POLITECNICO DI MILANO

Scuola di Ingegneria Civile, Ambientale e Territoriale

POLO TERRITORIALE DI COMO

Master of Science in

Environmental and Land Planning Engineering

Life Cycle Assessment (LCA) of Food and Beverage Packaging

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Ingegneria per l'Ambiente e il Territorio

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ABSTRACT

Food and beverage industry is tightly bound to packaging industry to enable the protection of products and to transport them safely to the consumers. Multi material packaging is one of the most common packaging type and is usually adopted to contain liquid products like milk, juice, and wine. Multi material packaging generates potential adverse impacts to the environment over its life cycle. In recent years, the major multi material packaging producers have been utilizing Life Cycle Assessment (LCA) as a tool to analyze the environmental performance of their packaging systems. In this work, twelve LCA studies on multi material packaging were reviewed to get a general picture of the current LCA practice in these systems. The common potential processes in multi material packaging were summarized. These include the extraction and production of raw materials, the production of packaging, the filling phase, the end-of-life, transportation. Raw materials production and end-of-life were found to be the most impacting phases in multi material packaging life cycle. Examined LCA studies faced limitations in data quality and its reliability, in the setting of system boundaries, and in methodological issues like the choice of impact categories and allocation procedure. The complexity and subjectivity in carrying out an LCA study might yield arguable results. A simplified approach to LCA using a standardized methodology could be a subject for future development.

SOMMARIO

L’industria alimentare è strettamente legata all’industria del confezionamento, perchè permette la protezione dei prodotti ed il loro trasporto verso i consumatori. Il packaging multi materiale è uno dei più comuni tipi di confezionamento ed è solitamente utilizzato per prodotti liquidi come latte, succhi di frutta, vino. Il packaging multi materiale genera potenziali impatti negativi per l'ambiente nel suo ciclo di vita. Negli ultimi anni, i maggiori produttori di packaging multi materiale stanno utilizzando il Life Cycle Assessment (LCA) come strumento per analizzare le prestazioni ambientali dei loro sistemi di confezionamento. In questo lavoro, dodici studi di LCA su packaging multi materiale sono stati analizzati per ottenere un quadro generale della attuale prassi LCA in questi sistemi. I potenziali processi comuni per il packaging multi materiale sono stati riassunti. Questi includono l'estrazione e la produzione di materie prime, la produzione di imballaggi, la fase di riempimento, la fase di fine vita, il trasporto. La produzione di materie prime e la fase di fine vita sono risultati essere le fasi più impattanti del ciclo di vita del packaging multi materiale. Gli studi LCA esaminati hanno affrontato limitazioni in termini di qualità dei dati e affidabilità, di definizione dei confini del sistema, e di questioni metodologiche come la scelta delle categorie di impatto e la procedura di allocazione. La complessità e la soggettività nella realizzazione di uno studio di LCA può produrre risultati discutibili. Un approccio di LCA semplificato utilizzando una metodologia standardizzata potrebbe essere oggetto per futuri sviluppi.

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Cynthia E. L. Latunussa

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Abbreviations

AC	Acidification
ACE	The Alliance of Beverage Cartons and Environment
AE	Aquatic Eutrophication
Al	Aluminium
AR	Abiotic Resource Depletion
ARA	Altstoff Recycling Austria
BC	Beverage Carton
BiB	Bag in Box
C	Carcinogen
CED	Cumulative Energy Demand
CENR	Cumulative Energy Demand Non Renewable
DG Environment	Directorate for Sustainable Development and Integration
DMT	Dimethyl Terephthalate
DSD	Duales System Deutschland
EC	European Commission
ENEL	Ente Nazionale per l'Energia Elettrica
EPA	Environmental Protection Agency
EPD	Environmental Product Declaration
EEA	European Environment Agency
ET	Eutrophication
EU	European Union
EUEB	European Union Eco-label Board
FS	Sedimental Toxicity
FWT	Freshwater Aquatic Toxicity
GER	Gross Energy Requirement
GPA	Global Packaging Alliance
GWP	Global Warming Potential
HT	Human Toxicity
IFEU	Institut für Energie- und Umweltforschung Heidelberg GmbH
IFU	Institut für Umweltinformatik
ILCD	International Reference Life Cycle Data System
ISO	International Standard Organization
JRC	Joint Research Center
JRC-IES	Joint Research Center Institute for Environment and Sustainability
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LDPE	Low Density Polyethylene

LLDPE	Linear Low Density LLDPE Polyethylene
LPB	Liquid Packaging Board
LU	Land Use
MEG	Monoethylene glycol
MFF	Mineral and Fossil Fuel
NR	Non Renewable Resource Depletion
NW	Non Hazardous Waste
OD	Ozone Depletion
PAS	Publicly Available Specification
P&G	Procter and Gamble
PA	Polyamide
PCR	Product Category Rules
PE	Polyethylene
PET	Polythylene Tetraphtalate
PM10	Particular Material
POCP	Photochemical Ozone Creation POtential
PP	Polypropylene
PTA	Purified terephthalic acid
REPA	Resource and Environmental Profile Analysis
RI	Respiratory Inorganics
SEMC	Swedish Environmental Management Council
SETAC	Society of Environmental Toxicology and Chemistry
SME	Small and Medium Enterprise
STP	Stand Up Pouch
TB	Tetra Brik
TBA	Tetra Brik Aseptic
TRA	Traffic
UHT	Ultra High Temperature
UNEP	United Nations for Environment Programme
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WA	Waste
WC	Waste Consumption
WHO	World Health Organization
WRATE	The Waste and Resources Assessment Tool for the Environment

INTRODUCTION

Food and Beverage industry is one of the most important industrial activity both in developed and developing countries. Food and Beverage industry is relatively stable even in time of economic crisis since it serves one of the most basic human needs. Rapid population growth in developing countries and the raising consciousness of health in developed countries are the major driving force in the development of food and beverage technology. People demand for the availability of foods and drinks as well as the adequate quality of the related products.

One of the important stakeholders in food and beverage industry supply chain is packaging industry. Packaging is necessary in food and beverage industry because it plays an important role in preserving the quality and safety of the products, protecting the products during transportation to the consumers, and eventually preventing food wastage. On the other hand, packaging waste creates problems in municipal solid waste site. Depending on the products it protects, packaging has a relatively short life time which means it ends up quickly in disposal systems.

Life Cycle Assessment is a relatively recent tool in an attempt to evaluate potential environmental impacts of a product or service throughout its life cycle. In packaging industry, it's been used in practice by several companies in order to improve the environmental performance of their products, for example by using recycled material, lightweighting the material, or the use of bio-based plastic.

This work is aimed at giving a review of Life Cycle Assessment application in food and beverage packaging, in particular multi material packaging. This work is divided into three parts. Chapter one presents introduction to basic concepts of LCA, including its structure and methodology. Chapter two introduces the importance of food and beverage industry, various packaging types in food and beverage industry, as well as regarding multi material packaging. Finally, chapter three presents review of publications in multi material packaging and related issues encountered in the studies.

A total of 12 publications regarding Life Cycle Assessment in multi material packaging were gathered and reviewed. Related information was gathered from various sources, related books, scientific journals, publications, as well as internet website sources.

CHAPTER 1 - LCA concept, structure, framework

1.1 History of LCA

The idea of life cycle thinking started in the 1960s. Some researchers in that period considered that in order to study resource consumption and the industrial process flows in a product system from the environmental point of view in a comprehensive manner is to examine each step of the process from the raw material extraction, transformation processes and transport, until they become waste.
In 1969, some early LCA studies were conducted. One of them was carried out by The Coca Cola Company, aimed to determine which containers would have the lowest impact to the environment. In the seventies, some of LCA practices were conducted as a part of decision making process. In North America, this study was called REPA. REPA was the process of quantifying the resource use and environmental releases of products. In Europe, a similar practice was known as ecobalance.

From the year of 1975 to 1980, after the influence of the oil crisis started to fade, the interest in LCA practices shifted to hazardous and household waste management. In 1979, Boustead and Hancock published The Handbook of Industrial Energy Analysis which offered a description of operation in analytic procedure that is fundamental in nowadays LCA practice. The term LCA was first proposed during SETAC congress in USA in 1990. Since then, the initiatives to standardize LCA methodology started to develop through publications of manuals, calculation instrument, database, and so on.

At the international level LCA refers to ISO 14001 that stated LCA as a scientific instrument to identify environmental aspects in a systematic way. At European level the European Union has declared sustainable development as one of the fundamental objectives. One of the efforts in reaching this objective was by establishing the European Platform on LCA project carried out by the European Commission's Join Research Center Institute for Environment and Sustainability (JRC-IES) in collaboration with DG Environment, Directorate for Sustainable Development and Integration to support life cycle thinking. In the United States, LCA is a part of the research promoted by US-EPA to advance the practice of LCA across the public and private sectors. Researchers who work on the LCA projects are closely involved in the international development process such as SETAC, UNEP (United Nations for Environment Programme) and also JRC.

1.2 The Definition of LCA and Product System

LCA is a technique for assessing the environmental aspects associated with a product over its life cycle. Life cycle assessment is a "cradle to grave" approach for assessing industrial system. It begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade offs in products and process selection.

From methodological point of view, LCA definition proposed by SETAC is :
"LCA is a procedure objected to assess energy and environmental charge of a process or an activity, carried out by identification of energy and material involved and the generated waste to the environment. The assessment include the internal life cycle of process or activity, including the extraction and treatment of primary material, manufacturing, transport, distribution, usage, reuse, recycle, and the final disposal. "

Based on the definition stated in ISO 14040, LCA is a compilation and assessment of all the life cycle of input and output and the potential environmental impact of a product system. LCA aims to assess the environmental aspects and potential impacts associate with a product, process, or service. This is done by compiling an inventory of relevant energy, material inputs, and environmental releases, evaluation of the potential environmental impacts associated with identified inputs and releases, interpreting the results to help decision makers make a more informed decision.

The international standard ISO for Life Cycle Assessment are ISO 14040 : 2006 and ISO 14044 : 2006. They replace the previous standards for Life Cycle Assessment ISO 14040: 1997, ISO 14041: 1999 about Goal and scope definition and inventory analysis, ISO 14042:2000 on Life cycle impact assessment and ISO 14043:2000 on Life cycle interpretation.

"ISO 14040:2006, Environmental management; Life cycle assessment Principles and framework, provides a clear overview of the practice, applications and limitations of LCA to a broad range of potential users and stakeholders, including those with a limited knowledge of life cycle assessment. ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines, is designed for the preparation of, conduct of, and critical review of, life cycle inventory analysis. It also provides guidance on the impact assessment phase of LCA and on the interpretation of LCA results, as well as the nature and quality of the data collected " (www.iso.org).

Product Systems

LCA models the life cycle of a product as its product systems from environmental analysis point of view. Product system according to ISO 14040 means a collection of unit processes with elementary product flows, which perform one or more defined functions and which models the life cycle of a product.

The important property of a product system is characterized by its function and cannot be defined only in terms of the final products. Product systems are composed by a set of unit processes that are linked one another by flows of intermediate products and/or waste for treatment, to other product systems by product flows, and to the environment by elementary flows. Dividing a product system into its components unit processes facilitates identification of the inputs and outputs of the product system. An example of a product system is shown in figure 1-1.

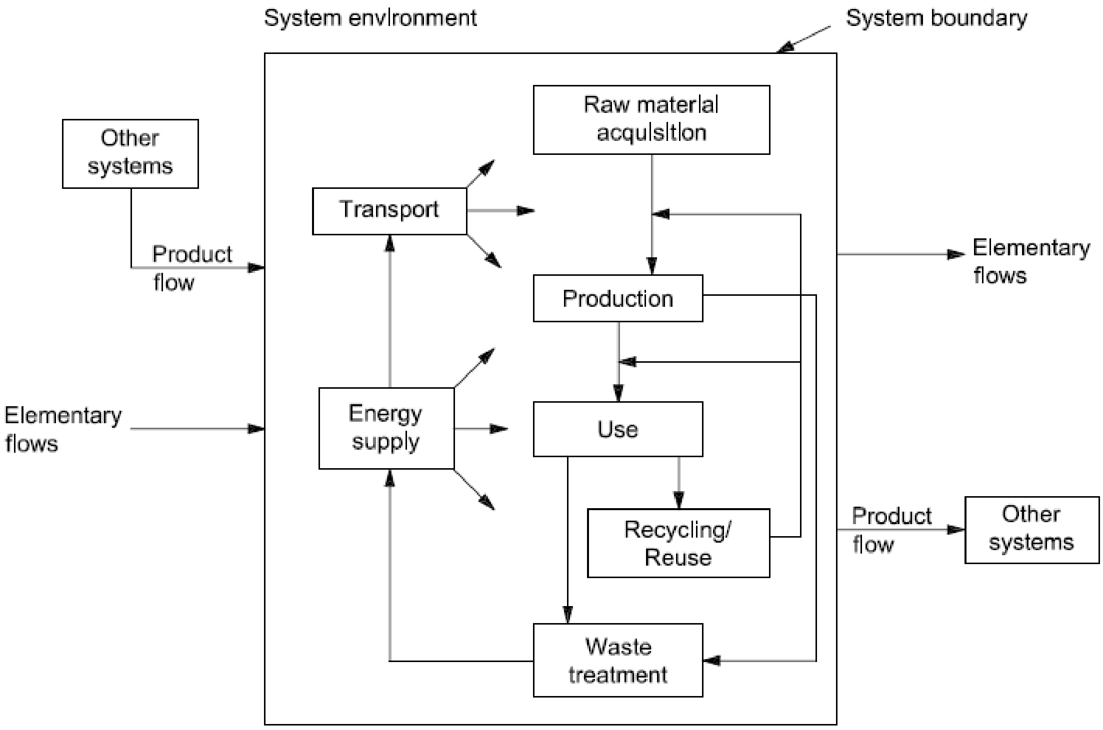

Figure 1 - 1 Example of a product system
Source : ISO 14040

1.3 The Structure of LCA

The modern structure of LCA proposed by ISO 14040 norm consists of four phases as follows :

1. Goal Definition and scoping phase which contains definition and description of the product, process, or activity, establishing the context in which the assessment is to be made.
2. Inventory analysis phase which contains identification and quantification of input or output data regarding to the system being studied. These input/output can be energy, water, and

material usage and environmental releases.

3. Impact assessment phase aims to assessing the potential human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis
4. Interpretation phase which is the evaluation of the results of the inventory analysis and impact assessment to select the preferred products, process, or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

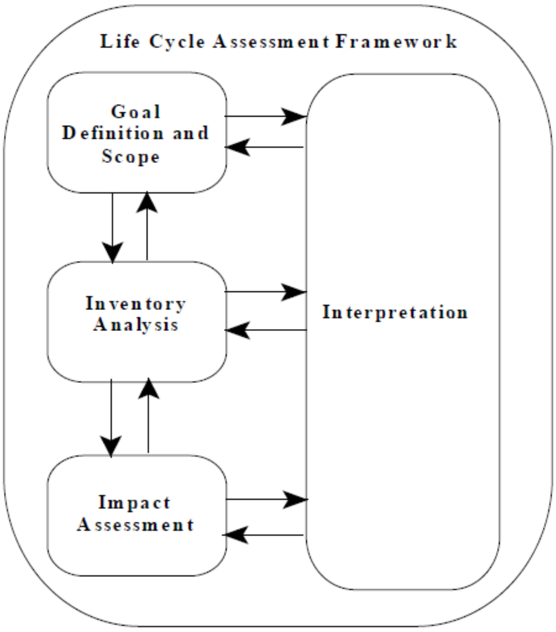

Figure 1 - 2 Phases in Life Cycle Assessment
Source : EPA

1.3.1 LCA as an iterative process

LCA is almost always an iterative process, at the beginning as the goal of the work is defined, the scope setting are derived that define the requirements on the subsequent work (ILCD handbook). During its phases, as more information becomes more available the initial scope settings might need to be refined and even revised. According to ILCD handbook : "LCAs are performed in iterative loops of goal and scope definition, inventory data collection and modelling, impact assessment, with completeness, sensitivity, and consistency checks, as a steering instrument. This is done with a possible limited revision of the goal and scope until the required accuracy of the system's model, processes, completeness and the precision of the inventory results has been attained". However it is possible that after several iterative processes, the level of precision does not reach the requirement.

This limitation has to be documented in the report. A picture of LCA iterative process is shown in figure 1-3.

There are two different approaches in LCA, attributional LCA and consequential LCA. The first one evaluates how things flow within the chosen temporal window. The second one evaluates the flow change as a response of a decision applied in a system. The difference between the two approaches can be seen when making a life cycle inventory modelling. Attributional LCA would include full life cycle, use average data, and out allocation in proportion. Consequential LCA will include processes that are affected, use data that reflect expected effects of changes, and avoided allocation through system expansion (Ekvall, 2003).

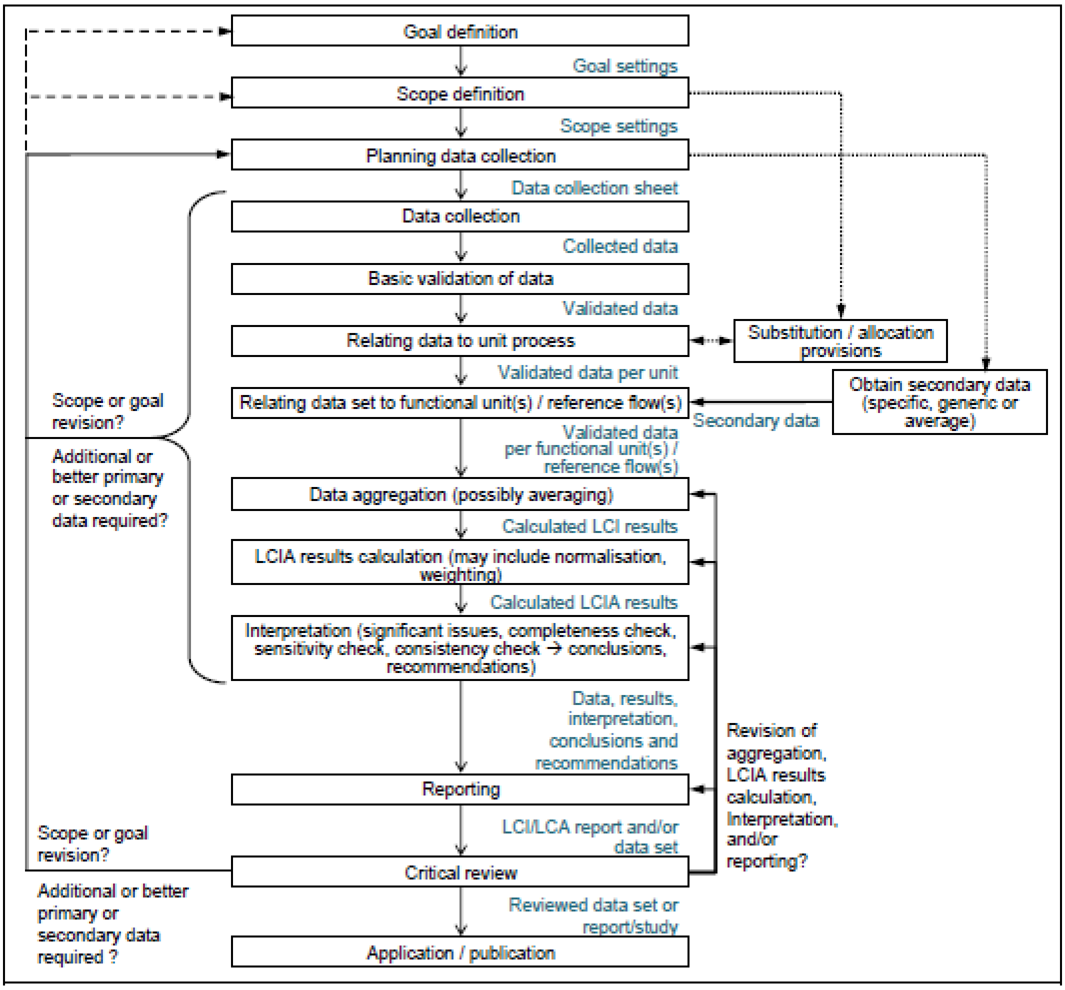

Figure 1 - 3 The Iterative Approach of LCA
Source : ILCD Handbook General Guidelines for LCA

1.4 Phases in Life Cycle Assessment

1.4.1 Phase 1 : Goal Definition and Scoping

Goal definition is the very first phase of any life cycle study that will guide scope definition and define a clear frame to the next phases of inventory analysis and impact assessment. According to EPA, goal definition and scoping is the phase of defining the purpose and methods of including life cycle environmental impacts into the decision-making process. In this phase, the type of information needed to add value of decision-making process, the accuracy of the result and the interpretation of the result and how to display it in order to be usable must be determined.

In general, the goal of an LCA must state the intended application, the reasons for carrying out the study, the limitations due to method, assumptions and impact coverage, the intended audience i.e. to whom the results of the study are intended to be communicated and whether the results are intended to be used in comparative assertions intended to be disclosed to public. The goal and scope definition of the LCA project will determine the time and resources needed and guide the entire process in order to guarantee that the most meaningful results are obtained.

Once the goals and purpose of an LCA is understood, boundaries of the study must be determined. Life cycle of a product, processes or activity is therefore studied. Environment is defined as the surrounding of the system, input is generally applied for the natural sources and output is applied for any release to the environment. The boundaries of an LCA or LCI study are however not endless. In defining the boundaries of the study, exclusion of sets can be done. The general rule in excluding some steps from an LCA study is that if doing so does not change the conclusion of the study. This can be done through preliminary research to understand the potential contribution of each subsystem to the total system. For example, in making a comparative LCA, it is logical to exclude operations that are common in the products being studied.

Another important thing in goal definition and scoping is the selection of time and spatial boundaries. The data used in LCA study should be representative of the stated time and spatial boundaries. These can be very significant and in some cases, data for one place can not be used in another location. Time boundaries are important because industrial practices, legislative requirements and consumer habits may vary over time.

1.4.1.1 Defining the Scope of the Study

The scope of an LCA study based on ISO 14040 includes the following items :

1. The product system to be studied
2. The functions of the product system, or in the case of comparative studies, the systems
3. The functional unit

4. The system boundary
5. Allocation procedures
6. Impact categories selected and methodology of impact assessment, and subsequent interpretation to be used
7. Data requirements
8. Assumptions
9. Limitations
10. Initial data quality requirements
11. Type of critical review (if any)
12. Type and format of the report required for the study

1.4.1.2 Functional Unit and System Boundary

In goal and scope definition phase, functional unit and system boundary of the study has to be stated. An LCA study must specify the functions of the system being studied. A system can possibly have more than one functions and the selected one depends on the goal and scope of the LCA. The chosen functional unit is used as a reference to which the input and output data are normalized. It must be consistent with the goal and the scope of the study, clearly defined and measurable. If a comparison between systems is to be made, it shall be based on the same function, quantified by the same functional unit in the form of their reference flow. An example is in the function of a beverage packaging comparative study, it’s relevant to use one litre of a juice as a unit function to compare PET bottle and glass packaging than how many litres of juice one kilogram of PET plastic can contain.

A system boundary in LCA means the definition of the unit processes included in the system. Unit processes and the level of details of these unit processes have to be decided. The choice of the components in the physical system model depends on the goal and scope definition of the study, the intended application and audience, the assumptions, data and cost constraints, and cut-off criteria. It is possible to omit life cycle stages, processes, inputs or outputs but the reasons and the implications of this decision has to be clearly explained.

There are several life cycle stages, unit processes and flows to be considered in setting the system boundary in LCA, they are :

1. Raw Material Acquisition

   Life cycle of a product begins with the removal of raw materials and energy sources from the earth, as well as the transportation of these materials from acquisition to the processing has to be included.

2. Manufacturing

   The process of transforming raw materials into a product or package. This consists of three steps as follow :

   - Materials manufacture ; involving the activities that convert raw materials into a form that can be used to fabricate a finished product.
   - Product Fabrication ; Processing of manufactured material into a product ready to be filled or packaged.
   - Filling/Packaging/Distribution ; finalizing the product and preparation for shipment. This stage accounts for the environmental effects caused by the mode of transportation.

3. Use/Reuse/Maintenance

   Involving consumers' actual use, reuse, and the maintenance of the product. When the consumer doesn't need the product any longer, product will be recycled or disposed.

4. Recycle/Waste Management

   This stage includes the energy requirements and environmental wastes associated with disposition of the product or material

1.4.1.3 Data requirement in LCA process

The required level of data accuracy for the project depends on the use of the final results and the intended audience, for example whether it is to support local community or regulator, or for internal decision making purpose. Understanding data quality are important to understand the reliability and the interpretation of the study outcome results.

