study.

6. Conclusion

The application of the LCA procedure to two egg packages, polystyrene and recycled paper, has made possible the comparison of their environmental impacts by using EcoIndicator 95. However, the results do not provide a clear-cut answer for defining the friendlier product, but the goal was a preliminary approach to perform a comparative analysis.

Nevertheless, in this preliminary study, the obtained results have revealed that the polystyrene eggcup, during its life cycle has a higher environmental impact than the recycled paper one, taking into account the uncertainty of the findings. It is revealed that PS eggcups contribute in a greater degree to photochemical oxidant formation, while those of recycled paper contribute more to the Greenhouse effect, and charge the environment with heavy metal containing wastes.

Since the accuracy of a LCA can only be as good as the accuracy of the input data, it is imperative that more dependable and open-access databases be created.

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