Level of the specificity has to be clearly defined and communicated so that readers are more able to understand the differences in the final results. Some requirements for data quality according to ISO 14040 norm are :

1. Time related coverage
2. Geographical coverage
3. Technology coverage
4. Precision
5. Completeness
6. Representativeness
7. Consistency

8. Reproducibility
9. Sources of data
10. Uncertainty of the information

Level of the specificity has to be clearly defined and communicated so that readers are more able to understand the differences in the final results. There are three levels of data, they are :

1. First level of data which is the experimental data
2. Second level of data which is from the literature (database and other studies)
3. Third level of data, which is the estimated and the average data

There are two types of data, foreground and background data. Foreground system means the system of primary concern, for example on-site data of a production process. Background data refers to energy and materials to the foreground system as aggregated data sets in which individual plants and operations are not identified. Example of background data is the data of annual consumption of electricity in a specific country, and so on.

Data should be organized in terms of a functional unit that describes approximately the function of the product or process being studied. Careful treatment to this data will improve the accuracy of the study and the usefulness of the results. When an LCA is used to compare two or more products, the basis of comparison should be equivalent use which means each system has to be defined so that an equal amount of product or equivalent service is delivered to the consumer. This can be described in term of volume or weight. For example, defining a shopper bag with capacity of 20 litre as a reference of a comparative study between imported organic shopper bag and the local plastic-based shopper bag.

1.4.2 Phase Two : Life Cycle Inventory Analysis

1.4.2.1 Definition of Life Cycle Inventory Analysis

Life cycle inventory is a process of quantifying energy and raw materials requirements, atmospheric emissions, waterborne emissions, solid wastes, and other releases for the entire life cycle of a product, process, or activity. LCI is useful for example in helping to organize product or processes comparisons considering environmental factors.

Life Cycle Inventory Analysis involves the compilation and quantification of inputs and outputs for a product throughout its life cycle. In this phase data shall be collected for each unit process that is included within the system boundary, and these data are utilized to quantify the inputs and outputs of a unit process. The data shall be referenced to the functional unit and the process of conducting an inventory analysis is iterative.

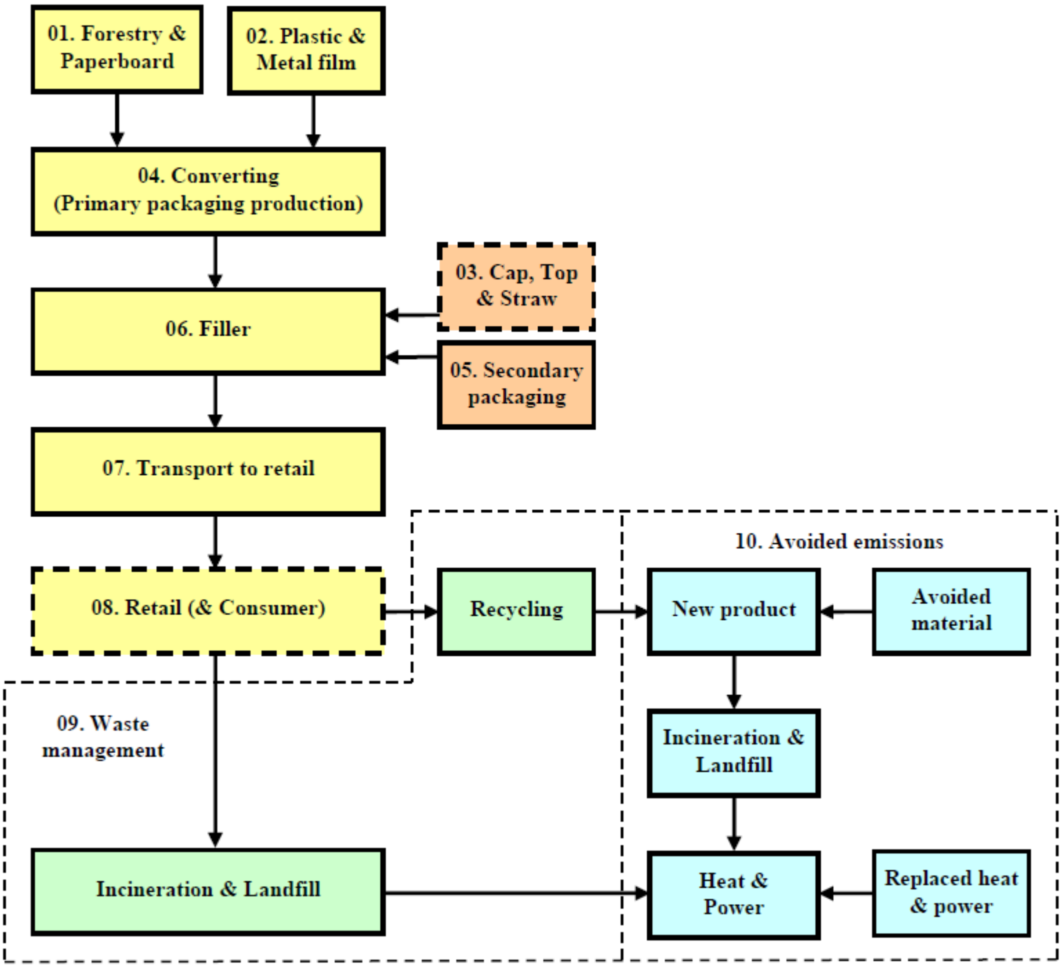

Figure 1 - 4 An example of a simplified flowchart of a typical carton beverage
Source : LCA Nordic final report 2009

1.4.2.2 Steps in conduction Life Cycle Inventory

According to the document by EPA in 1993 "Life Cycle Assessment : Inventory Guidelines and Principles" and the "Guidelines for Assessing the Quality of Life Cycle Inventory Analysis" from 1995, there are four steps in conducting a life cycle inventory.

1. Develop a flow diagram of the processes being evaluated

   First of all, in previous goal definition and scoping phase establishes initial boundaries defining what is to be included in a particular LCA and these are used as the system boundary for the flow diagram. A flow diagram is a tool useful for mapping the inputs and outputs to a process or system.

   In gathering data, it is appropriate to view the system as an individual step or process as a part of the defined production system. This individual step is called a "subsystem". Each subsystem requires inputs of materials and energy, transportation of product produced, and has outputs of products, co-products, atmospheric emissions, waterborne wastes, solid wastes and possibly other releases. Each subsystem must describe the materials and energy sources used and the types of environmental releases. All transportation from one process location to another is included in the subsystem, quantified in terms of distance and weight shipped and identified by the mode of transport used.

2. Develop an LCI Data Collection Plan

   The required quality and accuracy of data was determined to meet the expectations of the decision-makers.

   There are key elements of data collection plan such as :

   2.1 Defining data quality goals; providing a framework for balancing available time and resources against the quality of data required to make a decision regarding overall environmental of human health impact (EPA 1986)

   2.2 Identifying data sources and types; providing sufficient accuracy and quality of data source aimed to meet the study's goals. Examples of data sources are laboratory test results, reference books, trade associations, etc.

   2.3 Identifying data quality indicators; these are the benchmarks to which the collected data can be measured to determine if data quality requirements have been met.

   2.4 Developing a data collection worksheet and checklist.

   Life cycle inventory spreadsheet covering most of the decision areas in the performance of an inventory, prepared to guide data collection and validation and to enable construction of a database to store collected data electronically. It is a valuable tool or ensuring completeness, accuracy, and consistency.

3. Data Collection

   Data collection efforts involve a combination of research, site-visits and direct contacts with experts, which generate large quantities of data.

   For each unit process within the system boundary, the data can be classified as :

   1. Energy inputs, raw material inputs, ancillary inputs, other physical inputs,
   2. Products, co-products, and waste,
   3. Emissions to air, discharges to water and soil
   4. Other environmental aspects

In data collection process, practical constraints should be considered in the scope and documented in the study report. However, there are alternatives that can be done in order to reduce data collection time and resources, such as :

1. Use commercially available LCA software package
2. Obtain non-site specific inventory data
3. Evaluate and Document the LCI Results

In this step, the report of the final result of the life-cycle inventory should describe the methodology used in the analysis, the system analyzed and the boundaries that were set.

1.4.2.3 Allocation

Sometimes allocation is needed when dealing with systems with multiple products and recycling systems. Allocation means "partitioning the input or output flows of a process or a product system between the product system under study and one or more other product system" (ISO 14040). An example of allocation procedure application is in reuse and recycling scenario in waste management system. A sensitivity analysis has to be conducted when allocation procedure is applied. Allocation procedure can be applied in process with multi output processes or multi input processes.

1.4.3 Third Phase of Life Cycle Assessment : Life Cycle Impact Assessment (LCIA)

LCIA is the phase of evaluation of potential human health and environmental impacts of the environmental resources and releases identified during LCI. This process involves associating inventory data with specific environmental impact categories and category indicators, in order to understand these impacts. It also has to be coordinated with other phases in order to achieve the goal and scope of the LCA study.

There are two ways in modelling LCIA, midpoint and endpoint. Midpoint impact category, also known as problem-oriented approach, translates environmental impacts into environmental themes such as climate change, acidification, human toxicity, etc. Endpoint impact category, is a damage-oriented approach and it translate environmental impacts into issues of concern such as human health, natural environment, and natural resources (PRé Consultants). Less assumptions are used in midpoint modelling but endpoint modelling is easier to understand.

In LCIA phase, there are several uncertainties regarding the quality of LCI data and results, reliability of the system boundary and cut-off decision, as well as environmental relevance of the LCIA results. Therefore, LCIA phase has to be planned with careful attention.

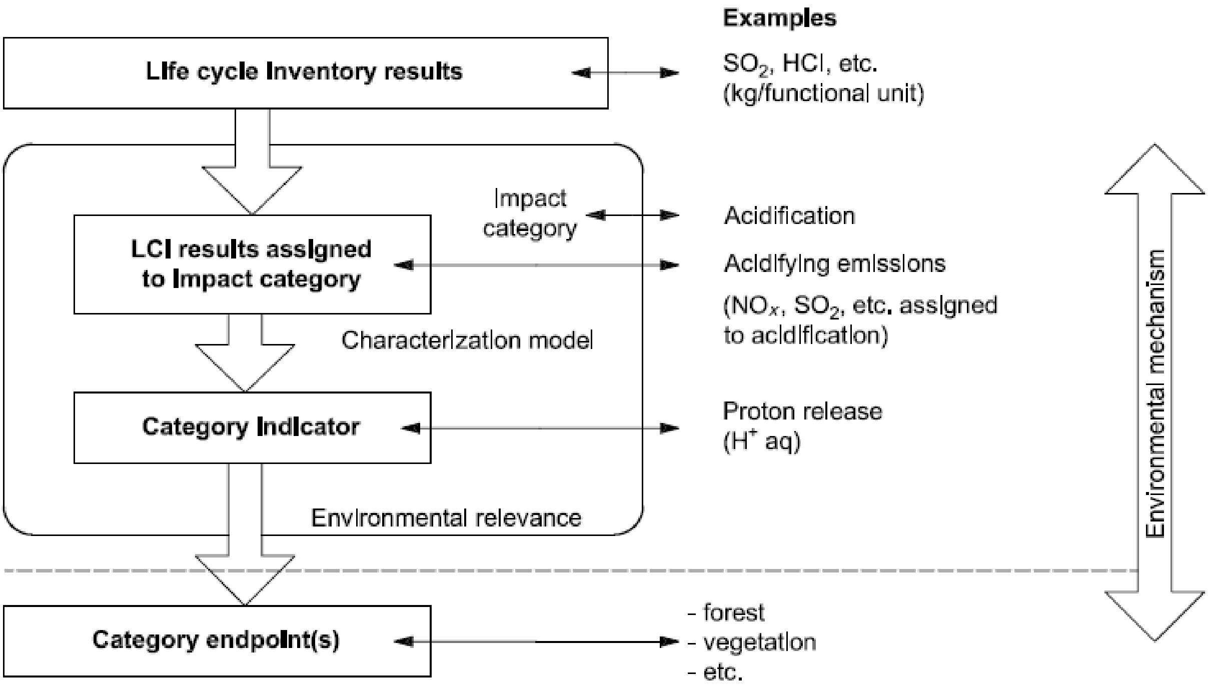

Figure 1 - 5 Concept of Category Indicator in ISO 14044
Source : ISO 14044

1.4.3.1 Key Steps in Life Cycle Impact Assessment

The key steps of a Life Cycle Impact Assessment are. :

1. Selection and Definition of Impact Categories
2. Classification
3. Characterization
4. Normalization
5. Grouping (optional)
6. Weighting (optional)
7. Evaluation and report of LCIA results in order to gain a better understanding of the reliability of the LCIA results.

The selection of impact categories, category indicators and characterization models shall be consistent with the goal and scope of the LCA, internationally accepted, environmentally relevant, scientifically and technically valid based upon a distinct identifiable environmental mechanism and reproducible empirical observation. Value choices and assumptions made during the selection of impact categories, category indicators and characterization models should be minimized.

The first three steps are the mandatory steps in conducting an LCIA according to ISO 14040 standard. They are :

1. Select and Define Impact Categories, Category Indicators, and Characterization Models

   This step is fundamental step as a part of the goal and scope definition phase that would guide the LCI data collection process. Impacts in an LCIA are defined as the consequences that could be caused by the input and output of a system, typically focused on three main categories that are aimed to be protected by conducting an LCA study: human health, ecological health, and resource depletion.

   Some examples of impact categories are :

   - Concerning input: Depletion of abiotic resources (fossil fuels, minerals), depletion of biotic resources (e.g. Wood, fish), and land use (land occupation, land transformation, decrease of biodiversity)
   - Concerning output: climate change, stratospheric ozone depletion, human toxicity, ecotoxicity (terrestrial, fresh water aquatic, marine aquatic), photochemical ozone formation, acidification, and eutrophication

   There are existing models for impact categories, characterization, and category indicators that can be selected for an LCIA phase. The selection of the impact categories shall delineate a set of environmental issues related to the product system of the study. In choosing the impact categories, the environmental mechanism has to be clearly described. Environmental mechanism is defined as the total environmental processes related to the characterization of the impacts

2. Classification

   The objective of this step is to organize and possibly combine the LCI results into impact categories. One example is methane emissions that can be classified into the global warming category. Some commonly used life cycle impact categories include Stratospheric ozone depletion, global warming potential, acidification, eutrophication, photochemical smog, human health, resource depletion, land use, water use, etc. In this step, LCI result can be assigned to only one impact categories or more through parallel or serial mechanism. Table 1-1 shows examples of elementary flows and their classification into impact categories.

Table 1 - 1 An example of elementary flows and their classifications into impact categories
Source : Comparative Life Cycle Assessment of beverage cartons cb3 and cb3 EcoPlus for UHT milk (Wellenreuther, Falkenstein, Detzel, 2010)

Impact Categories	Elementary Flows								Unit
Land Use (forestry)	forest area								cm² * year
Fossil Resources	crude oil	natural gas	brown coal	hard coal					kg crude oil eq.
Climate Change	CO_2*	CH_4**	N_2O	$C_2F_2H_4$	CF_4	CCl_4	C_2F_6	R22	kg CO_2 eq.
Summer Smog (POCP)	CH4	NMVOC	Benzene	Formaldehyde	Ethyl acetate	VOC	C-total	Ethanol	kg ethene eq.
Acidification	NOx	NH_3	SO_2	TRS	HCl	H_2S	HF		kg SO_2 eq.
Terrestrial Eutrophication	NOx	NH_3	N_2O						kg PO_4 eq.
Aquatic Eutrophication	COD	N	NH_4^+	NO_3^-	NO_2^-	P			kg PO_4 eq.
Human toxicity: PM10	PM10	SO_2	NO_X	NH_3	NMVOC				kg PM10 eq.
Human toxicity: Carcinogenic risk	As	B(a)P	Cd	Cr VI	Ni	Dioxin	Benzene	PCB	kg As eq.
Total Primary Energy	hard coal	brown coal	crude oil	natural gas	uranium ore	hydro energy	Other renewable		MJ
Non-renewable Primary Energy	hard coal	brown coal	crude oil	natural gas	uranium ore				MJ
Transport intensity	lorry distance								km

* CO_2 fossil   ** CH_4 fossil and CH_4 regenerative included

3. Characterization

Impact characterization is based on scientific conversion factors called characterization factors. It's used to convert and combine the LCA results into representative indicators.

Characterization provides a way to directly compare the LCI results within each impact category. The characterization factors are calculated using characterization models that reflect the environmental mechanism by describing the relationship between the LCI results and category indicators. The method used to do this calculation has to be specified.

The accuracy and the validity of the characterization models and factors influence the results of the study with a given goal and scope. Variations in the quality of the category indicators may occur, for example in the complexity of the environmental mechanism chosen for the study, and the spatial and temporal characteristics where the LCA study is conducted. These variations also influence the overall accuracy of an LCA study.

However, the key point to impact characterization is using the appropriate characterization factor. A properly referenced LCIA will document the source of each characterization factor to guarantee that they are relevant to the goal and scope of the study.

4. Normalization

   Normalization is an optional tool used to express impact indicator data in a way that can be compared among impact categories, usually by dividing the indicators result by a selected reference value. This reference value may be influenced by the goal and scope of the LCA.

   Some examples of references value are (ISO 14044) :

   - The total inputs and outputs for a given area that may be global, regional, national, or local
   - The total inputs and outputs for a given area on a per capita basis or similar measurement
   - Inputs and outputs in a baseline scenario, such as given alternative product system

5. Grouping

   Grouping means assigning impact categories into one or more sets to better facilitate the interpretation of the results into specific areas of concern, typically involve sorting or ranking indicators.

   According to ISO 1998,. there are two possible ways to group LCIA data :

   1. Sorting indicators by characteristics such as emissions or location. This sorting is used on a nominal basis, for example by characteristics such as spatial scale of the impact category (global, regional, local), area of protection for the impact category (human health, natural environment, resources).
   2. Sorting indicators by a ranking system, based on value choices. Examples of this ranking system are the degree of reversibility of the impacts, the degree of certainty of the impacts, policy priorities regarding the types of the impact (e.g. low priority, medium, high).

6. Weighting

   Weighting means converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices. Weighting or valuation step of an LCIA include the following activities :

   1. Identifying the underlying values of stakeholders

2. Determining weights to place on impacts
3. Applying weights to impact indicators

Weighting assigns weights or relative values to the different impact categories based on their perceived importance or relevance. There is no scientific way to reduce LCA results to a single overall score or number. Weighting can particularly be useful for routine decisions in product design, and for decisions that imply many different types of information, for example environmental, economic, legal and social information.

There are three main types of weighting method :

1. Monetary weighting, which is based on willingness-to-pay or on revealed preference approaches
2. Distance-to-target weighting, using policy standards
3. Social panel weighting, using the judgement of experts or of stakeholders in the decision process

However, there are several issues that make weighting a challenge, such as subjectivity and decision making based on environmental subjective preference.

7. Evaluate and Document the LCIA Results

After having the impact potential for each selected category, the accuracy of the results must be verified if it's sufficient to support the purposes for performing the LCA as defined in the goal and scope.

The lack of spatial and temporal dimensions in the LCI results may introduce uncertainty in the LCIA results and there are no generally accepted methodologies for consistently and accurately associating inventory data with specific potential environmental impacts. Models for impact categories are in different stages of development.

1.4.4 Life Cycle Assessment Phase : Life Cycle Interpretation

Interpretation is the last phase of the LCA process. It is a systematic technique to identify, quantify, check, and evaluate information from the results of the inventory analysis and the impact assessment and communicate them effectively. The interpretation phase should deliver results that are consistent with the defined goal and scope and which reach conclusions, explain limitations and provide recommendations. The interpretation shall reflect the fact that the LCIA results are based on a relative approach, and indicate potential environmental impacts, which means that they do not predict actual impacts on category endpoints, the exceeding of thresholds or safety margins or risks.

There are two objectives of life cycle interpretation:

1. Analyze results, reach conclusions, explain limitations, provide recommendations based on the findings of the preceding phases of the LCA and to report the results in a transparent manner.
2. Provide a readily understandable, complete, and consistent presentation of the result of an LCA study in accordance with the goal and scope of the study.

The following steps to conduct a life cycle interpretation were taken from the ISO 14044.

1. Identification of the Significant Issues based on the LCI and LCIA

   In this element, the results derived from LCI/ LCIA is structured to help to determine the significant issues. Significant issues can include inventory parameters, impact category indicators, essential contributions for life cycle stages to LCI or LCIA results.
2. Evaluation which considers completeness, sensitivity, and consistency checks

   The evaluation step of the interpretation phase establishes the confidence in and reliability of the results of the LCA. This step includes completeness check to examine the completeness of the study, sensitivity check to assess the sensitivity of the significant data elements that influence the results most greatly, and consistency check to evaluate the consistency used to set system boundaries, collect, data, make assumptions, and allocate data to impact categories for each alternative.
3. Conclusions, recommendations, and limitations

   The objective of this step is to interpret the results of the life cycle impact assessment to determine which product/process has the overall least impact to human health and the environment, and or to one or more specific areas of concern as defined by the goal and scope of the study.

1.5 Limitations of Conducting an LCA

LCA performance can be resource and time intensive. Gathering data can be problematic, and the availability of data can greatly impact the accuracy of the final results. It is therefore important to weigh the availability of data, the time necessary to conduct the study, and the financial resources required against the projected benefits of the LCA.

There are some key limitations depending on the methodology selected in conducting LCIA, such as lack of spatial and temporal resolution, inventory specification, threshold and non threshold impact. LCIA addresses only the environmental issues that are specified in the goal and scope, therefore it's not a complete assessment of all environmental issues of the product system under study. LCIA cannot always demonstrate significant differences between impact categories and the related indicator results of alternative product systems. This may be due to the limited development of the characterization models, sensitivity analysis and uncertainty analysis for the LCIA phase, limitations of the LCI phase such as system boundary setting that do not include all possible unit processes for a product system or do not include all inputs and outputs of every unit process, since there are cut-offs and data gaps. There's also limitations of the LCI phase, such as insufficient LCI data quality, and limitations in the collection of inventory data appropriate and representative for each impact category.

1.6 LCA Software and Database

There is various software developed for conducting LCA study. Some examples of these software are as follow :

Boustead model version 5.0: aimed mainly at educational users, consultancy companies, government agencies, companies who manufacture a large number of various products, and technical trade associations. Boustead 5.0 enables the user to build a full life-cycle inventory modelling, calculation of various environmental effects, and easily conduct sensitivity analysis. The database for the calculation is updated by Boustead Consulting limited, and it is not based on commercially available database products.

Another example of the software is SimaPro 7, developed by a Dutch company named PRé Consultants. It is widely used throughout the the world. SimaPro has many advanced features at the same time very easy to use and understand. The database of SimaPro is provided by several suppliers such as BUWAL250, Danish Food data, Dutch input output data, and Ecoinvent data.

The German's IFU Hamburg GmbH developed a software named Umberto 5.5. It has been developed and improved for about 15 years. Umberto software is known for its flexibility for being able to be used regardless the size of a company or the industry. It has been used in industries and it's also embraced by consulting businesses and research facilities. In conducting impact assessment phase in LCA application, it includes the following impact assessment methodologies : Ecoindicator 99, CML 2001, Swiss Ecopoints, German EPA method, Cumulative Energy Demand. The main database of Umberto is supplied by Umberto library, Ecoinvent data and Sabento library.

1.7 Applications of Life Cycle Assessment

LCA can be applied in various types of activities, among them are :

Decision Making Supporting Tool

LCA can be used as a tool to guide decision making process. As an example, P&G has been utilizing LCA approach to analyse their products. Some studies have been made, such as a study to obtain the environmental profiles of different P&G laundry detergents on the UK market to identify which type was more environmentally preferable (Van Hoff, et al. 2003).

Eco-labelling

LCA is used as a tool in environmental labelling. There are three types of environmental labels established by the ISO. The first type, Type I is the label in which a third party organization sets out the standards for certain environmental-friendly products. Examples of this type are Eco Mark from Japan, Blue Angel from Germany, The Thai Green Label Scheme from Thailand. European Eco-label belongs to this group as well. European Eco-label was introduced by European Union aimed at encouraging companies to adapt environmentally sustainable production processes. European Eco-label has strict criteria for the selection and evaluation conducted by European Union Eco-label Board (EUEB) through a series of analysis. EUEB sets a certain standard for various product groups for Eco-label criteria. If a company would like to request Eco-label brand for their products, they should propose it to a competent body at national level. The competent body collaborates with a group of experts to implement a study of LCA type to evaluate the product in proposal. This competent body will inform EUEB if the evaluation results is positive.

The second type, Type II labels indicate an environmental claim made by the manufacturer without evaluation by third party. The third type, Type III, have no standards to comply with, unlike the first two types. One example of Type III is Environmental Product Declaration (EPD).

Environmental Product Declaration (EPD)

EPD is a certified environmental declaration developed in accordance with the ISO 14025 standard. EPD initiative was started in 1998 by Swedish Environmental Management Council (SEMC). EPD contains factual based and verified information about the environmental performances of product and services from life cycle approach. It provides the basis for a fair comparison between goods and services having the same principal function based on their environmental performances. EPD issues a set of calculation rules dedicated to various groups of products to meet specific methodological requirements to ensure that every EPD will follow the similar procedures. This document is called PCR (Product Category Rules) and they are usually prepared by institutions involving LCA experts in coordination with companies and interest organisations. Eventually, EPD is intended to stimulate the potential for market driven continuous environmental improvement.

Evaluating Waste Management and Strategies

LCA can be applied in waste management in order to compare the environmental performance of alternative waste treatment system to identify area in need of a system performance. It can help to identify the significant environmental burdens and eventually help strategic planning and decision making process in waste management.

1.8 Sectors of Application of Life Cycle Assessment

LCA can be applied in various fields, for example in automotive industry, consumer goods, building and construction, agriculture, electronics, food and beverage industry, and so on.

CHAPTER 2 – Food and Beverage Industry and Packaging Overview

2.1 Food and Beverage Industry Overview

2.1.1 Global Trends of Food and Beverage Industry

Food and beverage industry is an industry which includes three major subdivision : farming, processing, and distribution (Imap report on food and beverage industry, 2010). Food and beverage industry is a major industrial sector in developed as well as developing countries worldwide. In countries like New Zealand, Mexico, Brazil, and Australia, the relative share of the total manufacturing food and beverage industry is prominent, accounting for almost one fourth of manufacturing output (FoodDrinkEurope). This shows that in the mentioned countries, food and beverage industry play an important role in manufacturing process.

Table 2 - 1 Food and Drink Industry Worldwide, 2009
Source : FoodDrinkEurope

Food and drink industry worldwide, 2009

	Total sales (€ billion)	Total sales compared to previous year (%)	% of total manufacturing sales	Employees (x1000)
Australia*	49.1	0.1	17.0	206
Brazil*	103.9		17.5	1,412
Canada*	55.8	-0.4	13.5	240
China	379.0		9.1	5,827
Japan	223.2	-0.7	11.8	1,400
Mexico*	33.6	1.6	21.0	309
New Zealand	16.7		32.0	63
Korea	32.2	1.4	6.0	265**
United States	393.9	5.4	10.8	1,661

(*) 2008 data
(**) 2006 data

Source: CIAA calculations, available upon request

In terms of share value, EU and USA are the largest share in world food and beverage exports. The EU are the world's largest food and beverage exporters having an export value of 77.2 billion dollars which is 18.6% world's share. In terms of exporters, the US, Brazil, and China follow behind the EU respectively. The EU is also the biggest food and beverage importer, having the imports value in 2009 around 72 billion $. Figure 2-1 shows the overall share value in world food and beverage exports. Table 2-2 shows the top exporters and importers of food and beverage products in 2009.

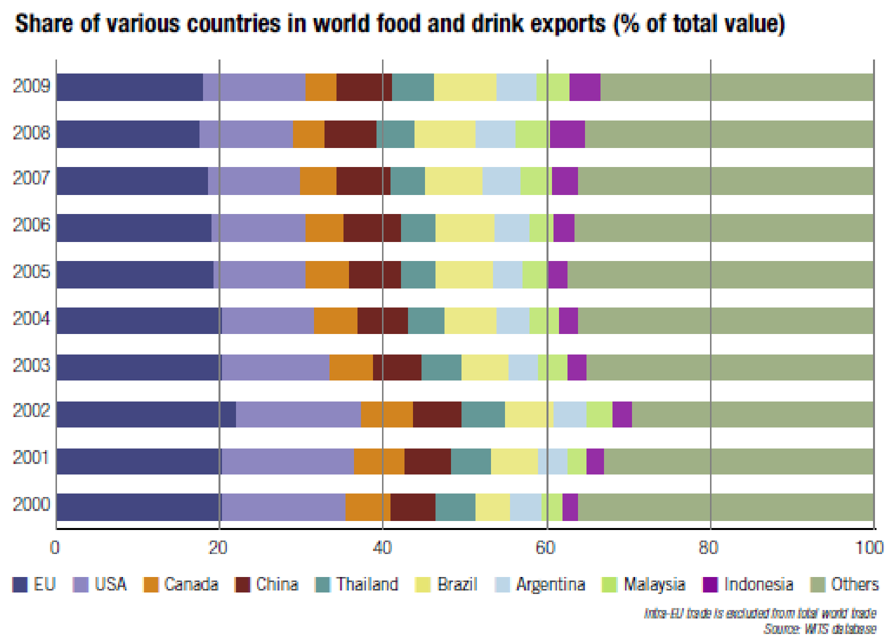

Figure 2 - 1 Share of various countries in world food and drink exports
Source : FoodDrinkEurope

Table 2 - 2 The 15 biggest food and drink exporters and importers (2009)
Source : FoodBeverageEurope

Top 15 exporters of food and drink products, 2009

	Exports ($billion)	*Share in world (%)*
European Union	77.2	18.6
United States	49.6	11.9
Brazil	32.4	7.8
China	28.0	6.7
Thailand	21.2	5.1
Argentina	20.7	5.0
Canada	16.7	4.0
Indonesia	15.9	3.8
Malaysia	15.8	3.8
Australia	12.3	3.0
New Zealand	12.1	2.9
India	9.5	2.3
Mexico	8.8	2.1
Chile	7.6	1.8
Switzerland	6.2	1.5

Intra-EU is excluded from world trade — *Source: WITS database*

Top 15 importers of food and drink products, 2009

	Imports ($billion)	*Share in world (%)*
European Union	72.0	17.6
United States	63.5	15.6
Japan	39.0	9.6
China	20.9	5.1
Canada	18.6	4.6
Russian Federation	18.2	4.5
Mexico	11.2	2.7
South Korea	10.8	2.7
Hong Kong	10.8	2.6
Australia	7.9	1.9
Switzerland	7.2	1.8
India	6.9	1.7
Malaysia	6.7	1.6
Saudi Arabia	6.6	1.6
Singapore	5.8	1.4

Intra-EU is excluded from world trade — *Source: WITS database*

In terms of labour productivity however, industrialised countries are one step further. In developing countries labour productivity is much lower. The labour productivity of the food and drink industry worldwide is shown in table 2-3.

Table 2 - 3 Labour Productivity of the food and beverage industry worldwide
Source: FoodDrinkEurope

Productivity of the food and drink industry worldwide

	Labour productivity (output in € per employee) x1000 2008	2009
Australia	238	
USA	236	237
Canada	242	
EU	**214**	**214**
Japan	157	159
Korea		122
Mexico	103	109
Brazil	74	
China	49	65

(*) 2008 data — Source: CIAA calculations, available upon request

Table 2-4 shows the world's largest food and beverage companies in terms of global sales. On top five are Switzerland's multi-products Nestlè, followed by Cargill, a Minnetonka-based privately held multinational corporation whose major businesses are in grain and agricultural commodities, Archer Daniels Midland, Decatur-based agribusiness and food processing industry, PepsiCo, Kraft Foods Inc., and The Coca-Cola Company, all of them are from the United States.

Food and beverage industry is a relatively less affected by economic crisis compared to other industries since food product is essential to consumers. In developing countries, development in food and beverage industry is driven by the population growth, favourable demographics, and the rising income level. In developed countries instead, the development is driven by the rising health consciousness and the need for convenience foods (imap reports, 2010).

Table 2 - 4 Ranking of world agri-food companies by global food and drink sales
Source : FoodDrinkIndustry

Ranking of world agri-food companies by global food and drink sales

Name	Head-quarter	Fiscal year end	Sales in € billion	Growth to previous year (%)	Employees (x1000)	Main sectors
Nestlé	CH	Dec10	82.7	6.2	281	*multi-product*
Cargill	US	May10	79.3	-6.2	131	*multi-product*
Archer Daniels Midland	US	Jun10	45.9	-11.0	29	*cereal processing*
PepsiCo Inc.	US	Dec10	41.4	34	285	*beverages, snacks*
Kraft Foods Inc.	US	Dec10	37.1	27	127	*dairy, snacks, beverages*
The Coca-Cola Company	US	Dec10	26.5	13	140	*beverages*
Anheuser-Busch InBev	BE	Dec09	25.0	2.5	116	*beer*
Unilever Plc/Unilever NV*	NL/UK	Dec10	22.8	8.1	167	*multi-product*
Mars	US	Dec10	22.6		65	*prepared food, confectionery*
Tyson Foods Inc.	US	Sept10	21.4	6.4	115	*meat*
SABMiller Plc	US	Mar10	18.9	4.0	70	*beer*
Groupe Danone	FR	Dec10	17.0	6.9	81	*dairy, waters, baby &med. nutrition*
Kirin Brewery Company Ltd	JP	Dec10	16.7	4.4	35	*beer, alcoholic beverages*
Heineken N.V.	NL	Dec10	16.1	9.7	66	*beer*
Asahi Breweries Ltd.	JP	Dec09	16.0	0.7	17	*beer, alcoholic beverages*
Suntory Ltd.	JP	Dec10	15.0	12.4	25	*alcoholic beverages*
Associated British Food	UK	Sep10	11.7	12.0	97	*sugar, starch, prepared foods*
Diageo Plc	UK	Jun10	11.4	5.0	23	*alcoholic beverages*
General Mills Inc.	US	May10	10.3	1.0	33	*prepared foods*
ConAgra Foods Inc.	US	May10	9.1	-5.1	24	*prepared foods*
Kellogg Company	US	Dec09	9.0	-0.7	31	*breakfast cereals, convenience food*
Vion	NL	Dec09	9.0	5.0	27	*multi-products, ingredients*
Lactalis	FR	Dec09	8.5			*dairy products*
Fonterra	NZL	Jul10	8.2	4.0	16	*dairy products*
Royal FrieslandCampina NV	NL	Dec09	8.2	0.1	20	*dairy products*
Dean Foods Company	US	Dec09	8.0	-9.7	27	*dairy products*
Smithfield Foods Inc.	US	Apr10	8.0	-10.4	48	*meat, processed foods*
Sara Lee Corporation	US	Jun10	7.9	0.8	33	*prepared foods*
HJ Heinz Company	US	Apr10	7.7	4.8	33	*prepared foods*

(*) Food and personal care products included

Source: CIAA, available upon request. The exchange rates are from ECB (2010) bilateral exchange rates series

2.1.2 Food and Beverage Industry in European Union

In the EU, the food and beverage industry plays a significant role in economic sector. Based on the data of FoodDrinkEurope, in 2007 there were about 310,000 food and beverage companies. In 2010, there were about 4.2 million people working in the sector.

Table 2 - 5 Labour productivity of Food and Drink Industry
Source : FoodDrinkEurope

Labour productivity, profitability and investment in the manufacturing industry

	Labour productivity[1] €1000	*Gross operating rate[2] %*	*Investment per employee €1000*
Manufacturing	52.5	9.6	7.6
Food and drink products	42.7	9.1	8.0
Automobile	68.9	5.8	11.8
Basic metals	80.2	10.0	13.9
Chemicals	104.2	12.8	15.6
Textiles	30.0	9.0	4.2

(1) Value added per employee
(2) The gross operating rate is the gross operating surplus expressed as a percentage of the turnover generated. The gross operating surplus is value added minus personnel costs. It is an indicator of profitability.

Source: Eurostat, SBS, 2007

Labour productivity per person employed, 2004-2009, annual growth rate (%)

	2004	*2008*	*2009*	*2004-2009*
Manufacturing	4.7	-1.6	-8.2	0.4
Food products	3.3	-0.6	1.4	1.2
Drinks	-1.2	-0.7	4.5	2.8

Source: European Competitiveness Report 2010

This makes the food and beverage as one of the largest manufacturing sector in EU. The turnover value in 2009 reached up to 954 € billion which made it as the second leading manufacturing sector in terms of value added. Figure 2-2 Shows the turnover share of food and beverage sector in the manufacturing industry among EU countries.

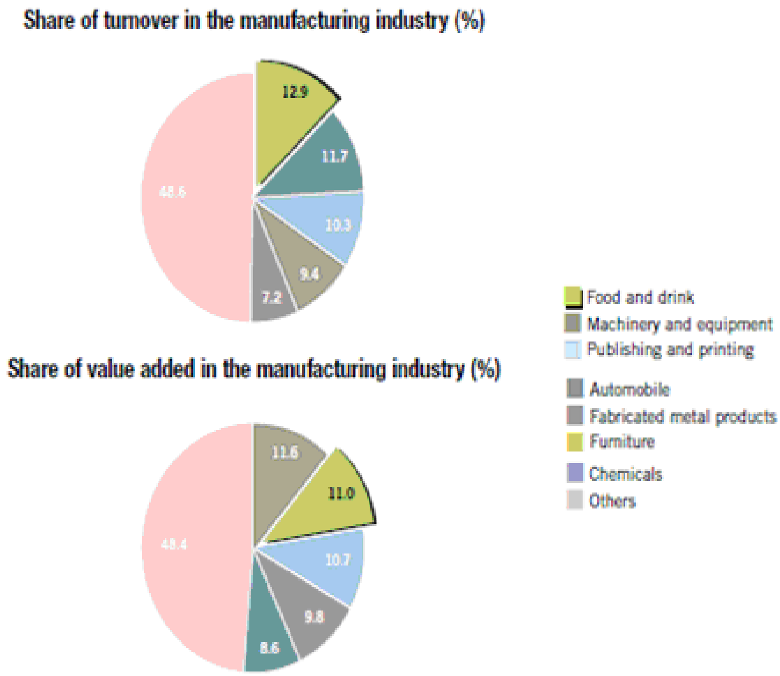

Figure 2 - 2 Share of turnover and value added in European Manufacturing Industry (%) in 2007
Source : FoodDrinkEurope

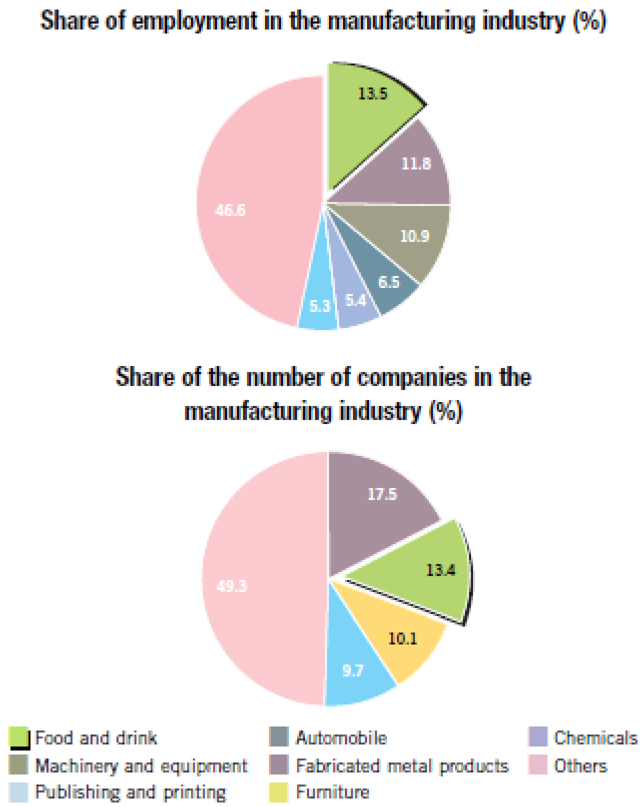

Figure 2 - 3 Share of employment and the number of companies in the manufacturing industry (%)
Source : FoodDrinkEurope

The food industry is divided into nine main sub-sectors :

1. Meat products
2. Oil and fats
3. Animal feeds
4. Fish products
5. Dairy products
6. Various food products
7. Processed fruit and vegetables
8. Flour and starch products
9. Beverages

In terms of turnover, dairy products, meat products, beverages, and various food products are the major contributors by representing 75% of the value. These four sub sectors also represent the biggest number of employees, 84% in total. In terms of value added, these four sectors also give the highest contribution, making up 82% of the total value added from the food and beverage sector. The profile of the turnover, number of employees and value added of various food products is presented in figure 2-4. The various food products subsector is a heterogeneous group which includes bakery, chocolate, pastry, and confectionery products, pasta, and baby food. The profile of this various food products is shown in figure 2-5.

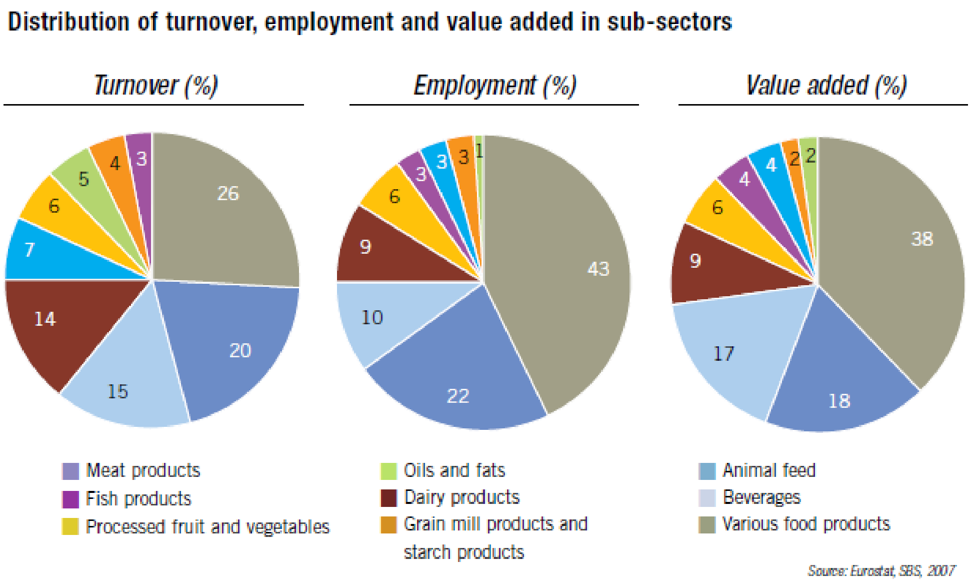

Figure 2 - 4 Distribution of turnover, employment and value added in sub-sectors of food and beverage industry
Source : FoodDrinkEurope (taken from Eurostat data 2007)

The food and beverages manufacturing sector is composed by a relatively small number of companies with global market presence and a big number of small enterprises that serve more local, regional, and national markets. Employment in food and drink sector is relatively stable and it's distributed in a relatively balanced way according to the size of the companies.

Among the 954€ billion of turnover value in European Food and Beverage industry, SMEs represent 450€ billion of turnover which make up 48.2% of the F&B turnover in total. Small and Medium enterprises are defined as enterprises that employ less than 250 people according to EU standard. Based on FoodDrinkEurope report, large companies are primarily based in northern Europe while SMEs are often in the south (Eurostat 2004). Among the European Union countries, Germany, France, Italy, Spain and UK are the largest food and drink producers.

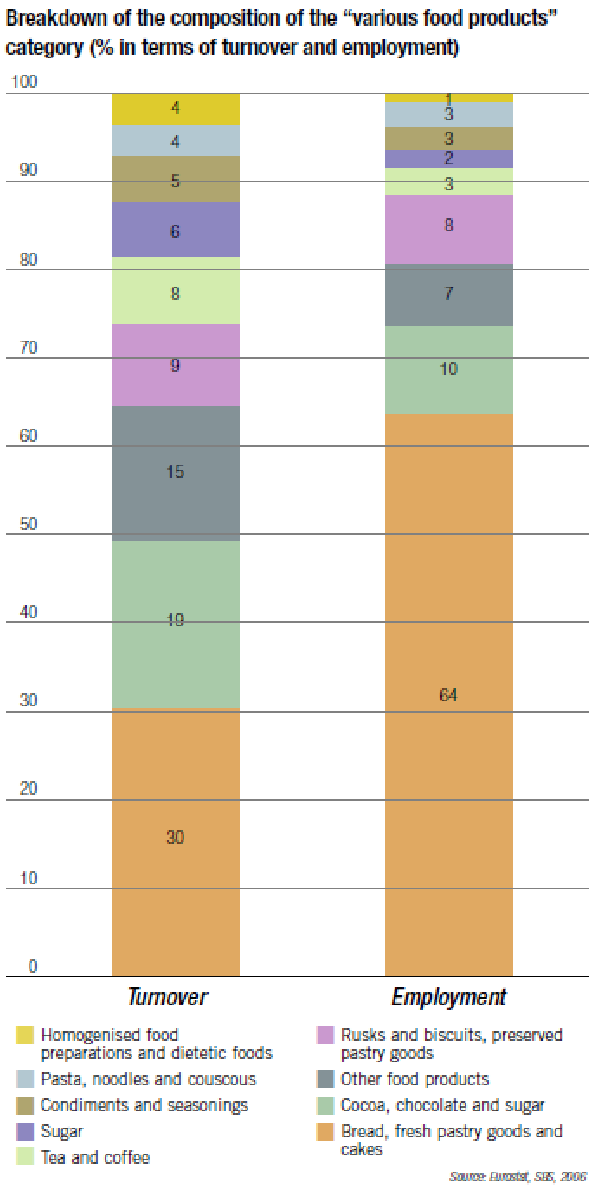

Figure 2 - 5 Various Food Products sector
Source : FoodDrinkEurope

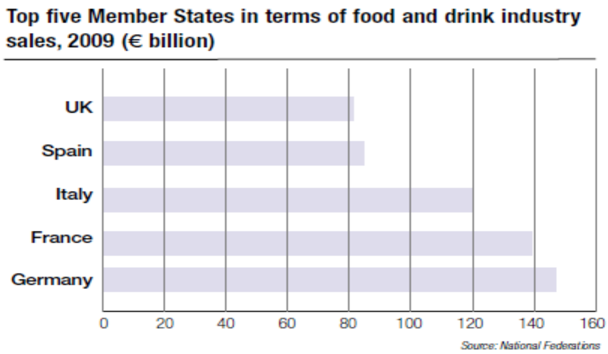

Figure 2 - 6 Top five Member States in terms of food and drink industry sales in 2009
Source : FoodDrinkEurope

The nine biggest food and beverage enterprises in Europe are listed in the table below.

Table 2 - 6 The nine biggest food and beverage enterprises in Europe
Source: FoodDrinkEurope

	Country	Main products	Food sales (EUR billion)
Nestlé	CH	Multi-product	58.5
Unilever	NL/UK	Multi-product	21.4
Diageo	UK	Alcoholic beverages	14.3
Danone	FR	Dairy products; multi-product	14.1
InBev	BE	Beer	13.4
Cadbury Schweppes	UK	Beverages, confectionery	10.9
Heineken	NL	Beer	8.7
Lactalis	FR	Dairy products	7.5
Associated British Foods	UK	Sugar, starches, prepared foods	8.8

Source: CIAA, http://www.ciaa.be

2.1.3 EU Trade with non EU countries

EU food and beverage industry export in 2009 reached €53.7 billion. The largest markets for the export activity are U.S, Russia, and Japan which was estimated to contribute one third of EU food and drink exports in the same year.

Table 2 - 7 Exports and Imports to and from emerging countries (2000-2009)
Source : FoodDrinkEurope

Exports to emerging countries, 2000-2009

	Rank[1]	2009 € million	2009/2000
China	7	1,657	↗284%
Turkey	16	735	↗78%
Brazil	18	701	↗41%
South Africa	19	682	↗142%
Mexico	24	472	↘-18%
Thailand	26	423	↗11%
Morocco	27	403	↗60%
Malaysia	31	358	↗29%
Philippines	32	313	↘-11%
Indonesia	33	263	↘-10%

(1) Rank in top countries of destination for EU food and drink exports — Source: Eurostat, Comext

Imports from emerging countries, 2000-2009

	Rank[2]	2009 € million	2009/2000
Brazil	1	5,899	↗69%
Argentina	2	5,062	↗76%
China	3	3,114	↗130%
Indonesia	6	2,426	↗124%
Thailand	7	2,227	↗87%
Turkey	8	1,601	↗74%
Chile	11	1,316	↗97%
India	12	1,129	↗82%
Malaysia	13	1,057	↗63%
Morocco	14	925	↗51%

(2) Rank in top countries of origin for EU food and drink imports — Source: Eurostat, Comext

The major food and beverage export product sectors to non-EU countries are various food products, beverages, meat, and dairy products and ice cream. These sectors altogether contributed more or less 80% of EU food and beverage exports. The complete figure of the exports by sector is shown in table 2-8.

Table 2 - 8 Exports of EU contries to non-EU countries by Sector in Food and Beverage Industry (2008-2009)
Source : FoodDrinkEurope

Exports by sector 2008-2009 (€ million)

	2008	2009	'09/'08
Various food products	16,106	15,932	-1%
of which biscuits, preserved pastry goods	1,425	1,439	1%
chocolate and confectionery	3,183	3,287	3%
coffee and tea	3,136	3,043	-3%
Beverages	17,613	15,792	-10%
of which spirits	6,174	5,688	-8%
wines	6,140	5,274	-14%
mineral waters and soft drinks	2,058	1,823	-11%
Meat sector	6,139	5,498	-10%
Dairy products and ice cream	6,554	5,255	-20%
Animal and vegetable oils and fats	2,992	2,718	-9%
Processed fruit and vegetables	2,751	2,643	-4%
Flour and starch products	2,063	1,899	-8%
Fish products	1,983	1,860	-6%
Prepared animal feed	1,220	1,225	0%

Source: Eurostat, Comext

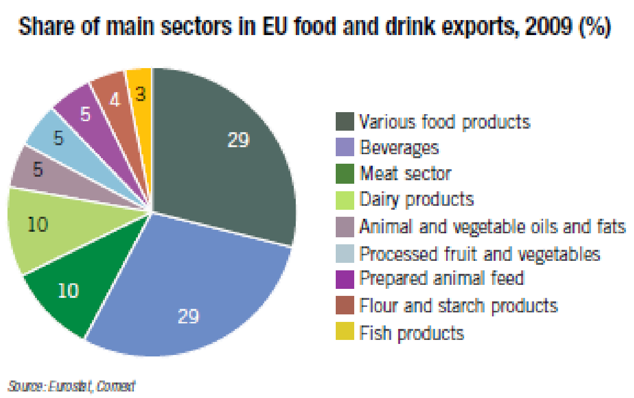

Figure 2 - 7 Share of main sectors in EU food and drink exports in 2009 (%)
Source : FoodDrinkEurope

2.1.4 Packaging in Food and Beverage Industry

In order to preserve the quality of foods and beverage and to enable them to travel until they reach the consumers safely, packaging technology is required. Packaging technology in its historical development has attempted to decrease the volume or weight of materials in order to minimize resources use and costs (Han, Jung, 2005).

In The United States, Food and beverage packaging represents 55% to 65% of the 130$ billion value of packaging. Food processing and packaging industries spent approximately 15% of the total variable costs on packaging materials (Brody, et al. 2008).

According to the Global Packaging Alliance (GPA), the European packaging market worth is estimated as US$ 127 billion. The breakdown of European Packaging industry is shown in figure 2-8. Germany and the UK lead by contributing 20% of the total market worth each. The major European countries in packaging industry are shown in figure 2-9.

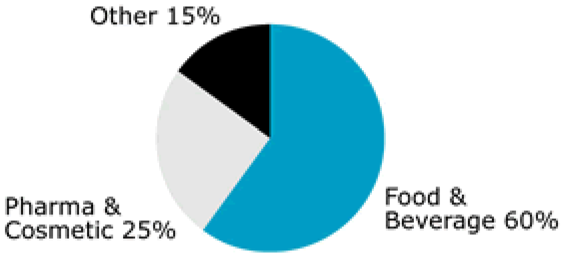

Figure 2 - 8 European Packaging Sector Breakdown
Source : Global Packaging Alliance, 2011

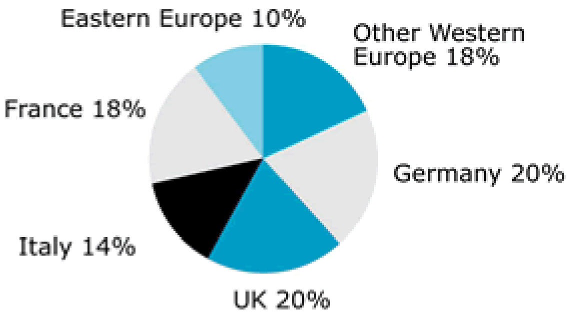

Figure 2 - 9 Regional Breakdown of European Packaging Industry
(Source : Global Packaging Alliance, 2011)

Food and Beverage accounts for the biggest sector in European Packaging, with 60% of value, followed by Pharma and cosmetic industry at 25%. This fact is supported by the report of Emballage 2012, which stated that the major packaging machinery markets are foods (40%), beverages (20%), pharmaceuticals and cosmetics (20%). The rest is other industries, for example construction. World production of packaging and containers in 2006 reached 454 billion US$, of which 128 billion US$ was contributed from Europe, 114 billion US$ for Asia.

Regarding the world production of packaging machinery, Germany is the world's leading producer and exporter with its 23% market share in 2006. The major packaging machinery markets remain packaged foods (40%), beverages (20%), pharmaceuticals and cosmetics (20%), and other industries.

2.2 Types of Food and Beverage Packaging and Related Manufacturing Process

2.2.1 Introduction

Packaging plays an important role in food and beverage industry. Packaging has a fundamental function to protect the food or drink product by providing protection from external influences such as chemical, biological, and physical that might cause damages to the product. Packaging can maintain the quality and safety of the products and extend their shelf-life and prevent food wastage.
According to its function, packaging is divided into primary, secondary and tertiary packaging. Primary packaging is the material that first envelop the product and comes into contact with the product. It is usually the smallest unit of distribution. Secondary packaging is the material used to enclose the primary packaging. Tertiary packaging is packaging used to group secondary packaging, give protection to the products during transport, and aid in bulk handling, storage, and warehouse.

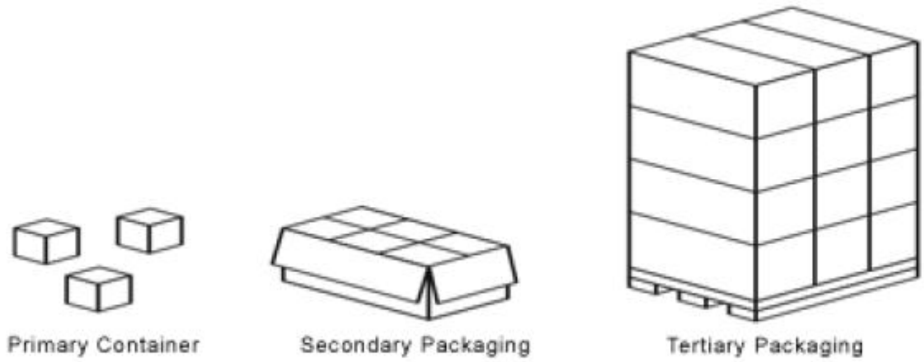

Figure 2 - 10 Three levels of packaging
Source : Nordic Wine LCA

The successful packaging and food technology is reflected by the fact that the contents of billions of packs are being safely consumed everyday (Coles, 2003). An optimum level of packaging is crucial in order to minimise food waste throughout the supply chain and save cost. Approximately 30-50% of food produced in less developed countries are wasted due to inadequate means of preservation, protection, storage, and transportation (WHO). In developed counties, food wastage before it reaches the consumer is only 2-3% because of the already-existing modern processing, packaging and distribution (Coles, 2003).
Packaging is used as a communication tool to the consumers. It is a media to provide information to the consumers about the products, for example regarding the nutritional value, ingredient, and the disposal information of the packaging itself. Packaging also serves a function as a marketing tool, being designed in a way to attract people.

Figure 2 - 11 Various food and beverage products and their packaging
Source http://www.brown-machine.com

Other functions of packaging include providing traceability of a product, giving convenience to the consumers such as ease of handling, carrier of a present, etc. Depending on the type of the product contained and the function needed, there are basic packaging materials available in the market. These materials include glass, paper, plastics, and metal.

2.2.2 Types of food and beverage packaging material

2.2.2.1 Glass

Humans have been using glass for over 4000 years. Glass is composed by a mixture of purified sand heated with sodium and calcium carbonate together with some sodium sulphate. Calcium is necessary to make the glass insoluble in water. Common glass is made from sodium and potassium calcium metasilicate with metal ions like Pb, Ba, Fe, and Co. By replacing the silicate with borate or phosphate, different variety of glasses can be made. The two main types of glass container used in food packaging are bottles with narrow necks, and jars and pot with their wide openings.

Figure 2 - 12 Glass bottles
Source : http://www.winebussiness.com

There are several qualities of glass that make it good to be utilized as food and beverage packaging material, they are :

1. Safety; glass is an inert material therefore it's beneficial from a health and hygiene viewpoint
2. Product compatibility; glass enables liquid and solid foods to be stored for a long period of time without adverse effects on the quality or flavour of the product.
3. Consumer acceptability; it's preferable by consumers because of the aesthetic appeal, quality perception, preferred taste, product visibility that is associated with appetite appeal and the resealability of glass.

Glass and Glass Container Manufacture

The glass and glass container manufacture follows several steps; melting, container forming, and surface treatments which are composed by hot end treatment and cold end treatment. Each of these steps are explained briefly in the following sections.

1. Melting Process

   In this process, glass is melted at furnace at 1350°C, and it's homogenized in the melting process, producing a bubble-free liquid. The molten glass is then put into flow through a temperature controlled channel to the forming machine into the feeder.

2. Container forming

   The molten glass in the feeder is extruded through an orifice of known diameter at predeterminated rate and is cropped into a solid cylindrical shape, known as a gob. This gob is then allowed to enter a series of deflectors into the forming machine, entering the parison which comprises a neck finish mould and a parison mould. The parison is then reinverted and placed into the final mould, and blown out to the shape of the final mould at temperature of more or less 650°C. There are two primary methods of making a glass container; the blow and blow method and the press and blow method. The first one is used for narrow neck containers and the second one is used for jars and increasingly narrow neck containers. The forming phase utilizes forming machines. The forming machines hold and move the parts that form the container. This machine is usually powered by compressed air and the mechanisms are timed to coordinate the movement of all these parts so that containers are made.

3. Surface Treatments

   Surface treatment is applied to the container as soon as it is formed. There are two stages in surface treatments, hot end and cold end treatment.

   Hot End Process

   Hot end process is aimed to prevent surface damage while the bottle is still hot and to help maintaining the strength of the container. In this process tin oxide is commonly used as a coating material. Lubricant is also added to overcome the problem of high friction surfaces generated from this treatment. The furnace in the hot end of glassworks works form the molten glass into glass products. The batch in this system is fed into the furnace at a slow and controlled rate. Furnaces are natural gas or fuel oil fired and operate at temperature up to 1575°C. After the forming process is done, some containers undergo a treatment to improve the chemical resistance of the inside. This process is called internal treatment or dealkalization, which is done by the injection of sulphur or fluorine containing gas mixture into bottles at high temperature. The treatment will result in the production of containers that are more resistant to alkali extraction, which can cause pH increase in the product and some container degradation.

When the glass cools down unevenly, it shrinks and solidifies and poses to risk of weak glass due to stress. An Annealing oven (known as Lehr in industry) works to make an even cooling for 20-6000 minute period depending on the glass thickness.

Cold end treatment process

After the annealing process, cold end process is applied. The purpose of the cold end process is to create a lubricated surface that does not break down under the influence of pressure or water, helps the flow of containers through a high speed filling line. This process is conducted to inspect the containers for defects, package the containers for shipment and label the containers. Some typical faults include small cracks in the glass and foreign inclusions, bubbles, and tear.

After these processes are done, an inspection to the container quality is done to ensure that consumer safety, brand owner's needs and efficiency in handling, packing, distribution and merchandising are achieved.

2.2.2.2 Paper

Paper and paperboard are widely used as packaging, accounting up to one-third of the total packaging market. The use of paper and paperboard for packaging purpose increased during the end of 19th century to satisfy the needs of manufacturing industry. Paper packaging is used for dry food products, liquid foods and beverages, frozen foods, fast foods, fresh foods, and confectionery.

Figure 2 - 13 Example of paper packaging for pasta product by Barilla
Source : www.comunicandoweb.com

The paper and paperboard market size (2007) valued 630.9 billion USD and had a volume of 320.3 million metric tons. Around 40.1% of that market is European. About 50% of all produced paper is used for packaging, followed by printing and writing.

Some fundamental properties of paper and paperboard are :

1. It is a low density material
2. It has a good stiffness and it is not brittle
3. It can be modified into a grease resistant material
4. It can be torn easily
5. It is a poor barrier to light, liquids, gases and vapours, unless they are coated, laminated or wrapped
6. It's an absorbent to liquids and moisture vapour

Paper making Process

Paper are sheet materials composed by a network of cellulose fibres derived from wood. The papermaking process has come a long way since 105 A.D. in China. Paper was manufactured for the first time in Italy in 1220 and in 1400 in Germany. Since that time, the principle of papermaking has remained essentially the same, but the technology has become much more efficient. Modern papermaking began in the early 19th in Europe. On 16th February 1665, Charles Hildeyered received a patent for 'The way and art of making blew paper used by sugar-bakers and others', noted as one of the earliest references of the use of paper for packaging food product (Food Packaging Technology, 2003).

Paper fibre nowadays comes principally from two sources, wood and recovered paper. Trees used for papermaking are specifically grown and harvested for that purpose. The amount of fibre is expressed by the weight per unit area (grams per square metre g/m^2) known as grammage, or thickness (in microns, inch, thou).

The process of papermaking begins with passing logs through a debarker, that would cut the wood into pieces then pressure-cooked with a mixture of water and chemicals in a digester. Paper is made from a pulp mixture of 1 percent fibre and 99 percent water. The mixture also includes other additives such as dyes, resins, fillers that provide paper and paperboard with different characteristics necessary for its final use.

Pulping Process

There are three forms of pulping : mechanical pulping, chemical pulping and recycled pulping. Each of these processes are explained in the following paragraphs.

Mechanical pulping

There are two major mechanical pulps, thermomechanical pulp and groundwood pulp. The groundwood process involves grinding wood and mixing the fibres with water. In thermomechanical pulp process, wood is chipped and fed into large steam-heated refiners where the chips are squeezed and made into fibres between two steel discs. In this process, wood chips that are ground under pressure will produce heat that will weaken the lignin in the wood chips, making the separation of the fibres easier.

Chemical pulping

In chemical process pulping, some chemicals such as sulphate is utilized. The wood chips are cooked along with various chemicals in a high pressure vat. The purpose of chemical pulping process is to break down the chemical structure of lignin and make it soluble in the cooking liquor, therefore to wash away the cellulose fibres.

The characteristics of the resulting pulp are generally much more favourable in terms of overall strength, colour, and durability. There are six types of pulp produced by chemical pulping : chemical pulp, desolving pulp, fluff pulp, Kraft pulp, sulphite pulp, and unbleached pulp.

The manufacture process of paper and paperboard

Paper and paperboard manufacture process follows these steps :

1. Stock preparation

   Pulp is dispersed in water in hydropulper, in this phase additives can be added such as Fluorescent whitening agents to increase whiteness and brightness of the paper.
2. Sheet forming

   Fibre in water suspension is formed in an even layer by depositing the suspension of fibre at a constant rate onto a moving plastic mesh. The result of this process is a layer of entangled fibre from which water is then removed by drainage.
3. Pressing

   The sheet is sufficiently consolidated by removing the water to support its own weight to transfer into the press section. In this process, the sheet is held between absorbent blankets and gently pressed using steel rolls. Vacuum assistance is also utilized to reduce the moisture content to about 60-65%.
4. Drying

   Drying process is done by passing the sheet over steam heated cylinders, resulting in the reduction of moisture content up to less than 10%, depending on grade.

5. Coating

   It is the process of application of white pigmented coating to one or both sides of many types of paper and board on machine. Multiple coating layers can be applied. In the end of this process, the sheet is dried by passing the sheet over steam heated drying cylinders.

6. Reel up

   The paper on board is reeled up prior to finishing

7. Finishing

   In this process, large diameter full machine with reels of paper and board are slit into narrower reels of the same or smaller diameter and cut into sheets to meet customer and market needs.

However, more functional properties of paper and paperboard can be added by applying additional process, such as delaying the rate at which water is absorbed (sizing), lamination process to apply decorative material or another functional, plastic extrusion coating and laminating for heat sealing function, printing and varnishing process to improve the appearance, post printing roller, varnishing, coating, and laminating paper and paperboard materials.

There are some common paper products types used for packaging. Some of them are :

1. Containerboard or Corrugated Containers

Containerboard is made on modified paper machines than can handle higher grammages. In the United States, corrugated boxes ship more than 95% of all products because of its strength and convenience. Container board is made mainly out of natural unbleached wood fibres, therefore it's generally brown.

Containerboard is solid fibre or corrugated and combined board used in the manufacture of shipping containers and related products. Containerboard is made up by two types of paper, linerboard and corrugating or fluting medium. Linerboard makes up the outer shell, which contains the ruffled corrugated medium. The fluted corrugating material helps it stay in face and the outer shell protects the flutes from damage. Containers made from these materials can protect product both from external forces and sudden temperature changes. Arches of the flute act like springs when given a pressure and the air trapped between the flutes acts as a cushion as well serve as a thermal insulator.

The benefits of corrugated boxes lie on its strength and convenience. Corrugated box is designed to be stacked, it can resist against top and side pressure, and it is crush resistant. Corrugated boxes are also relatively lightweight and can be broken down for easy transport. It is also very designable, it can be cut and folded into various shapes and the surface can be printed.

2. Kraft Paper

Kraft paper is made from wood pulp produced by a modified sulphate pulping process. Bleached and unbleached Kraft paper is used for paper grocery bags, multiwall sacks, and other consumer and industrial packaging.

3. Paperboard

Paperboard is a thick paper based material, usually more than 0,25 mm/0,010 inch. Paperboard is lightweight, strong, can be easily cut and formed.

Paperboard is made by fibrous material that come from virgin sources or from recycled waste paper. These fibrous materials are turned into pulp and then bleached to create one or more layers of board. These layers are pressed together to make a stiff board. This stiff board be optionally coated to create a better surface and also to improve their visual appearance. Paperboard can be made from bleached, unbleached, or recycled fibre.

Bleached paperboard is made from virgin solid bleached sulphate pulp, examples of this type are milk and juice cartons. Recycled paperboard is made from a combination of recovered fibres for example from newspaper and corrugated cardboard. Examples of this type usually may have one side of the paperboard gray in colour, like cereal box, detergent boxes, toy and hardware boxes, and so on. Unbleached paperboard is made from predominantly unbleached Kraft fibre and may contain some recycled content. Examples of this type of paperboard are beverage carrying cases and folding cartons.

Today it is mandatory in many countries for paper-based packaging to be made totally or partially from recycled material because of the increasing attention to environmental, health, and regulatory issues.

2.2.2.3 Metal Cans

A can is a sealed container for the storage or distribution of good, and it is composed of thin metal. Tin cans are made of tin-coated steel or aluminium (which is called tin cans in some places).

The process of canning was found in 1790 by a French confectioner, Nicolas Appert when he discovered the application of heat to food in sealed glass bottles preserved the food from deterioration. In 1806 these principles were successfully tried by the French Navy to preserve many types of foods, among them are meat, vegetables, fruit, and even milk. The tin can was patented in 1813 by Peter Durand, which works based on the work of Nicolas Appert. The very first canned goods were produced in 1813 for the British Army. In 1901, the American Can Company was founded and at the time they satisfied 90% of United States tin cans.

It is estimated that the total world market for metal containers reach 410 billion units per year, composed by 320 billion of drink cans (non-carbonated drinks and carbonated beverages) and 75 billion of processed food cans, and the rest is aerosol and general line cans.

Some important properties of tinplate and aluminium (therefore, metal cans) are :

1. It is a rigid material, high density for steel and low density for aluminium
2. It has a good tensile strength
3. It is a good barrier to light, liquids, and foods
4. It however needs closures, seams, and crimps to form packs
5. There is the risk of reacting with product which may cause the dissolution of the metal.

Figure 2 - 14 Metal cans
Source : http://www.themoralliberal.com

To perform as safe packages for foods to be delivered to the consumer, metal must follow the basic functions :

1. Preserving and protecting the product, resisting chemical actions of products
2. It must resist the handling and processing conditions and environmental conditions
3. Possessing correct dimensions and interchangeable with similar products from other supply sources
4. Having the required shelf display properties at the point of sale
5. Easy opening and simple and safe product removal

6. Being constructed from recyclable raw materials
7. All the functions mentioned above must perform perfectly until the end of the stated shelf life period

Raw Materials for Can-Making

Generally, in can making, steel and aluminium are used as raw materials, because they are both relatively low cost and non-toxic, with adequate strength and are capable of being work hardened.

Steel

Steel is produced at the Basic Oxygen Steel making Plant. The main materials used in this process are molten iron made in the blast furnace, scrap steel, and various alloy addition to obtain the required steel chemistry and metallurgy. The molten steel is continuous cast into slab form and the slabs are rolled hot in the hot strip mill coils of steel strip with a thickness of 2 mm. Tinplate is created by electrolically coating black plate with a thin layer of tin on both sides of the plate. In the tin mill, these coils are cold rolled to the final thickness, usually in the range of 0,16 to 0,3 mm for food cans.

The tin coating is applied by continuous electro-deposition of tin on to thin steel strip, after which the tinplate is either sold in coil form or cut into sheets for the can manufacturer. Tinplate with sufficient thickness will provide resistance to corrosion properties to steel therefore it's suitable for direct contact with many products. Usually, most foods and drinks require an application of organic coating to the inside surfaces of the tinplate container to provide an inert barrier between the metal and the packed product. This barrier prevents chemical action between the product and container and staining.

Aluminium

Aluminium is usually used for light metal packaging in relatively pure form, with the addition of manganese and magnesium to improve the strength properties.

Can-making process

Basically, the amount of metal in any metal containers make the most significant cost item, and it is related to the metal thickness, temper, and its surface area.

There are three basic operations commonly used in can making process :

1. Drawing ; the operation of reforming a metal sheet without changing its thickness
2. Re-drawing ; the process of reforming a two-piece container into one of smaller diameter

with greater height without changing its thickness

3. Ironing; the operation of thinning the wall of a two-piece can by passing it through hardened circular dies.

Cans for food and drinks can be constructed as three-piece of two-piece containers. Three piece can is constructed from rolling a piece of flat metal into a cylindrical body with a longitudinal seam, together with two can ends that are seamed onto each end of the body. This type of cans are only constructed from steel because aluminium is not suitable for welding. Two-piece cans are made from a disc of metal that is reformed into a cylinder with an integral end making a seamless container.

The closure system for foods and drinks are different depending on their mode of operation. Cans for containing foods need an aperture either total or virtually full internal diameter of the containers through which to remove the product. The aperture for drink can is designed to suit the method of consumption.

Recycling of packaging metal

Aluminium and steel do not experience loss of quality, therefore they are readily re-melted by the metal manufacturers. Post consumer metal packaging waste is collected and finally returned to the metal manufacturers for re-melting.

2.2.2.4 Plastics

According to the EU Directive 2001/62/EC, plastics are organic macromolecular compounds obtained by polymerisation, polycondensation, polyaddition or any similar process from molecules with a lower molecular weight or by chemical alteration of natural macromolecular compounds.

Some important properties of plastics are :

1. Plastics have a wide range of barrier properties
2. It's permeable to gasses and vapours to varying degrees
3. Low density materials with a wide range of physical and optical properties
4. It can be made transparent
5. Plastics are flexible
6. It generally has low stiffness
7. Its tensile and tear strengths are variable
8. Depending on the type of plastic, plastics are functional over a wide range of temperatures

Most of the widely used plastic that we use today, polyethylene, was invented in 1933. In Europe, around 40% of all plastics is used in the packaging sector, making it the biggest sector of plastic usage. Europe's food is packed in plastic packaging at about 50%.

Plastics are widely used for packaging materials and in food processing plant and equipment because they are flow-able, and mouldable under certain conditions, chemically inert, lightweight, and they are cost effective in meeting market needs. Plastics also prove choices regarding transparency, colour, heat sealing, heat resistance, and barrier. Other than that, plastics are resistant to many types of compound, being not very reactive with inorganic chemicals, among them are acids, alkalis, and organic solvents, and it does not support microorganism growth. Plastics are able to protect food from spoilage, and they do not interact with foods.

Figure 2 - 15 Example of plastic packaging application in food industry
Source : www.treehugger.com

In food and beverage packaging, plastics are used as containers, container components and flexible packaging. Some of the examples are rigid plastic containers such as bottles, jars, and pots, plastic lids and caps, components of coatings, adhesives, and inks. Plastic films can be combined with other plastics, coloured, printed, and decorated. Moreover, plastics can be used as coatings and laminations, combined with other materials.

Manufacture process of plastics packaging

The raw material in plastic packaging is supplied by the polymer manufacturer in the form of pellets and in some other applications in powder. This material, also known as resin is first of all changed from solid pellets form to liquid or molten phase in an extruder by a combination of high pressure, friction, and externally applied heat.

Film is one of the products of plastic packaging which has dimension of 100 micrometer thick. Film is utilized as a wrapping product, to make sachets, bags, combined with other plastics and other materials into a packaging based on the needs.

Film is made by following two methods, cast film process and the blown process. The first one extrudes the molten plastic through a straight slot die onto a cooled cylinder, known as the chill roll. The second one, known also as tubular, the molten plastic is continuously extruded through a die in the form of circular annulis, so that it emerges as a tube. Air pressure inside the tube needs to be maintained in order to prevent the tube from collapsing.

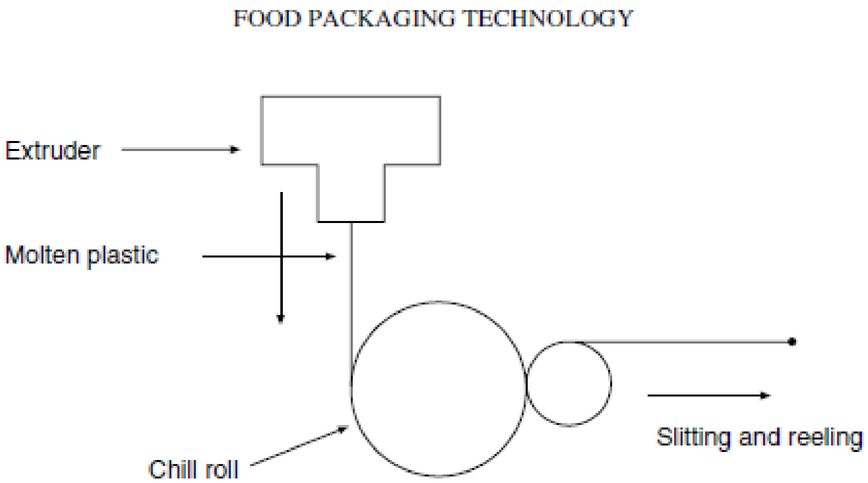

Figure 2 - 16 Production of cast film
Source : Food Packaging Technology

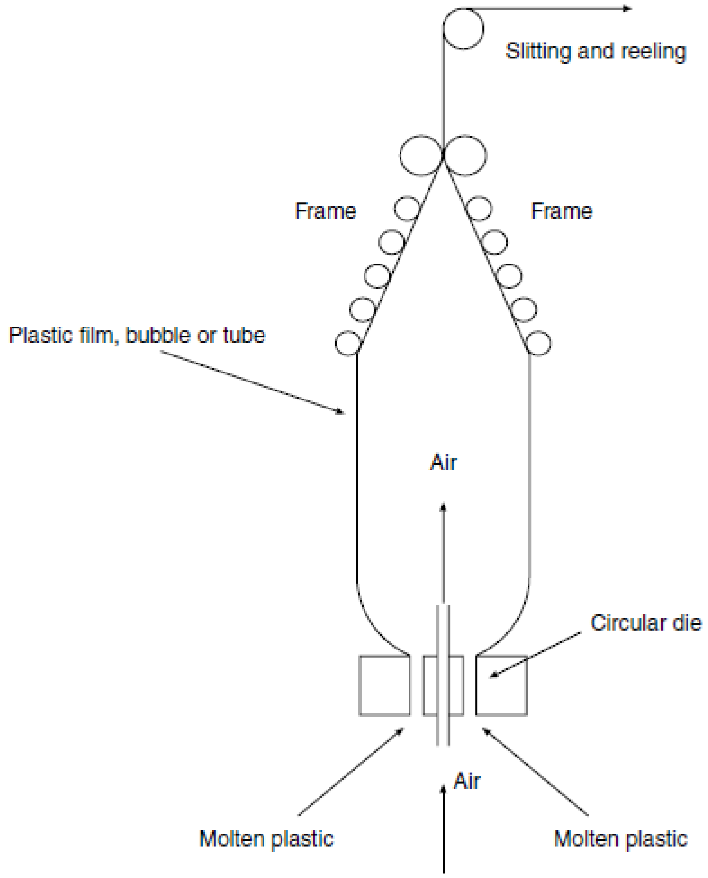

Figure 2 - 17 Manufacture of Blown film
Source: Food Packaging Technology

In order to increase the strength and to improve barrier properties, films can be stretched to realign the molecules in both the machine direction and across the web in the transverse of cross section. Single films, coextruded films and coated and laminated film in reel form are used to make single plastic bags, sachets, pouches, and overwraps.

Bottles are instead made of extrusion blow moulding, which follows the processes such :

1. A thick tube of plastic is extruded into a bottle mould which closes around the tube, resulting in the characteristic jointed seal at the base of the container. Air pressure is used to force the plastic into the shape of the mould.

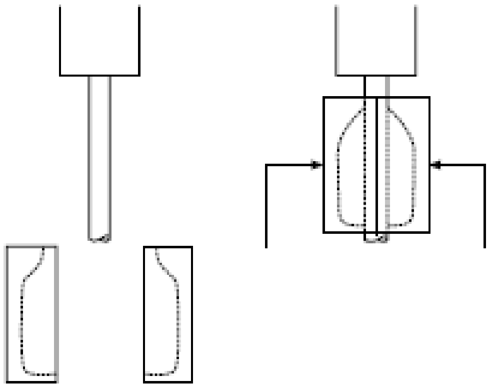

Figure 2 - 18 Parison and mould are ready, then the mould would move over
Source : Food Packaging Technology

2. After cooling process, the mould is opened and the item is removed. The bottles produced form this process will show a thin line in the position where the two parts of the mould are joined.

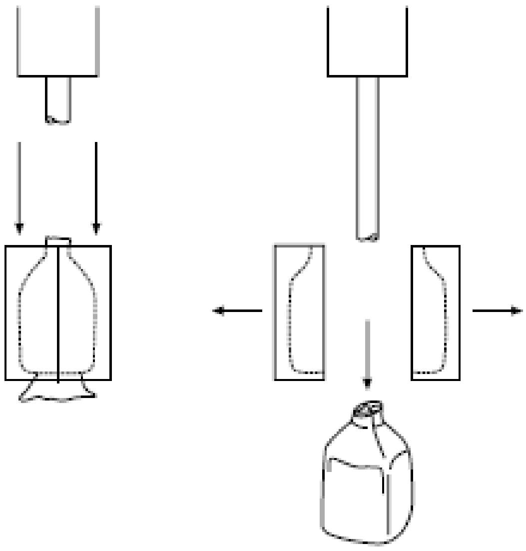

Figure 2 - 19 Plastic bottle forming process
Source : Food Packaging Technology

Some examples of the use of rigid and semi rigid thermoformed containers are dairy products, yoghurt, and single portion pots.

Some types of plastics commonly used for food and beverage packaging are :

1. Polyethylene

Polyethylene or polythene is the most widely used polymer. It is the most popular plastic in the world, it is used mainly for packaging, for example grocery bags, children's toys, etc. Polyethylene was first synthesized by accident by Hans von Pechmann, a German chemist in 1898. The first industrially polyethylene synthesis was discovered by accident in 1933 by Erich Fawcett and Reginald Gibson in Northwich, Enaldn.

Polyethylene is a thermoplastic polymer. It consists of long chains of ethene or ethylene monomer. A molecule of polyethylene is a long chain of carbon atoms with two hydrogen atoms attached to each carbon atom. This is called lineary polyethylene because there is no branching. Sometimes the hydrogen atoms are substituted with longs chains of polyethylene. In that condition, this polyethylene is called branched or low density polyethylene, or LDPE. Linear polyethylene is much stronger than branched polyethylene but it is more expensive and more difficult to make than branched polyethylene.

Polyethylene is created through polymerization of ethene. It is derived from either modifying natural gas or from catalytic cracking of crude oil into gasoline. In its purified form, polyethylene is piped directly from the refinery to a separate polymerisation plant, and under the right conditions of temperature, pressure and catalysis, ethylene monomer forms long chains.

Polyethylene can be produced through radical polymerization, anionic addition polymerization, ion coordination, anionic addition polymerization, cationic addition polymerization, or ion coordination polymerization. Each of these methods produces a different type of polyethylene.

Polyethylene is classified into several different categories based on its density and branching. Among them are HDPE, LLDPE, and LDPE. HDPE is commonly used as a packaging material for milk jugs, detergent bottles, water pipes, and garbage containers. LLDPE is used in packaging, especially to create film for bags and sheets. LDPE is used for rigid containers and plastic film applications such as plastic bags and film wrap. These three different types of polyethylene have different mechanical properties which depend on variables such as the extent and type of branching, the crystal structure, and the molecular weight.

The Polyethylene manufacturing processes nowadays are commonly categorized into "high pressure" and "low pressure" operations. The high pressure process generally will produce conventional low density polyethylene (LDPE) while the low pressure operation will makes high density (HDPE) and linear low density (LLDPE) polyethylene.

High pressure polyethylene production is executed with the addition of oxygen less than 10 ppm, under temperature of 80-300°C, and pressure 1000-3000 bar. The polymerisation reaction that occurs is random and it will produce a wide range of distribution of molecule sizes. Molecule size and the distribution of sizes can be selected by controlling the reaction conditions.

The polyethylene produced by low pressure process is instead much stiffer than the previous one, having a density around 0.940 - 0.970 gram cm-3. This is due to a much lower level of chain branching. The polyethylene production with low pressure method involves Al-based catalyst and under pressure of 10-80 bar and temperature 70-300°C.

Polyethylene can be recycled, but it is not considered to be biodegradable. Most of the commercial polyethylene ends up in landfills and in the oceans resulting in a potential ecological problem.

2. Polypropylene

Polypropylene (PP) is one of the most versatile polymers. It was first polymerized to crystalline isotactic polymer by Giulio Natta and his co-workers in March 1954, and the use of it has developed since then.

PP is similar to polyethylene, except that in polyethylene, one carbon atom in the backbone chain is occupied by a methyl group. Polypropylene synthesis is generally conducted by using metallocene catalysis polymerization and it can be made with different tacticities. Most polypropylene we use is isotactic which means that all the methyl groups are on the same side of the chain. Its counterparts, atactic polypropylene means that the methyl groups are placed randomly on both sides of the chain.

PP owns some qualities that make it good as a food and beverage packaging. PP is chemically inert and resistant to most commonly found chemicals, both organic and inorganic, it is a barrier of water vapour and it has oil and fat resistance. It has a characteristic of being thermoplastic having a melting point at 160°C which is the highest of all the high volume usage thermoplastic, making if suitable for application where thermal resistance is needed. Last but not least, PP is relatively low cost.

Manufacturing of polypropylene is conducted by melt processing through extrusion and molding. Common extrusion methods involve the production of melt-blown and spun-bond fibres to form long rolls for further conversion into a wide range of useful products. The shaping technique commonly involves injection molding, that is used for producing cups, cutlery, containers, housewares, etc.

PP functions both as a plastic and as a fibre. As a plastic it is used to make safe foods containers due to its higher melting point. As a fibre, it is used to make indoor-outdoor carpeting for example around swimming pools. However, the Environmental Working Group classifies PP as of low to moderate hazard.

3. Polystyrene

Polystyrene is an aromatic polymer made from the aromatic monomer styrene which is a liquid hydrocarbon commercially manufactured from petroleum by the chemical industry. Polystyrene is an inexpensive and hard plastic and very common in use in everyday life. Because of its chemical inertness, polystyrene is used to fabricate containers for chemicals, solvents, as well as foods. Polystyrene is commonly flexible and can be present in moldable solids or viscous liquids.

Polystyrene was discovered in 1839 by Eduard Simon, a pharmacist in Berlin. Polystyrene manufacturing for the first time was initiated in Ludwigshafen, Germany in 1931. Polystyrene is a long hydrocarbon chain with phenyl group attached to every other carbon atom. Polystyrene is produced by free radical vinyl polymerization from the styrene monomer.

Polystyrene in foams are good thermal insulators and are often used as building insulation materials for example in structural insulated panel building systems. Other derivative of Polystyrene are expanded polystyrene and extruded polystyrene foam. Polystyrene is not easily recycled because of its light weight and its low scrap value. Polystyrene is not biodegradable for hundreds of years. Polystyrene foam give an environmental impact when its debris are discarded in the ocean. When it is degraded by the weather, it emits suspected carcinogens. Currently, most of polystyrene products are not recycled.

4. Polyester

Polyester belongs to polymers category that contains esther group in their main chain. Depending on the chemical structure, polyester can be a thermoplastic or thermoset. The thermoplastic polyesters can change shape with the application of heat.

Polyester is a synthetic polymer made of purified terephthalic acid (PTA) or dimethyl terephthalate (DMT) and monoethylene glycol (MEG). In its production, antimony trioxide is commonly used as catalyst in order to increase the molecular weight of the polymer.

5. Polytheylene terephthalate (PET)

A common product of polyester group that is commonly used as a packaging material is Polyethylene terephthalate or PET. PET was discovered by Nathaniel Wyeth and PET bottle was pantented in 1973 to the same person. PET is produced by polymerisation of terephthalic acid and ethylene glycol. PET is a thermoplastic resin used in synthetic fibres including beverage, food, and other liquid containers, thermoforming applications, and engineering resins often in combination with glass fibre. Depending on its thickness, PET can be semi rigid or rigid. It is a good gas, moisture, alcohol and solvents barrier.

Figure 2 - 20 PET bottles
Source : http://www.made-in-china.com

Around 60% of the world's PET production is aimed for synthetic fibres, with bottle production accounting for around 30% of global demand. The polyester industry makes up about 18% of world polymer production after polyethylene and polypropylene.

Some characteristics of PET are as follow :

- PET can be made into film by blow or casting process.
- Melts at a much higher temperature compared to PP, typically 260°C, the PET film is also flexible in extremes of cold, down to -100°C
- It is a medium oxygen barrier on its own but it becomes a high barrier to oxygen and water vapour when it's metallised with aluminium.

6. Polyamide (PA)

Polyamide (PA) are commonly known as nylon. At the beginning, it is used in textiles, but nowadays the application also includes the use in packaging. Polyamide plastics are formed by a condensation reaction between a diamine and a diacid or a compound that contains each functional group (amine). Polyamide plastics types are differed by the number of carbon atoms in the originating monomer. PA film is used in retortable packaging in structures such as PA/aluminium foil/PP. It is relatively expensive but it is quite effective in low thickness.

2.2.2.5 Multimaterial Carton Packaging

Multilayer carton packaging saw its history both in the US and in Europe. The first paper used to carry liquids on commercial scale was recorded in 1908 in San Francisco and Los Angeles. This early carton packaging had a problem because the paraffin wax based adhesive came into contact with the contents resulting contamination. Seven years later in 1915, patent for a “paper bottle” known as Pure-pak was granted to John Van Wormer that soon in 1928 was acquired by American paper bottle company. In 1937 it was remembered as the first full year which put Pure-pak cartons in the market.

Following trend in the US was Jagenberd Werke AG in Dusseldorf, Germany who developed the leak-proof paper can during the first world war. This packaging was known as Perga Pack and it obtained its patent in 1929 in England and in 1930 in Germany. In 1932, the production of the Perga milk carton 200 ml started to operate.

In the meanwhile, Erling Stockhausen in Norway developed a paper milk carton and milk equipment in 1939-1940 but soon had to stop because of the second world war. In Switzerland, a multimaterial carton company PKL was founded and it’s nowadays known as SIG Combibloc.

In 1920, Reben Rausing in Sweden was interested in the US’s multilayer carton packaging. By 1930, he owned Akerluna & Rausing, the pioneering Swedish packaging company. In 1944, the company developed a starting point of a milk package. The company used sealing and cutting a tube of moisture-proofed paperboard at alternate right angles making tetrahedron shape, hence the company name became Tetrapak.

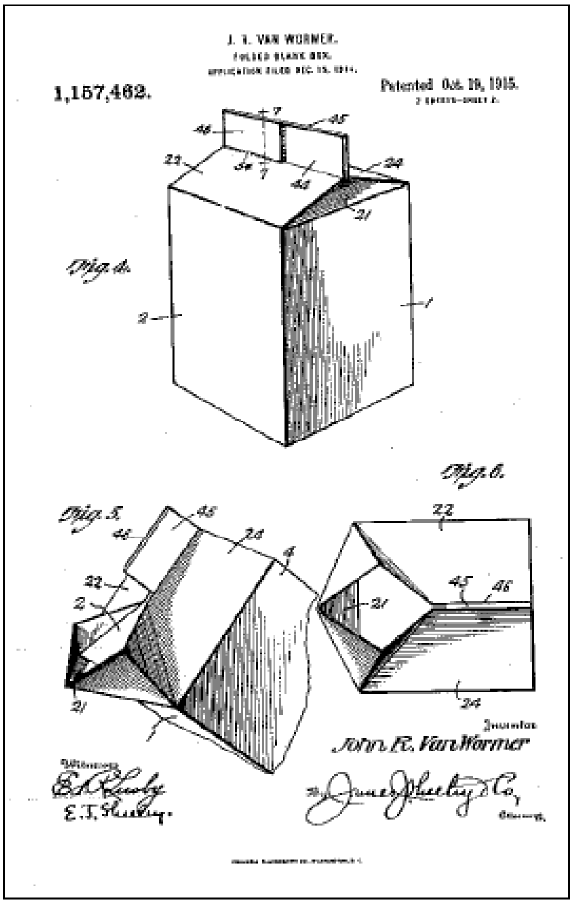

Figure 2 - 21 First Patent of Gable Top Carton
Source : Food Technology

Since the 1950's to present carton packaging has been developing either in its machinery technology and the packaging itself e.g. changes in the material composition for example changing the paraffin wax moisture proofing with a polyethylene extrusion coating, and the innovation in aseptic packaging technology.

Manufacturing Process of Multi-layer Carton Packaging

A typical beverage carton is composed by 75% paperboard, 21% polymers (mostly polyethylene) to prevent leakage, and 4% aluminium, to protect the content from light and Oxygen. A common aseptic packs for long-life products at ambient temperature uses a super thin aluminium foil layer in order to prevent the intrusion of Oxygen. Another type of beverage carton is intended to be used for refrigerated foods and drinks. This type is usually composed by paper board and polymer layer in the inside as a liquid barrier. The outer layer keeps out moisture which is the case for refrigerated condition.

Figure 2 - 22 Multi material packaging
Source : http://latimesblogs.latimes.com

The production of beverage carton involves forestry. In case of The Alliance of Beverage Cartons and Environment (ACE) whose members are Tetrapak, SIG combibloc and Elopak, the papers are produced by paper companies Stora Enso and Körsnas.

An example of beverage carton is Combibloc filler packs. It is produced from multilayer laminate of paperboard, aluminium foil, and low density polyethylene. First of all, rolls of paperboard are loaded, printed up to five colours and coated to a composite laminate including aluminium foil and low density PE. These rolls are cut into individual blanks, creased to assist folding on the filling machine, this is called sleeve. The sleeve is then folded, seam sealed, inspected, packed and delivered to the customer.

Disposal Option

Beverage packaging waste are handled differently in different countries. Beverage cartons can end up in landfill, incineration, or paper recycling, depending on the waste management system in specific country. In Europe, beverage cartons are typically collected in four different ways such as :

- With all recyclable items together
- With all paper waste or with all paper packaging
- With other lightweight packaging such as plastic bottles and metal cans

- In a dedicated beverage carton container, i.e. cardboard “Öko-Box” in Austria

Beverage cartons collected together with paper or with mixed collection are separated from other wastes.

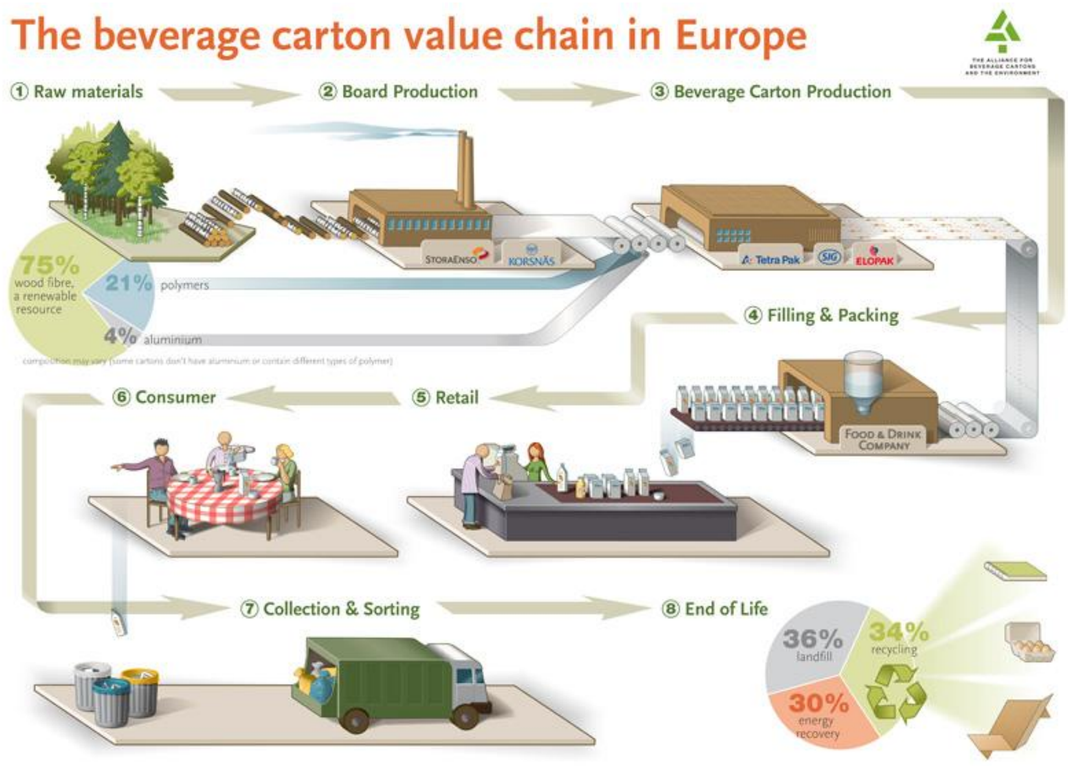

Figure 2 - 23 The Beverage Carton Value Chain in Europe
Source : http://www.beveragecarton.eu

In Austrian households, beverage cartons are seperated in a special cardboard box named Öko Box, supplied by The Öko Box Sammelges.mbH. Beverage carton is not a part of Altstoff Recycling Austria (ARA) waste management system. The Öko Box can be found in household waste management system in particular collection days, in post offices or in particular shops called Hofer stores, According to Elopak presentation, Austrian market for beverage cartons reaches up to 24000 tons annually. In 2006, 9000 tons or about 36% of this quantity were recycled. In Austria, about 30% of all depots and waste collection centres in Austria offer a collection of eco-filled boxes (www.oekebox.at).

In Germany, about 200.000 tons of beverage cartons are produced for the German market. This corresponds to 9 billion box or 2.4 kg per year per-capita (http://www.getraenkekarton.de). Beverage carton waste management is included in German's waste management dual system, Duales System Deutschland (DSD). In this system, manufactures and fillers participate with their sales packaging in DSD's dual system, in which participation of producer, government, and households are involved. In Germany, composite packaging like beverage cartons are disposed via yellow bin, like other types of lightweight packaging. The collected material is then transported to be separated at the sorting plant. The collected and pressed beverage carton is then transported to recycling plant where the re-pulping process will take place.

Recycling of Beverage Carton

Beverage carton recycling achieved on average 34% recycling rate in Europe, according to latest industry-wide figures (ACE, 2010). This number represents approximately 340.000 tons which is more than 12 billion used beverage cartons recycled in paper mills. Among the countries which reached up to 50% of recycling rate are Belgium, Germany, Luxembourg, Spain, and Norway. There are about 20 paper mills that recycle used beverage cartons in Europe (www.beveragecarton.eu). Figure 2-24 shows the map of beverage carton recycler in Europe.

"Combined recycling and energy recovery, rates for the whole region reached roughly 650,000 tonnes (a 66% recovery rate). These figures reflect a clear long-term growth trend in beverage carton recycling since 1992, when only 6,000 tonnes were recycled" (www.beveragecarton.eu).

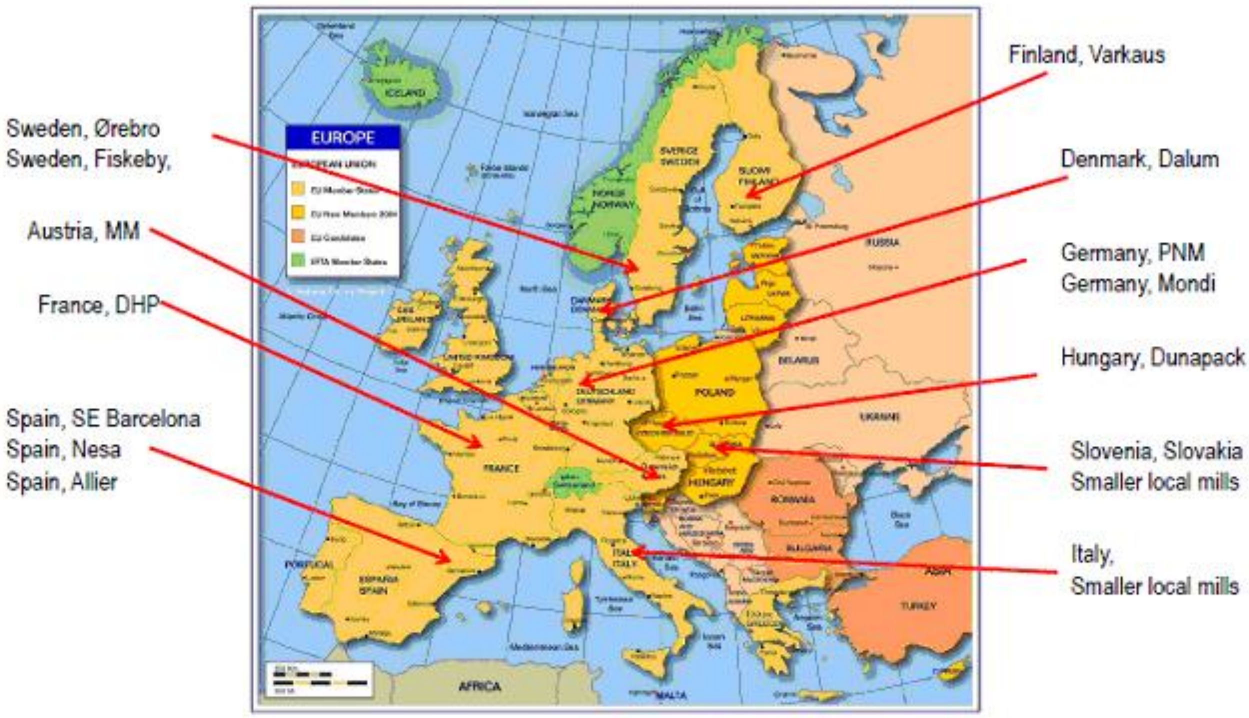

Figure 2 - 24 Beverage cartons recycling sites in Europe
Source : Elopak

Recycling of beverage carton is done through hydropulping process. The recycling process of beverage cartons is shown in figure 2-25 In hydropulping plant, cartons are shredded and stirred in a sort of mixers called pulper. During this process, paper fibres will soak up in the water which causing them to swell and separate from the thin layers of polyethylene and aluminium. The pulp is cleaned and thickened before being pumped to the paper machine before being converted into other products such as egg cartons, tissues, toilet papers, fine writing papers, and so on. The aluminium can be recovered in pure form in highly specialised plants.

There are three ways in recovering the aluminium and polyethylene layers :

1. Generation of energy through incineration
2. Recovery of aluminium in pyrolysis ovens
3. Processing of the mixture of plastic and metal to obtain high-end plastic lumber products.

(Korkmaz, et al, 2009)

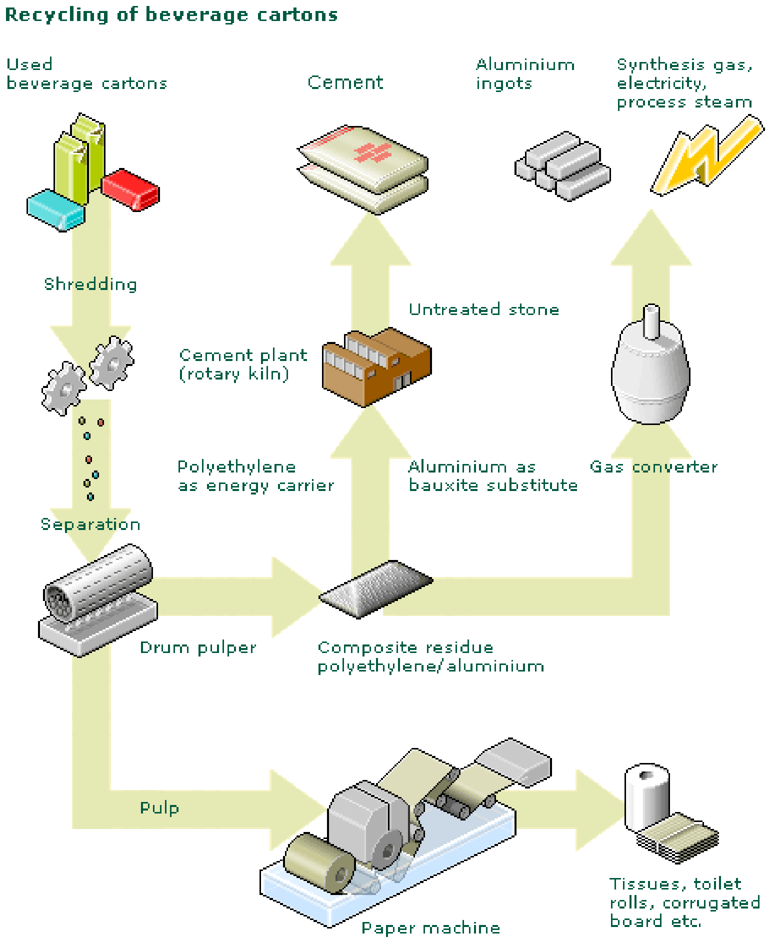

Figure 2 - 25 Recycling process of beverage carton
Source : http://www.gruener-punkt.de

CHAPTER 3 – LCA of Multi Material Packaging

3.1 Review of LCA Studies in Multi Material Packaging

In order to give a general idea about the application of LCA in food and beverage industry, twelve studies on LCA, specifically in multi material packaging were reviewed; all of the studies have beverage carton or liquid packaging board as a part of comparative study or as the main subject evaluated. Nine of the studies were comparative study, one was a scenario study, and two were environmental profile study. The studies were produced within a range of 12 years, eleven were conducted after the year of 2000. The studies covered various geographic locations, among them ten were conducted in Europe. The fill goods of the beverage carton are juice, fresh milk, UHT milk for long conservation and wine. All of the studies evaluated beverage carton of 1 litre capacity, and one study analyzed also other different size, 750 ml, 500 ml, and 250 ml. Among the studies, eight referred to Tetra Pak, in which one of them was also supported by Elopak, and one was carried out for SIG Combibloc.

Table 3 - 1 List of reviewed LCA multi material packaging studies

Year	Fill Goods	Types of Evaluated Packaging	Country
1999	Apple juice and milk	BC	Sweden
2002	UHT Milk	BC, HDPE	Italy
2002	Fresh Milk	BC, PET	Italy
2005	Fresh milk and UHT milk	PET, BC, HDPE	Italy
2008	Milk	LPB	Brazil
2008	Milk	PET, BC	Serbia
2009	Milk and Juice	PET, BC, HDPE	Denmark, , Finland, Norway, Sweden
2009	Milk	BC, HDPE, Glass bottle	United Kingdom
2010	UHT Milk	BC	Western Europe (EU 15 and Switzerland)
2010	Juice	BC, HDPE, Glass bottle	Spain
2010	Milk	BC, BiB, Glass, PET, STP	Norway and Sweden
2011	Milk	BC, PE	China

BC	Beverage Carton	**BiB**	Bag in Box
HDPE	High Density Polyethylene	**LPB**	Liquid Packaging Board
PE	Polyethylene	**PET**	Polyethylene terephthalate
STP	Stand Up Pouch		

The main features of all the studies, reported in ascending order of publication, are summarized in table 3-2. Each single LCA study is subsequently described in details, with particular respect to the the goals, assumptions and results.

Table 3 - 2 Summary of the LCA studies

ID ,Type of the LCA study	Data	Impact Categories	Results	Remark
Oestfold 1999, Sweden. Environmental profile study to identify the most impacting phase in BC life cycle with and without fill products	Mostly site data	AC, AR, EU, GWP, POCP, CED, NW	The production of fill products are the most impacting factor when considering packaging and fill products. When considering packaging without fill products, the most impacting phase is raw material production	LCA of Fill products (milk and juice) + packaging were considered The study was dedicated to Non-LCA Expert
Tetra Pak 2002 Italy Comparative Study: BC (Tetra Rex), PET	Local and software database, Site data	AC, CED, EU, GWP, NR, POCP, WC, WA	Tetra Rex is less impacting than PET except for water consumption. It was not possible to decide which waste disposal alternative is more favourable. Production phase is the most impacting one for Tetra Rex systems	The study considered the direct and indirect environmental and energetic aspect. Production of semi-finished material was taken into calculation.
Tetra Pak 2002(2), Italy. Comparative Study; BC (Tetra Brik Aseptic), HDPE	Local Database, Software database, Site data	AC, CED, EU, GWP, NR, POCP, WC	Generally, BC is less impacting than HDPE except for waste generation. Production phase is the most impacting stage in BC life cycle. Water consumption of BC is high and it is attributed to paper manufacturing process	Allocation procedures in end-of-life phase were process dependent and material dependent.
Tetra Pak 2005, Italy.	Local Database, Software	AC, EU, GWP, POCP	Both BC (Tetra Top and Tetra Prisma) are in general less	Some allocation procedures were based on chemical

Comparative Study; BC (Tetra Top) vs PET and BC (Tetra Prisma) vs HDPE	database, Site data		impacting, except for acidification of Tetra Prisma and water consumption of Tetra Top. For both systems, production of raw materials is the most impacting phase	composition and biodegradability of the material
ScienceDirect 2007, Brazil. Scenario study on BC Recycling rate in Brazil	Database, Site data	CED, GWP	The increase of recycling rate reduces the EC and GWP. Manufacturing and end-of-life are the most impacting stages	Addressed to understand the impact of increasing recycling rate to EC and GWP, assumed rates were from 0% to 70%
Quality Festival 2008, Serbia. Comparative Study; BC, PET	Not specified	AC, AR, EU, FWT, GWP, HT, OD, POCP, TE	BC is less impacting than PET, but PET can be as competitive as BC with increasing recycling rate	Lack of Data was the main limitation of the study
SEI 2009, Nordic. Comparative Study; various BC types, PET, HDPE, glass in four different Nordic countries	Database, Site data	AC, EU, GWP, POCP, OD	Various results depending on the format of the BC; BC is not the least impacting packaging in absolute term.	Non-BC packaging environmental profile was mostly based on database and literature study
WRAP, 2010, UK. Environmental Profile study of milk packaging systems : BC, HDPE, Glass	Database, Site data	AC, AR, EU, FWT, GWP, HT, POCP	The production of raw materials was found to be the most impacting phase for BC. Lightweighting BC was shown to be favourable to the environment	Lack of supporting data was the limitation of the study
IFEU, 2010, EU. Comparative Study, BC named Cb3 and BC Cb3 Ecoplus	Database, Site data	AC, HT: C, CED, CENR, LU , GWP, NR TEU, AE, HT: PM, POCP, TRA	Cb3 Ecoplus is less impacting than Cb3 except for aquatic eutrophication. The most impacting phase for both system is production and end-of-life	Aimed at comparing the new BC with the existing system that uses Polyamide instead of aluminium

Elsevier, 2010, Spain. Comparative Study; BC, HDPE for juice	Database, Site data	CED, GWP	BC is a better performer than HDPE in general and raw material production is the most impacting stage. BC is more impacting than the juice production	LCA of Fill products and packaging were considered
BioIntelligent, 2010, Norway and Sweden. Comparative Study ; BC, BiB, Glass, PET, SuP	Database, Site data	AC, AR, EU, ET : FWT, FS, and TE, GWP, HT, CED, OD, TE, WC	BC is less impacting for packaging format 1 litre, 750 ml, and 250 except for water consumption category. BC was particularly sensitive to transport distance	The LCA study was PAS 2050 - ISO compliant
Elsevier, 2011, China. Comparative Study; BC, PE	Software Database, Site data, Lack of local data	AC, C, ET, EU, GWP, LU, MFF, RI	BC is more impacting than PE	Data was said to be inadequate

AC	Acidification	**AE**	Aquatic Eutrophication
AR	Abiotic Reources depletion	**C**	Carcinogen
CED	Cumulative Energy Demand	**CENR**	Cumulative Energy Demand non renewable
ET	Eco Toxicity	**EU**	Eutrophication
FS	Freshwater Sedimental Ecotoxicity	**FWT**	Aquatic Freshwater ecotoxicity
GWP	Global Warming Potential	**HT**	Human Toxiciy
LU	Land Use	**OD**	Ozone layer depletion
MFF	Mineral Fossil Fuel	**NR**	Non Renewable resource depletion
NW	Non-Hazardous Waste	**PM**	Particulate Matter
POCP	Photochemical Ozone Creation Potential	**RI**	Respiratory Inorganics
TE	Terrestrial Ecotoxicity	**TEU**	Terrestrial Eutrophication
TRA	Traffic/Lorry	**WA**	Waste
WC	Water consumption		

3.1.1 Investigating the life-cycle environmental profile of liquid food packaging systems Tetra Brik Aseptic and apple juice Tetra Brik and milk

<table>
<tr><td>ID</td><td>Oestfold 1999, Sweden</td></tr>
<tr><td>Year</td><td>1999</td></tr>
<tr><td>Writer,
Publisher</td><td>Andreas Barkman, Cecilia Askham, Lars Lundahl, Elin Økstad
Oestfold Research Foundation</td></tr>
<tr><td colspan="2">Goal</td></tr>
<tr><td colspan="2">• Identify and evaluate the relative environmental importance of different process steps in the investigated liquid food packaging systems
• Give insight on where Tetra Pak should focus to efficiently allocate resources to reduce the environmental impact</td></tr>
<tr><td colspan="2">System Evaluated</td></tr>
<tr><td colspan="2">Tetra Brik Aseptic (TBA) packaging system with apple juice (TBA/juice)
Tetra Brik (TB) packaging system with milk (TB/milk)</td></tr>
<tr><td>Functional Unit</td><td>100 litres of food product delivered to the consumers in 1 litre packages</td></tr>
<tr><td>Geographical Boundary</td><td>The TBA/juice system was based on European average data
The Tetra Brik (TB) packaging system with milk (TB/milk) was based on Swedish data sets.</td></tr>
<tr><td>Time Boundary</td><td>1999</td></tr>
<tr><td colspan="2">Processes included</td></tr>
<tr><td colspan="2">• Aluminium production (TBA juice only)
• Board production
• Plastic Production
• Apply juice and milk production
• Converting
• Filling
• Distribution retail
• Consumption
• End of Life : Recycling, Energy recovery, Landfill</td></tr>
<tr><td colspan="2">Processes excluded</td></tr>
<tr><td colspan="2">Waste of packaging material and food production in the retails consumption</td></tr>
</table>

Disposal of packaging material waste in converting and filling step
Assumptions
• The wastage rate of packaging material at converting site referred to the average of 13 Tetra Pak factories in Europe in 1998 • The split between recycling, energy recovery, and landfill was assumed; for juice container the percentage chosen to facilitate comparison of different waste management corresponds to the EU Directive target on packaging waste • In Tetra Brik for juice, 50% of incinerated reject was assumed to replace hard coal. In energy recovery it was assumed to replace energy sources based on natural gas and oil. In landfill, 8,5% of the methane was assumed to generate energy replacing European average electricity • In Tetra Brik for milk, the split percentage between recycling, energy recovery and landfilling reflected approximately the Swedish situation in 1996 • The waste from converting and filling process as well as food products were allocated to the converting and filling steps and not to primary packaging material and food products • In recycling of beverage cartons, cartons are collected and sent to repulping; the recovered fibres are assumed to replace production of virgin pulp • The fraction of the rejected aluminium and plastic are assumed to be incinerated replacing other energy source • In landfill, beverage carton would be partly decomposed, producing methane gas in which a fraction of it was assumed to be used for energy generation • Biological allocation was taken regarding the environmental load of farming activity, 85% was allocated to milk production and the rest to meat production • Biological resources were assumed not to give a net contribution to the CO_2 emissions
Impact Categories
Abiotic resources depletion, Acidification Potential, Eutrophication, Global Warming Potential (GWP), Non-hazardous waste (Waste), Photochemical Ozone Creation Potential (POCP), Total renewable and non-renewable energy use (Primary Energy)
Results
Tetra Brik Aseptic + apple juice • The production of the apple juice dominates the contribution to the environmental impacts due to the fact that it contributes to 97% by weight (packaging + product)

- The filling and the waste management steps are generally of less importance compared to the apple juice production and processing
- The contribution of transport in the waste management steps varies considerably and is difficult to assess in a clear and consistent manner

Tetra Brik Aseptic without apple juice

- The most contributing phase in environmental impact is the production of raw material. Although aluminium is only 5% by weight, it gives a significant environmental impact
- In general, transport gives a less than 5% contribution in all life cycle steps, exception for the distribution, retail, consumption (90%) in which transport is the main activity involved
- The converting step is also an important process step, the most important factor in the converting step is the packaging waste generated which contributed more than 50% to each impact category of this phase
- Energy consumption in the filling step, primarily in the form of electricity contributes the most to the potential environmental impacts
- Both recycling and energy recovery of packaging material generally results in a net environmental credit to the system and it is dependent on the assumptions regarding which material and energy type will be replaced by recycling and energy recovery respectively

TB including milk

- Milk production is the biggest environmental impact contributor, since it constitutes 97% of the product by weight. Cattle and cattle feed in farming is the major source of the impacts
- Waste category is dominated by the waste of raw materials, but it's lack of data
- In filling process, the important affected impact categories are acidification and eutrophication due to the milk wastage.

TB without milk

- Raw material production still gives the biggest potential effect to the environment. The plastic production gives a similar potential impact as the board production even if it's only 20% of the package weight
- In converting phase, raw material waste is an important contributor, therefore reducing material wastage is important
- Recycling does not result in reduction of GWP, it would be more beneficial if the reject was

replacing more fossil fuel intensive energy sources. • Landfilling of beverage carton waste is an important contributor of GWP because of the release of Methane General Conclusion • Inclusion or exclusion of the food product in LCA studies of liquid food packaging systems is an important consideration as it may change the relative environmental importance of the process steps • For a given environmental impact category, the ranking between recycling and energy recovery is greatly affected by the assumptions and data bases with regard to the displaced material and energy
Limitations
Not Specified

3.1.2 Analisi comparativa del ciclo di vita tra due contenitori per latte fresco: Tetra Rex – PET

<table>
<tr><td>ID</td><td>Tetra Pak 2002, Italy</td></tr>
<tr><td>Year</td><td>December 2002</td></tr>
<tr><td>Writer, Publisher</td><td>Antonio Scipioni, Francesca Arena, Andrea Rigato, Giovanni Drago, Tetra Pak</td></tr>
<tr><td colspan="2">Goals</td></tr>
<tr><td colspan="2">Create ecoprofile (from cradle to grave) of PET vs Tetra Rex
Compare environmental impacts and energetic/environmental charge related to the life cycle of the two packaging systems
Identify potential impacts related to different phases of life cycle considered
Identify possible field of improvement
Environmental communication to the public</td></tr>
<tr><td colspan="2">System Evaluated</td></tr>
<tr><td colspan="2">Tetra Rex and PET</td></tr>
<tr><td>Functional Unit</td><td>The containment function of 1 litre of UHT milk</td></tr>
<tr><td>Geographical Boundary</td><td>Italy</td></tr>
<tr><td>Time Boundary</td><td>The primary data referred to 2001 data</td></tr>
<tr><td>Data Sources</td><td>Boustead Model Database, Tetra Pak Italia, Banca Dati Italiana</td></tr>
<tr><td>Software utilized</td><td>Boustead Model version 4.4</td></tr>
<tr><td colspan="2">Processes included</td></tr>
<tr><td colspan="2">Production of raw material
Production of semi-finished material
Production of packaging
Filling
End-of-life
Transport</td></tr>
<tr><td colspan="2">Processes excluded</td></tr>
<tr><td colspan="2">Production of milk
Secondary packaging
Secondary distribution of milk
Use phase</td></tr>
</table>

Assumptions
The study took into account : • Direct environmental energetic aspect (emission or direct release from all processes and activity) • Indirect energetic-environment aspects which are impacts related to production, transport, and the use phase necessary to the main system • Avoided environmental aspects • Allocation factor was used for dividing the flows of energy and material of input or output • Allocation factor regarding the consumption of electricity, methane, water, lubricant, and Sodium hypochlorite • Infrastructure of disposal site was taken into consideration • Scenario regarding end-of-life, assumption regarding the percentage of waste that goes to landfill, waste to energy, recycling, and composting was present • Emission at disposal of paper was calculated based on chemical composition and biodegradability of the treated waste
Impact Categories
Acidification, Eutrophication, Global Warming Potential, Non-renewable resource depletion, Photochemical oxidant formation, Energy consumption, Water consumption, Solid waste generation
Results
• Energy consumption of PET is higher than Tetra Rex • The most energy consuming phase in Tetra Rex is the production of paper and polyethylene. The production of raw or basic material is took 76% of the total GER (Gross Energy Requirement) • In water consumption however, PET performs better that Tetra Rex. The main water consumption in Tetra Rex system is related to paper production. • For acidification, eutrophication, photochemical smog, and non renewable resource depletion impact categories, Tetra Rex has a better performance. • Filling process of PET contributes to 20% for all impact categories while in Tetra Rex is only 2-3%. The energy consumption of PET is also higher, reaching up to 18 times more than Tetra Rex. • Tetra Rex is better in direct environmental and energetic aspects while PET is a better one in indirect one.

General results
• Inside a single life cycle of Tetra Rex, production phase is the one that contributes most in all impact indicators. In case of PET, it is in the filling process. • In the end-of-life phase, it's not possible to conclude if energy recovery, disposal, or recycle is a better alternative for the impact categories selected
Limitations
Not specified

3.1.3 Analisi comparativa del ciclo di vita tra due contenitori per latte a lunga conservazione: Tetra Brik Aseptic – HDPE

<table>
<tr><td>ID</td><td>TetraPak 2002(2), Italy</td></tr>
<tr><td>Year</td><td>December 2002</td></tr>
<tr><td>Writer, Publisher</td><td>Antonio Scipioni, Francesca Arena, Andrea Rigato, Giovanni Drago</td></tr>
<tr><td colspan="2" align="center">Goals</td></tr>
<tr><td colspan="2">Create ecoprofile (from cradle to grave) of Tetra Brik Aseptic – HDPE
Compare environmental impacts and energetic/environmental charge related to the life cycle of the two packaging systems
Identify potential impacts related to different phases of life cycle considered
Identify possible field of improvement
Environmental communication to the public</td></tr>
<tr><td colspan="2" align="center">System Evaluated</td></tr>
<tr><td colspan="2">Tetra Brik Aseptic and HDPE</td></tr>
<tr><td>Functional Unit</td><td>The containment function of 1 litre of UHT milk</td></tr>
<tr><td>Geographical Boundary</td><td>Italy</td></tr>
<tr><td>Time Boundary</td><td>The primary data referred to 2001 data</td></tr>
<tr><td>Data Sources</td><td>Data of filling process was taken from Boustead model for Tetra Brik, and from various sources for HDPE
Data for electricity mix was taken from ENEL
Data for end-of-life transportation of waste collection was based on statistics data of Comune of Brescia
Data did not totally refer to Italian system. For example the data of paper production referred to Sweden case, the data of PE production referred to the Belgian system</td></tr>
<tr><td>Software Utilized</td><td>Boustead Model 4.4</td></tr>
<tr><td colspan="2" align="center">Processes included</td></tr>
<tr><td colspan="2">Production of raw material (including extraction, refinery, etc)
Production of semi-finished packaging component material
Production of the packaging, both Tetra Brik Aseptic and HDPE were produced in Modena</td></tr>
</table>

- Filling process
- End-of-Life ;disposal, energy recovery, recycle, composting (for Tetra Brik Aseptic)
- Transportation (transport of raw material, basic material, packaging, packaged milk, to the site of the primary distribution)

Processes excluded

- Production of milk and UHT treatment
- Secondary packaging production in first distribution phase
- Secondary distribution of packaged milk
- Use phase (consumption, cooling in the fridge, etc)

Assumptions

- The results of inventory analysis in this study are divided in six principle categories of parameters : Energetic results, Water consumption, Raw Material, Emission to air, Emission to water, Solid waste
- The study took into account direct environmental energetic aspect (emission or direct release from all processes and activity) and indirect energetic-environmental aspects which are impacts related to production, transport, and the use phase necessary to the main system
- Avoided environmental aspects were assumed
- Energy consumption and utilities of the manufacture were divided by different products based on primary data on production mix with an allocation factor. This allocation factor was taken from proportion of various consumption of numbers of pieces of packaging produced. Every criteria was used also to divide the emission to water and air and the quantity of solid waste of the product (Tetra Brik Aseptic 1 L in this case).
- Allocation factor for solvent consumption in printing ink
- Allocation factor regarding electricity, methane, and water consumption
- Allocation factor used in classification of the generation of solid waste
- In end-of-life process, two types of allocation method were utilized : process-dependent and material-dependent. The first one means the impacts are function of technological process and they do not depend on the chemical and physical composition of the material. The second one means the impacts are a function of composition of the material, whether physical or chemical.

Impact Categories

Acidification, Energy consumption, Eutrophication, Global Warming Potential, Non-renewable

resource depletion, Photochemical Oxidation (smog), Water consumption
Results
• Tetra Brik Aseptic is less impacting than HDPE in average. The only impact category in which it performed worse than HDPE is the solid waste generation • In Tetra Brik Aspetic system, the most energy intensive processes are paper production, ethylene production, and aluminium production • Water consumption of Tetra Brik is quite high, and it's attributed to paper manufacturing process • Inside the single life cycle, production phase is the major contributor compared to other processes. In case of HDPE, the filling stage is the most contributing one • In End-of-Life phase, there was no conclusion if energy recovery, disposal or recycle is a better option among all
Limitation
Not specified

3.1.4 Analisi comparativa del ciclo di vita tra contenitori : PET-Tetra Top per latte fresco e HDPE - Tetra Prisma Aseptic per latte a lunga conservazione

<table>
<tr><td>ID</td><td>Tetra Pak 2005, Italy</td></tr>
<tr><td>Year</td><td>December 2005</td></tr>
<tr><td>Writer, Publisher</td><td>Consorzio Universitario di Ricerca Applicata c/o Dipartimento di Processi Chimici dell'Ingegneria Università degli Studi di Padova, Tetra Pak Italiana S.p.A.</td></tr>
<tr><td colspan="2" align="center">Goals</td></tr>
<tr><td colspan="2">Create the eco-profile of PET, Tetra Top, HDPE, and Tetra Prisma
Compare the environmental impacts, energy and environmental impact on the packaging’s life cycle
Identify the environmental and energy charge and evaluate the potential related to the life cycle phases of the packaging
Identify possible environmental priority to improve them
Provide information for Tetrapak communication i.e. to the clients</td></tr>
<tr><td colspan="2" align="center">System Evaluated</td></tr>
<tr><td colspan="2">Tetra Top and PET (both for fresh milk)
HDPE and Tetra Prisma Aseptic for long conservation milk</td></tr>
<tr><td>Functional Unit</td><td>The containment function of 1 litre of fresh milk</td></tr>
<tr><td>Geographical Boundary</td><td>Italy</td></tr>
<tr><td>Time Boundary</td><td>Not specified</td></tr>
<tr><td>Data Sources</td><td>Tetra PET Italiana, Boustead Database 2000, Bormioli (Milano) 2001, Granarolo (Bologna), 2000, Corepla, 2001, Media Nazional da banca dati I-LCA (Anpa, 2000), Studio LCA Università di Napoli-CONAI (2001), Froevi, Korsnaes, Stora Billerud, EXXON, Ec Erdolchemie, Polimeri Europa, Coates Lorilleux S.p.A. (Milano), La Mago s.a.s. (Modena), 2001, Rotoflex s.r.l. (Sesto S.Giovanni, MI),2001 , Comieco, Parmeggiani (San Cesario, MO), CEL (Mantova), 2001, Giuseppe Cambiagli S.p.A (Rho, MI), 2001</td></tr>
<tr><td>Software utilized</td><td>Boustead Model 4.4</td></tr>
</table>

Processes included
Production (of raw material, basic material and semi-finished), Production of packaging material for transportation of raw material and the final product End-of-Life; disposal, recovery, and recycling
Processes excluded
• Milk production • Secondary packaging for primary distribution, primary and secondary distribution of milk packaging • Use-phase (conservation in fridge, consumption)
Assumptions
• Allocation procedure regarding direct emission to air and water in the end-of-life phase was calculated based on chemical composition and biodegradability of the generated waste • Energy, chemical reagent, transport, and material for infrastructure of incinerator was calculated • Allocation in paper and LDPE incineration was applied regarding direct emission, consumption of materials and transport, production of electricity, quantity and chemical composition of dusts were calculated based on chemical composition of the treated waste • Disposal of dust and from paper and LDPE incineration : direct emissions were calculated based on the chemical composition of the dusts
Impact Categories
Acidification, Eutrophication, Global Warming Potential, Photo-Chemical Ozone Creation Potential (Generated by Boustead software)
Results
PET vs TetraTop • Tetra Pak packaging performs better than PET in energy consumption; the biggest contributor of energy consumption for both is in the production process. • Water consumption of Tetra Pak is instead higher and it's contributed by production process, especially in paper manufacturing • Tetra Top performs better than PET in GWP (within 20 years of time reference), acidification, eutrophication, and non renewable resource • End-of-life phase gives the biggest contribution in GWP of Tetra Top with the release of methane

- The biggest contribution phase in Tetra Top system for acidification and eutrophication is the production process of paper and LDPE

HDPE vs Tetra Prisma Aseptic

- Tetra Prisma Aseptic performs better than HDPE for all impact categories except acidification
- Energy consumption of HDPE is five times bigger than Tetra Prisma Aseptic, and the biggest contributor of energy consumption for both systems is production phase
- Tetra Prisma Aseptic consumes more water than HDPE and it's related to the production phase
- Both Tetra Prisma Aseptic and HDPE generate "mineral waste" type, in Tetra Prisma Aseptic it is correlated to the production of aluminium and paper
- GWP of Tetra Prisma Aseptic is attributed to the methane release during the end-of-life phase, filling process, and production
- For acidification and eutrophication impact categories of Tetra Prisma Aseptic, the biggest contribution of the potential impact comes from the production phase of paper and aluminium

Limitations
Not specified

3.1.5 Influence of recycling rate increase of aseptic carton for long-life milk on GWP reduction

ID	ScienceDirect 2007, Brazil
Year	24 October 2007
Writer, Publisher	Anna Lucia Mourada, Eloisa E.C. Garcia, Gustavo Braz Vilela, Fernando Von Zuben Published by ScienceDirect
Goals	
Measure GWP resulted from the reduction from green house gas emission associated with the increase of recycling rate (2%, 22%, 30%; 40%,70%) and based on different future scenarios	
System Evaluated	
Tetra Pak Aseptic post-consumer packaging	
Functional Unit	1000 liters of milk filled in aseptic packages with a holding capacity of 1 liter each
Geographical Boundary	Brazil
Time Boundary	Not specified
Data Sources	• The data concerning the generation and distribution of Brazilian electric energy were collected between 1997 and 1998 and updated in 2000 • The data concerning the production of the cardboard were provided by the main supplier of cardboard used to manufacture the aseptic carton • The data concerning the production of ethylene (catalytic cracking of naphtha) from crude oil refining were estimated based on public Brazilian sector data and the study published by Boustead • The data concerning the manufacturing of aluminium foil refer to data collected between 1998 and 2000 and were provided by all three Brazilian manufacturers of this metal
Software utilized	System—PEMS4 software purchased from Pira International
Processes included	
• Manufacturing of the packaging materials (extraction of natural resources) • Processing of raw materials • Manufacturing of the packaging	

• Filling process (sealing and sterilization) • Final disposal of the used packages
Processes excluded
• Production of inputs for the manufacturing of the packaging materials • Emissions related with the consumption of the milk and domestic disposal of the milk cartons • The aspects related to the life cycle of the milk
Assumptions
Scenario I : Recycling rate used varied from 0% to 70% only for cardboard Scenario II : Recycling of cardboard, polyethylene and aluminium The average distribution radius for packaged milk was estimated at 200 km, since there are long-life milk producers in practically all regions of the country. In the cases where the trucks returns empty to their point of origin, the distance was doubled
Impact Categories
Energy consumption, Global Warming Potential
Results
• In scenario I, the manufacturing of packaging system and the final disposal are the most significant contributor to GWP • Recycling has a beneficial effect in terms of global warming potential • Total energy consumption involved in the whole life cycle was reduced by 7% with the paper increasing recycling rate from 2% to 22% • The most significant reduction relative to air pollutants, considering the recycling rate from 2% to 22% is 20% of CH_4, 14% of renewable CO_2, 9% of CO, and a GWP reduction of 14%. These may attain a level as high as 56% of GWP reduction if the recycling rate increases to 70% in Scenario II where the plastic and aluminium are recycled as well
Limitations
The quality of the data

3.1.6 Environmental Impacts of Packaging Materials in Serbian Milk Industry, A Comparative Life Cycle Assessment

ID	QualityFestival 2008, Serbia
Year	Presented in Quality Festival 2008, 2nd International Quality Conference, May 13-15 2008
Writer, Publisher	M. Pavlovic, A. Pavlovic
Goal	
• Determine the environmental impacts (by applying life cycle assessment methodology, ISO series 1404x standards) of the most commonly used packaging materials in the milk sector: PET and LPB • Highlight the differences between the alternative ways of packaging waste treatment	
System Evaluated	
PET and LPB	
Functional Unit	The delivery of 1000 litres of milk in containers of 1 litre capacity
Geographical Boundary	Serbia
Time Boundary	Not specified
Data Sources	Not specified
Software utilized	SimaPro 7.0
Processes included	
• Extraction of the raw materials • Transportation and processing raw materials into intermediate materials • Waste management processes (Waste management scenario refers to estimated recycling and recovery rates for plastic in 2005, 5%; recycling of paperboard refers to the average European countries at about 20%)	
Processes excluded	
Filling and packaging process, use phase, transportation for the delivery to store (distribution phase), due to the lack of data	
Assumptions	
• Waste of filling process was assumed to be treated the same as disposed packaging after use • Transportation distance between manufacturers and filling facilities was assumed as an average, as well as the transportation of the disposed and collected materials • Recycling rate 20% of paperboard was considered according to the average of European	

countries • CML 2 baseline method was adapted for impact assessment • Single Score indicator was used to conduct the second goal, using eco indicator 99 method for evaluating the total impact of the waste treatment scenarios
Impact Categories
Abiotic depletion, Acidification, Eutrophication, Fresh Water Aquatic Toxicity, Global warming Potential, Human toxicity, Ozone layer depletion, Photochemical Oxidation, Terrestrial Ecotoxicity
Results
LPB showed a better environmental performance than PET. In case of the increase of recycling rate of PET, it showed that PET would be as competitive. This is due to the avoided impacts result from the diminution of the use of natural resources like petroleum products
Limitations
Lack of data regarding several processes

3.1.7 Life Cycle Assessment of consumer packaging for liquid food LCA of Tetra Pak and alternative packaging on the Nordic market

ID	SEI 2009, Nordic
Year	25 August 2009
Writer, Publisher	Kristian Jelse, Elin Eriksson and Elin Einarson Swedish Environmental Research Institute
Goals	
• Compare the environmental performance of the Tetra Pak Packaging with that of selective non-Tetra Pak packaging • Construct a model for the package life cycle systems from raw material production to recycling and waste treatment for the Danish, Finnish, Norwegian and Swedish markets	
System Evaluated	
In total 24 packaging types, and 115 packaging systems; various beverage carton types by Tetra Pak, and non Tetra Pak packaging : PET, HDPE, and glass bottle	
Functional Unit	Dairy packaging (1000 ml): Distribution of 1 litre of milk at retail. Juice packaging (1000 ml): Distribution of 1 litre of juice at retail. Grab & Go packaging (250–500 ml): Distribution of 0.5 litre of portion packed beverage at retail. Micro Grab & Go pack. (100 ml): Distribution of 0.5 litre of small portion packed beverage at retail
Geographical Boundary	Denmark, Norway, Finland, Sweden
Time Boundary	Tetra Pak site specific data 2005-2007
Data Sources	Data for liquid packaging board were taken from site-specific data of Tetrapak. No site specific data was able to be collected for the alternative packaging, therefore the data for the alternative packaging was taken from database i.e. Plastic Europe, EEA, GaBi 4 professional database which includes ELCD and BUWAL, Forestry Research Institute of Sweden (Skogforsk), European Federation of Corrugated Board Manufacturers (FEFCO) There were some known data gaps regarding secondary packaging, carton board packaging, as well as production, printing and transport of plastic label for glass

	bottle, production of paper label for PET 250 ml, production of tin cap (approximation: production of tin plated coil), transport to waste management for non-recycled material, resource use for production of liquefied petroleum gas (LPG)
Software utilized	GaBi 4 Professional by IVL Swedish Environmental Research Institute Characterization model : CML 2001 by GaBi 4 Professional

Processes included

Forestry and Paperboard , Plastics, Metals & Glass, Cap, Top & Straw, Primary packaging production, Secondary packaging production, Filler, Transport to retail, Retail (& Consumer), Waste management, Avoided emissions

Processes excluded

The production of milk, juice or other beverage has not been included in the study

Product loss is excluded due to the lack of data

Assumptions

- Allocation procedure was applied in recycling scenario, co-products, and cut-offs
- The recycling of material has been modelled as replacing other products/ material in open loop, except for glass which, due to the type of data was modelled in closed loop.
- Electricity production technology was chosen based on data on national average in Denmark, Finland, Norway, and Sweden. If it's outside, it's assumed to be based on local average and if transport by train is used, the average electricity mix for EU-25 is used

Waste management assumption

- The data for plastic regarding the rate of incineration with energy recovery was taken from Eurostat and Plastic Europe, the remaining was assumed to go to incineration without energy recovery
- Heat and electricity produced at waste incineration are assumed to replace the same amount of heat and electricity from national average electricity and district heating. In case of Sweden, this means 90% of energy converted at waste incineration is used for district heating and the rest for electricity. Norway refers to Sweden data
- Recycled Tetra Pak paper has been assumed to replace Tetra Brik type paperboard, recycled plastics to replace plastic granules, and recycled glass to replace glass
- Emission assumption : it's assumed that 12 gram of methane is released every kilogram of PE or PET and that 102 gram of methane is released for every kilogram of cardboard

Transport Assumptions were made regarding secondary packaging for transport, distance and type of vehicle
Impact Categories
Characterization factor used is adapted from CML 2001 : Acidification, Eutrophication, Global warming, Photochemical oxidant formation, Stratospheric ozone depletion
Results
• Liquid carton board packaging for chilled milk have significantly lower contribution to GWP than PET and HDPE. Transport to retail is the denominating life cycle phase of all markets. For the chilled liquid carton board it is the waste management phase. Grab&Go : Tetra Top HAAD 250 ml contributes the highest on GWP in all markets due to the presence of plastic cap and top Micro Grab&Go : On all four markets, HDPE 100 ml filled in France gives the higher contribution to GWP than Tetra Top micro system, due to the long transportation from filler to retail. • Choices of the impact categories are constricted by time and it was the reason why land use and loss of biodiversity were excluded from the study. Ecotoxicity and human toxicity were not included because it was not the focus of the study. • Electricity use makes difference in filling phase • Variation in environmental impacts in waste management are due to different electricity profiles and the recycling rate, and the rate of incineration with energy recovery. In order to assess the effects of recycling, the mechanism of the market for recycled material needs to be analysed. • Sensitivity check as performed in marginal electricity, distribution distance, PET replacing virgin/recycled material, Methane formation at landfill, delayed carbon emission, transport from retail to consumer, Norwegian district heating approximation that referred to Swedish system, Tetratop with smaller cap, and ambient and chilled Tetra Pak packaging. • Completeness check was performed to check the data gaps; most data gaps were shown to have a small impact on the total result • Consistency check was performed; a concern was present regarding the modelling of the systems within the same product based on equivalent method; system boundaries, allocation, data quality, impact assessment, etc. • Reducing the weight of the primary and secondary data was mentioned to be favourable for the life cycle impact of a selected packaging.

Limitations
• The choice of impact categories selected, toxicity and land use were excluded but it might give a contradictory result to the main conclusion of the report • The fact that the alternative packaging was modelled based on database, literature, and previous studies; it’s desirable to have site-specific data for the alternative packaging • There is a potential difference in product loss between the packaging

3.1.8 Life cycle assessment of example packaging systems for milk

ID	WRAP 2010, UK
Year	2010
Writer, Publisher	Jonna Meyhoff Fry, Bryan Hartlin, Erika Wallén, and Simon Aumônier (Environmental Resources Management Limited)
Goals	
To assess the potential environmental impact of different milk containers for UK market, with doorstep system	
System Evaluated	
HDPE bottles, Cartons with screwcaps, Gable top cartons, Returnable glass bottles	
Functional Unit	Packaging systems for containing, protecting, storing and transporting 1000 pints (568 litre) of pasteurized cow's milk to the consumer in UK
Geographical Boundary	United Kingdom Market
Time Boundary	2007-2010
Data Sources	The HDPE bottle production data is representative of one of the data supplier's sites and it represented the best scenario instead of average data The data for the conversion of raw materials into cartons and the filling data were provided by Tetra Pak Data describing the growing of trees, felling and pulping to produce liquid paper board is sourced from the Ecoinvent database. Data for the recycling process has been provided by Tetra Pak. Data for landfill and incineration are based on WRATE data.
Software utilized	The Waste and Resources Assessment Tool for the Environment (WRATE), a waste management life cycle assessment tool developed for the Environment Agency, has been used to model the waste management scenarios, from collection to final disposal, to identify more environmentally preferable routes for the management of the wastes.
Processes included	
Raw materials production, Conversion, Secondary and transit packaging for delivery to dairy, transport to dairy, filling, secondary and transit packaging for delivery to doorstep, distribution,	

end-of-life
Processes excluded
• Milk wastage, due to lack of data • Transport of the milk to the filler • Ink production and transport of ink
Assumptions
• Assumptions were made to overcome the data gaps, for example regarding milk wastage • Estimation of transport distance to the waste disposal was made • Infrastructure was not included in system boundary • Biogenic carbon was excluded from the climate change calculation to ensure all of them accounted correctly across life cycle stages • Scenario was made regarding beverage carbon; currently available with 100% virgin content but scenario with 10% lightweighting was made • Assumptions regarding distribution distance, refrigeration between dairy and depot
Impact Categories
Abiotic resource depletion, Acidification, Aquatic freshwater Ecotoxicity, Climate change (GWP), Eutrophication, Human toxicity, Photo-oxidant formation
Results
• In carton with screwcap system and Gable top carton, the production of laminate, cap, and distribution of packaging made the predominant contribution to the assessed impact categories. • Recycling was the best waste management option for carton with screwcap and gable top in several impact categories : photo-oxidant formation, eutrophication, acidification, human toxicity, and freshwater aquatic eco-toxicity; for the impact categories of abiotic resource depletion and climate change, energy from waste has the lowest potential environmental impacts. • Lightweighting the liquid paper board by 10% shows fewer potential environmental impacts for all of the impact categories assessed. • Sensitivity analysis was performed for allocation, exclusion of milk wastage, and the use of shrink wrap for industry. • The filling and packing of the cartons contributes little to the overall results, although some impact is seen for the impact categories of abiotic resource depletion, climate change and

human toxicity. • Landfill of the carton contributes to a minor extent to climate change and eutrophication, and shows some benefit for abiotic resource depletion and photo-oxidant formation.
Limitations
The whole data required was not available by the supply chains, therefore a lot of assumptions were made to overcome the data gaps. In the end it did not reflect the actual UK market condition.

3.1.9 Comparative Life Cycle Assessment of beverage cartons cb3 and cb3 EcoPlus for UHT milk

<table>
<tr><td>ID</td><td>IFEU 2010, EU</td></tr>
<tr><td>Year</td><td>30 July 2010</td></tr>
<tr><td>Writer,
Publisher</td><td>Frank Wellenreuther, Eva von Falkenstein, Andreas Detzel
IFEU - Institut für Energie- und Umweltforschung Heidelberg GmbH</td></tr>
<tr><td colspan="2" align="center">Goal</td></tr>
<tr><td colspan="2">Providing knowledge of environmental strengths and weakness of the new developed cb3 Ecoplus of 1 litre beverage carton for milk under European market conditions
Investigate some of the environmental impacts of Cb3 EcoPlus Beverage carton with the already established beverage carton system Cb3.</td></tr>
<tr><td colspan="2" align="center">System Evaluated</td></tr>
<tr><td colspan="2">SIG Combibloc beverage carton cb3 1000ml EcoPlus with a closure cCap
SIG Combibloc Beverage carton cb3 1000ml EcoPlus with a closure cCap without a closure
SIG Combibloc Beverage carton cb3 1000ml with closure cSwift
SIG Combibloc beverage carton cb3 1000ml without a closure</td></tr>
<tr><td>Functional Unit</td><td>Packaging and delivery to the point of sale of 1000 litre UHT milk</td></tr>
<tr><td>Geographical Boundary</td><td>Focusing production, distribution, and disposal of beverage cartons in Western Europe (EU 15 and Switzerland) which was considered as a market for the new Ecoplus. The difference between Ecoplus and the already established beverage carton is on the raw materials; its sleeve does not contain any aluminium but a small amount of polyamide as a barrier layer.</td></tr>
<tr><td>Time Boundary</td><td>2009/2010</td></tr>
<tr><td>Data Sources</td><td>Data collected from the site, literature, and IFEU database i.e. plastic Europe, EEA, Handbook of emissions factor for lorry transport referring to the year 2003, Eurostat</td></tr>
<tr><td>Software utilized</td><td>Umberto version 5.5 software, developed by IFU and IFEU</td></tr>
</table>

Processes included
• Production, converting, recycling and final disposal of the primary raw materials used in the primary packaging elements from the studied system. • Plastics used within the packaging system under study are : LDPE, HDPE, PP, and PA • Production, recycling and final disposal of transport packaging materials (pallets, cardboard trays) • Production and disposal of process chemicals, as far as not excluded by the cut-off criteria • Filling processes • Material transports and final distribution from fillers to point of sale
Processes excluded
Product loss, production and disposal of the infrastructure, beverage production, environmental effects related to storage phases, environmental effects of beverage losses due to breakability of packages, environmental effects from accidents, losses of beverage at different points in the supply chain
Assumptions
• The system boundary for recycling and recovery routes is set at the point where a secondary product whether energy or recycled material is obtained. These secondary products can either replace primary energy generation processes and virgin materials. • Cut off criteria was applied for energy related to the material inputs from pre chains that has no relevant environmental impacts • Electricity generation was considered using Swedish and Finnish mix of energy suppliers in 2004 for the production of paperboard and West European mix of energy suppliers in the year 2007 for converting and filling processes • Transport distance from filler to point-of-sale was assumed • Assumptions regarding the equipment and the efficiency of the landfill gas capture systems • Assumption was made regarding landfill model; emission and decomposition condition, • Average recycling rate for post-consumer packaging and average final waste disposal split (landfill/incineration) for Western Europe were used in end-of-life base scenario modelling • The average and country-specific figures scenario variants were calculated based on data obtained from ACE and Eurostat for the reference year 2008

Impact Categories
• Acidification, Climate change (GWP), Eutrophication: terrestrial eutrophication and aquatic eutrophication, Human toxicity : PM10, carcinogenic risk, Photo-oxidant formation (summer smog) • Impact indicators related to the use/consumption of resources : Fossil resource consumption, use of nature • Additional categories at the inventory level : Cumulative Energy Demand (Total primary energy), Cumulative energy demand non-renewable (Non-renewable primary energy) • Transport intensity by lorry
Results
• Cb3 Ecoplus was found to be more advantageous except for aquatic eutrophication. • The closure cCAp used for EcoPlus has smaller environmental loads than the closure cSwift in general, except for aquatic eutrophication • Sensitivity study was carried out regarding the choice of 100% allocation factor in modelling and calculating the open loop recycling process. It showed that recycling would be favourable for the environmental performance. • In all impact categories, the biggest part of the environmental loads were attributed from the production, provision and/or recycling of the components of the beverage carton (and closure) • The secondary and tertiary packaging also contribute to environmental loads for the regarded system, except in human toxicity-carcinogenic risk • The filling process causes the relatively largest contribution for climate change category, primary energy consumption; both total and non-renewable, as well as of fossil energy resources • The distribution of the final goods contribute to less significant or even insignificant environmental loads • The packaging end of life contributes most significantly to the final results in the categories Climate Change and Transport-Intensity lorry
Limitations
• Market segment; other filling products create different requirements towards their packaging, therefore certain characteristics may differ • The results were valid only for the examined packaging systems specified; any alteration may change the overall environmental profile

- Volume chosen was the predominant one
- Environmental and valuation method selected; the selection of the impact categories were based on those widely accepted by the LCA practitioner community. The use of different impact assessment methods could lead to different results. Therefore, the results are valid only for the specific valuation method used for the step from inventory data to impact assessment
- The filling volume and weight of a certain type of packaging can vary and it’s not possible to transfer the results of the study with its chosen 1000 ml volume to packages with other filling volumes or weight specifications.
- There may be a certain variation of design within a specific packaging system, the the ones used in the study cannot be compared directly with the other
- Geographical boundaries, which means that the packaging system is not representative even if it is set in Western European countries
- Time reference period; the results are valid only for the indicated time scope
- Retail distance which is highly variable depending on the location
- Limitations concerning data; the results are valid only for the data used and described in the report

3.1.10 The carbon footprint and energy consumption of beverage packaging selection and disposal

<table>
<tr><td>ID</td><td>Elsevier 2010, Spain</td></tr>
<tr><td>Year</td><td>16 November 2010</td></tr>
<tr><td>Writer, Publisher</td><td>Jorgelina Pasqualino, Montse Meneses, Frances Castells
Journal of Food Engineering – Elsevier</td></tr>
<tr><td colspan="2">Goals</td></tr>
<tr><td colspan="2">To evaluate the environmental impacts of the following beverage packaging :
– Juice: aseptic carton, glass and HDPE.
– Beer: aluminium can, glass and HDPE.
– Water: PET and glass.
Evaluate the contribution of packaging to the environmental profile of a product’s life cycle</td></tr>
<tr><td colspan="2">System Evaluated</td></tr>
<tr><td colspan="2">Aseptic Carton, Aluminium cans, Glass bottle, PET, HDPE</td></tr>
<tr><td>Functional Unit</td><td>1 litre of beverage</td></tr>
<tr><td>Geographical Boundary</td><td>Spain</td></tr>
<tr><td>Time Boundary</td><td>Not specified</td></tr>
<tr><td>Data Sources</td><td>Ecoinvent for juice production, including water and oranges
The process of cleaning, filling, capping and labelling the packaging was modelled according to Gleick and Cooley’s model for bottled water</td></tr>
<tr><td>Software utilized</td><td>Not specified</td></tr>
<tr><td colspan="2">Processes included</td></tr>
<tr><td colspan="2">Beverage production
Transport
Packaging production
Packaging disposal Material transports and final distribution from fillers to point of sale</td></tr>
<tr><td colspan="2">Processes excluded</td></tr>
<tr><td colspan="2">Not specified</td></tr>
<tr><td colspan="2">Assumptions</td></tr>
<tr><td colspan="2">Models and assumptions were made regarding the waste treatment of the post-consumer</td></tr>
</table>

beverage packaging; • In landfill and incineration the beverage carton was modelled as the combined disposal of 75% cardboard, 20% LDPE, and 5% Aluminium. • In recycling phase, only the cardboard layer was assumed to be taken into calculation with 0% loss rate in the recovery and 7% loss rate in the manufacturing stage; both rate referred to EPA. Aluminium and LDPE were assumed to be landfilled • Transport distance was assumed	
Impact Categories	
Cumulative Energy Demand (CED, MJ), Global Warming Potential	
Results	
• For juice, aseptic carton showed a better environmental profile. The stage with the highest impact in aseptic carton is the production stage. Considering the product environmental performance, carton packaging contributes more to environmental effects, more than the production of juice • Transportation stage is an important stage that influence the environmental performance of the products and packaging • In general, larger packages have a lower environmental impacts than the smaller packages for the same packaging type • The final impact of the product is highly dependant on the packaging weight and shape, which tends to differ from brand to brand • Recycling was recommended for all packaging types according to both GWP and CED indicators	
Limitations	
Data availability, lack of local database ; the data used depended on the open-access database and there was a limited information regarding the recycling process	

3.1.11 Nordic Life Cycle Assessment Wine Package Study - Final report – ISO Compliant

ID	BioIntelligent 2010, Norway and Sweden
Year	August 2010
Writer, Publisher	BioIntelligent
Goals	
• Identify and quantify the impacts of alternative wine packaging solutions • Identify which stages of the life cycle give rise to the impacts • Understand the drivers determining the life cycle impacts • Identify and investigate potential improvement opportunities for each solution • Carry out an ISO-compliant comparative assessment of the packaging systems • Carry out an LCA compliant with PAS 2050 2008 framework	
System Evaluated	
• PET bottle: 75 cl and 37.5 cl • Glass bottle: 75 cl and 37.5 cl • Bag in Box (BiB): 10 l, 5 l, 3 l, 2 l and 1.5 l • Stand up Pouch (SuP): 3 l, 1.5 l and 1 l • Beverage carton: 1 l, 75 cl, 50 cl and 25 cl	
Functional Unit	Packaging and distribution of 1000 litres of wine
Geographical Boundary	Norway and Sweden
Time Boundary	Not specified
Data Sources	• Ecoinvent 2.0, Plastic Europe, EAA, USEPA, Wisard 4.2, Eurostat • Swedish environmental protection agency, Green Dot Norway, Norwegian pollution authority • Data for beverage carton was provided by Tetra Pak and Elopak • End-of-life routes for packages after consumer use in Sweden and Norway have been taken from national statistics • Systembolaget and Vinmonopolet have provided data about end-of-life of secondary and tertiary packaging for their respective retailers network
Software utilized	Not specified

Processes included
• Extraction of raw materials and manufacturing of materials used in the composition of each packaging level: primary (body & closure), secondary, tertiary packaging • Filling and packaging of beverages • End-of-life of the various types of packaging (primary, secondary, tertiary) by retailer and consumer Transportations between each of these life-cycle steps, which includes : • Transport of raw materials to manufacturing and assembly plants for each packaging part • Transport of the packaging parts to the winery location (filling centre) • Supply of raw materials for closures and packaging materials • Transport of the packaged wine to the store including impacts due to the weight of the wine • Transport of waste generated at three stages of the package life cycle: production wastes from the manufacturer, wastes from the retail outlet and wastes from the consumer's place to recovery or disposal sites.
Processes excluded
Wine production
Assumptions
• In taking into account the recycling process, it's assumed that recycling avoids a conventional disposal route and avoid the need to extract virgin materials • Assumptions were made regarding transport distance of waste from the manufacturer, from the retail and from the consumer to their sites of recovery and disposal • Time perspective chosen was 100 years which was also consistent with PAS 2050 requirement; therefore the LCIA methodology was set to 100 years characterization factors, long terms emissions of landfilling have been disregarded, and biogenic carbon contained in landfilled materials that does not disintegrate after the hundred years assessment period is considered to be sequestered and accounted as an environmental credit • A specific road transport model was adapted for modelling road distribution of empty packaging to the filler; generic eco-invent data has been used. ADEME Bilan Carbone v5 methodology was used when taking into account weight and volume of the shipment. The heavier is the load, the higher are the impacts. All packaging systems have been considered to be transported from the producer factory to the south of France to be filled. • For end-of-life phase, waste from manufacturer and retailer were assumed to be recycled.

When no data is available, waste from the consumer was assumed to be sent to landfill (67%), and sent to incineration (33%); based on Eurostats data.

- Recycling rates 2008 for Norway and Sweden was taken from national statistics in order to model consumer disposal of primary packaging
- The emptying rate of wine was assumed to be 100%, which means there's no product wastage
- Normalisation was translated into inhabitant equivalent EU 25+3 to the environmental impact indicator over one year
- Four allocation procedures have been applied:
  - Allocation to the recycling rate (RR)
  - Allocation to the recycled content (RC)
  - 50/50 allocation to the recycling rate and recycled content (50/50)
  - Hybrid allocation as set in the PAS (PAS)

Impact Categories

Abiotic depletion, Acidification, Eutrophication, Ecotoxicity, Freshwater aquatic ecotoxicity, Freshwater sedimental, Global Warming potential, Human toxicity, Primary energy, Ozone layer depletion, Photochemical oxidation, Terrestrial ecotoxicity, Water consumption

Results

General results are divided based on the capacity of the packaging :

- For large format more than 1,5 litre, Stand Up pouch and Bag in Box are better options
- For large format 1 litre- 1,5 litre, beverage carton is the best for 1 litre and Stand up Pouch is better for 1,5 litre
- For medium volume (750 ml), beverage carton is the less impacting packaging except for water consumption
- For small format, less than 750 ml, the 250 ml beverage carton without cap is the least impacting, except for water consumption category

- Packaging production is the most impacting life cycle stage for all environmental indicators except for terrestrial ecotoxicity where the filling stage is more impacting due to secondary packaging
- Filling has a significant impact (more than 35%) in terms of water consumption, primary energy, photochemical oxidation potential and eutrophication for both systems due to secondary packaging

• Distribution appears as a moderate contributor with all indicators having a contribution below 23%. • Waste management tends to mitigate the environmental impact of the system. Increasing the post consumer recycling rate of the beverage carton has limited impact on the overall environmental performance of the system. The most sensitive indicator is water consumption with a 10% decrease with a 60% increase of the recycling rate • Beverage carton was found to be particularly sensitive to variation in the length of the supply chain • As a general rule, packaging with lower capacity have higher environmental impacts due to the fact that less packaging units are necessary to provide the same service
Limitations
Neglected were : the operations of research and development that have permitted the creation of the current wine packages, finished good transport from retail to consumer (since it did not include consumption phase), energy consumption to store the finished goods in the outlet or at the consumer’s place, cleaning products, glue related to the label of the packaging

3.1.12 A comparative study on milk packaging using life cycle assessment: from PA-PE-Al laminate and polyethylene in China

ID	Elsevier 2011, China
Year	23 June 2011
Writer, Publisher	Minghui Xie, Li Li, Qi Qiao, Qihong Sun, Tichang Sun Journal of Cleaner Production
Goals	
• Evaluate the environmental burdens associated with milk packaging, PA-PE-Al laminate and polyethylene • Assess the impacts of these products on the environment throughout their entire life cycle, including extraction and processing of raw materials, transportation, manufacturing, distribution, treatment and final disposal	
System Evaluated	
1000 L of milk, requiring 1000 stand-up composite packages of 1 L each 5000 pouched plastic packages of 200 ml each, produced in China	
Functional Unit	Packaging and distribution of 1000 litres of milk
Geographical Boundary	China
Time Boundary	Not specified
Data Sources	The data for the mass, energy fluxes and environmental emissions were obtained from published literature and from site investigations
Software utilized	SimaPro
Processes included	
• Manufacturing from raw materials • Transportation • Manufacture of the packaging • Energy required • The energy demands for the composite packages (electric power and natural gas) and for the manufacture of the plastic packages included (electric power only); both of them are based on Chinese value • Final Disposal • Allocation procedures	

Processes excluded
The filling process of the packaging with milk was not included in the study
Assumptions
Eco Indicator 99 was used for impact assessment step The paper production for composite packaging referred to Sweden, the aluminium was made in Japan and the Polyethylene in China.
Impact Categories
Acidification, Carcinogens, Climate change (GWP), Eco-toxicity, Eutrophication, Land use, Minerals and fossil fuels, Respiratory inorganics
Results
• The results of this LCA study are discussed and the results reveal that the composite packaging has a slightly higher environmental impact than the plastic one • Environmental impact of composite packaging comes mainly from fossil fuel, land use and respiratory inorganics. • Raw material extraction was the highest of the total environmental impacts contributor in the packaging life cycle except for the disposal stage • Fossil fuels, land use and respiratory inorganics categories exhibit a high contribution from the production process of paper and polyethylene and their transport • Composite packaging because of the extraction of the raw materials for cardboard and polyethylene, and the long shipping distances for transporting them • The raw material for aluminium foil, bauxite, has a minor significance on the minerals category as it builds up only 5% of the total composite package mass • In the carcinogens category, the waterborne emissions from landfills are the most significant aspect The contribution to the climate change category comes mainly from the airborne emissions from landfills • The environmental impact of the composite packaging is the highest for raw materials extraction step, with over 80.9% of the total environmental impacts in all stages of its life cycle except for the final disposal stage
Limitations
• Lack of local LCA database in China since LCA study is still at the beginning stage in China • The validity of the data used for the material use and energy flow; they were taken from Eco-Invent database and other open sources

3.2 Key Points in LCA Studies in Multi Material Packaging

3.2.1 Goal of the study

Among the common objective of the LCA application in multi material packaging according to the evaluated studies are :

1. Analyze the cradle-to-grave environmental performance of a multi material packaging; this is done by examining a set of environmental impact categories commonly used in current LCA practices
2. Compare the environmental performance of a multi material packaging

   Among the studies reviewed, nine of them were comparative study or aimed to compare beverage carton with alternative packaging, for example PET bottle, stand up pouch, bag in box, and so on. These comparative studies aimed at giving an insight on environmental performance of various packaging products. Comparative study can be used also to analyze the improved products compared to the existing system. An example is the LCA study conducted by Combibloc (IFEU 2010, EU). The study was carried out to assess the performance of the potential system Ecoplus which has a new barrier technology and does not contain aluminium like the conventional beverage carton. This allowed to understand the strength and weakness of the newly developed system.
3. Identify the stages that give rise to the environmental impacts

   Within an LCA studies, it was possible to determine which phase in its life cycle that contributed more in impacting the environment. Eventually, this type of information will lead the focus of environmental management effort. As an example, it was found that in all of the LCA studies of multi material packaging reviewed in this work, the most contributing step to the potential environmental impact is the raw material extraction and production. Therefore, focus should be paid more in this step in order to improve the more environmentally friendly design of packaging.
4. Carry out ISO-compliant LCA study. All of the LCA studies referred to the ISO 14040 and 14044 (2006) standard. The LCA study for Nordic wine (BioIntelligent 2010, Norway and Sweden) referred also to the PAS 2050 framework ISO-compliant standard. PAS 2050 stands for Publicly Available Specification; it has been developed for assessing the life cycle greenhouse gas emissions (GHG) of goods and services.
5. Provide information whether internal or external communication, for example to Non-government organization, retailers, authorities, consumers, the supply chains stakeholder

LCA for packaging can be either product or waste LCAs, depending on the information required. A product LCA includes an examination of different packaging systems, taking a closer look at how the packaging is produced, its distribution and service life, and its disposal at the end of its life cycle. Waste LCA instead has a more environmental orientation, aiming to answer question about a more favourable disposal route. Therefore, the past life of packaging systems can be omitted, for example manufacture, service life, and so on. The studies analyzed in this work considered packaging as a product LCA, since all of them take into account the production of the raw materials, transport, and related process before the packaging end up in disposal system.

Among the studies, four of the studies evaluated packaging as a part of product system (fill products and the packaging together). This fact is related to the goal of the LCA studies themselves. One study was intended to evaluate the contribution of the packaging to the environmental profile of the product (milk) life cycle and another was to identify and evaluate the relative environmental importance of different process steps in the liquid food packaging system evaluated. According to the study for Tetra Pak, the highest environmental impact contribution comes from the production of the fill products (juice and milk), considering that they constitute around 97% of the product (product plus the packaging) by weight. In general up to 90% of the environmental impact comes from the product and just 10 % from the packaging (BioIntelligent 2010, Norway and Sweden).

3.2.2 System Boundaries and the related issues

The system boundaries defined in an LCA study depends on the goal and scope of the study. It is not possible to generalize the results of several LCA studies together without considering the differences in system boundaries taken into account in each study. Among the LCA studies reviewed in this work, there are common phases in beverage carton life cycle. The recapitulation of the main processes in the LCA studies is presented in table 3-3. This common phases flow of the LCA studies is shown in figure 3-1. The explanation of each indicated phase and the issues related to system boundaries are presented in the following section.

Table 3 - 3 General Summary of the processes involved in the LCA studies

ID	Raw Material Production	Converting	Filling	Use Phase	End-of-Life	Transportation	Secondary Packaging	Fill product Life cycle
Oestfold 1999, Sweden	■	■	■	■	■	■		■
TetraPak 2002 Italy	■	■	■		■	■		
TetraPak 2002(2), Italy	■	■	■		■	■		
TetraPak 2005, Italy	■	■	■		■	■		
ScienceDirect 2007, Brazil	■	■	■		■			
QualityFestival 2008, Serbia	■					■		
SEI 2009, Nordic	■	■	■		■	■	■	
WRAP, 2010, UK	■	■	■		■	■		
IFEU 2010, EU	■	■	■		■	■		
Elsevier 2010, Spain	■	■	■		■	■		■
BioIntelligent, 2010, Norway and Sweden	■	■	■	■	■	■	■	
Elsevier, 2011, China	■	■			■	■		

■ = Process carried out

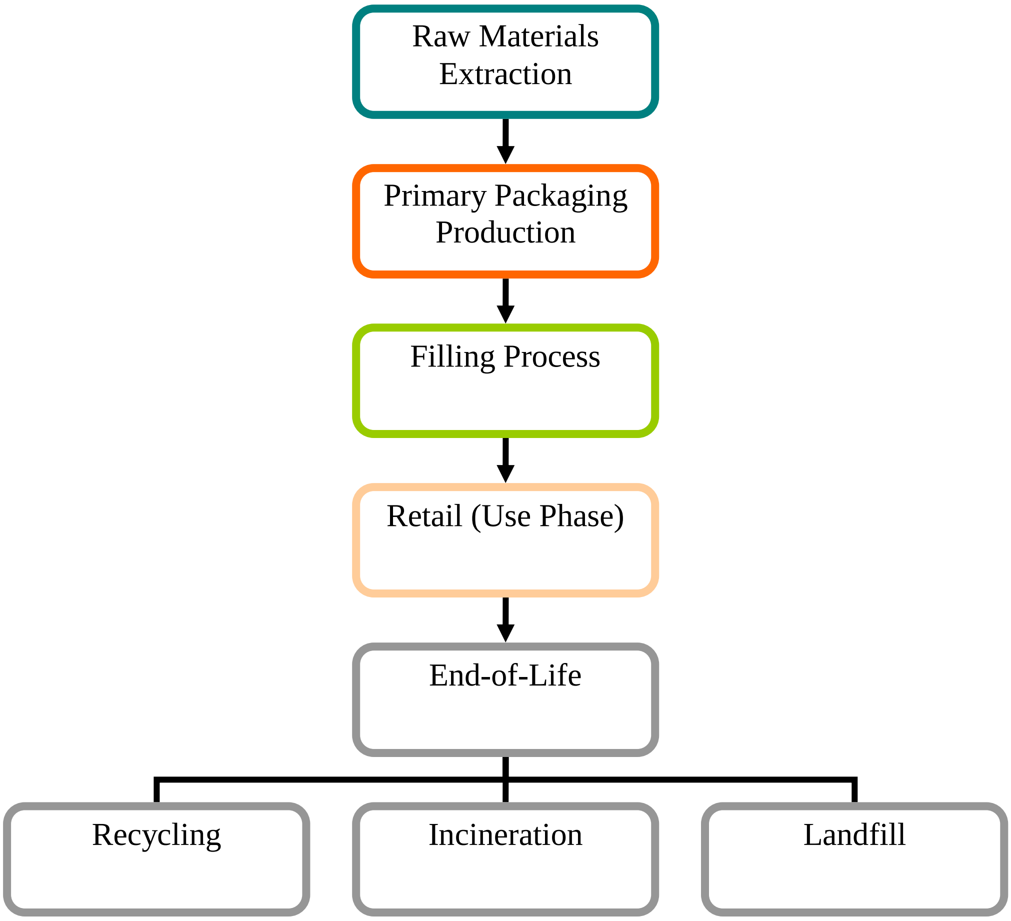

Figure 3 - 1 The Common Life Cycle Phases of Beverage Carton

3.2.2.1 Raw Materials Extraction

Raw material extraction was mentioned in all of the LCA studies. This phase involves the extraction and production of materials needed for producing beverage carton and it depends on the specific beverage carton type. The main processes involved in this phase are paper manufacturing, polyethylene production, the extraction and the production of aluminium. The possible environmental impacts in this phase are associated with forestry activity, water consumption related to paper manufacturing, waste generation, energy use and emission to water and air associated with the production of raw materials. In all of the LCA studies, raw material extraction was found to be the most impacting phase.

3.2.2.2 Primary Packaging Production / Converting Phase

This phase was taken into consideration in all of the LCA studies. During converting phase, output materials produced from previous phase are converted into a roll of ready to use beverage carton.

The output of this phase is to be sent to the filling system. The potential environmental impacts in this phase are associated with the use of energy, water consumption, waste generation, and emission both to air and water.

3.2.2.3 Filling Process

In this phase, the fill products are inserted into the beverage carton through a series of aseptic processes. The potential environmental impacts in this phase is attributed to the use of energy, emission to water and air. Only one study did not consider filling process due to lack of data (Elsevier 2011, China). In this study, the filling process was considered as the use phase.

3.2.2.4 Use Phase

Use phase is a commonly excluded process from the boundaries of evaluated studies. The use phase of packaging for the products starts when the product moves from the store to consumer. In this phase, packaging plays its role to retain the quality and the freshness of the product and to give security during transport process. In the case of considering fill product and packaging, potential environmental impacts at the use phase would be related to the energy required to maintain the function of a beverage carton to preserve its fill products in refrigerator.

3.2.2.5 End-of-Life Option

This phase was taken into account in all of the studies. Beverage carton might end up in landfill, incineration with or without energy recovery, or recycling, depending on the local waste management system and the waste management scenario specific for each study.

Certain types of packaging may be favourable at one market, for example with high recycling rate but it may have an environmental performance at another. It is therefore important to have an idea about the waste management system in the location where LCA study is conducted. In this phase of study, assumptions concerning the share of the disposal option, whether the post-consumer beverage carton goes to landfill, incineration, or recycling were often made.

In some of the study, recycling was found to be favourable to the environmental performance of the packaging. The LCA study conducted for Brazilian case (ScienceDirect 2007, Brazil) reported that a level as high as 56% of GWP reduction will be reached if the recycling rate of not only paper but also plastic and aluminium part of beverage carton increases to 70%. Promoting recycling of multi material packaging could be a solution in order to improve the environmental performance of the packaging. The LCA study conducted for Spain case (Elsevier 2010, Spain) showed that recycling may be favourable in GWP and CED indicators. Another study carried out by Combibloc to compare existing cb3 packaging and the potential new cb3 ecoplus (IFEU 2010, EU) concluded that recycling can be favourable to the environment. However, one study mentioned that recycling would not make any reduction in GWP (Oestfold 1999, Sweden). Two studies conducted for Tetra Pak Italy stated that there was no conclusion could be drawn whether recycling, energy recovery, or disposal is a better alternative for the impact categories selected for the study (Tetra Pak 2002, Italy and (Tetra Pak 2002(2), Italy).

3.2.2.6 Transport phase

Transportation was taken into consideration in all of the LCA studies. Transportation contribution is usually calculated based on the weight of the loads and the distance to reach. Transportation in life cycle of beverage carton are contributed from several possibilities such as :

1. Transportation from the raw material supplier to the packaging production site
2. Transportation from the converter to the filling site
3. Transportation from the filler to the retailer
4. Transportation from the retailer to the consumer
5. Transportation of the waste from the manufacturer, retailer, and consumer to the sites of recovery and disposal
6. Transportation for the supply of raw materials for secondary and tertiary packaging

It is difficult to make a generalization of the transport distances involved in the different stages of a packaging life cycle. Assumptions were made in many of the studies regarding transport distances, and since it’s based on expert judgements, deviation might have occurred. In some studies, transportation showed to give an important contribution, especially in distribution phase. The transport from filler to retailer is crucial and therefore filling at the local market was suggested instead of having the filling process abroad (Elsevier 2010, Spain).

3.2.2.7 Infrastructure

In most of the LCA studies, infrastructure and capital equipment such as machines and buildings were excluded from the study. This assumption is usually made in the LCA studies due to the fact that the environmental impacts involved can be neglected referring to the functional unit and compared to other impacts, because of the lifespan of these facilities. Three LCA studies conducted for Tetra Pak in Italy took the infrastructure of disposal site in urban landfill with biogas uptake and leachate treatment, controlled landfill, and incinerator (Tetra Pak 2002, Italy). The information regarding the contribution of infrastructure has to be taken into account to understand whether it can be omitted from the study or not.

3.2.2.8 Secondary Packaging

Secondary Packaging was evaluated in five out of twelve studies. Secondary packaging is material needed to transport a group of product in primary packaging, for example a cardboard to carry beverage in multi material carton packaging. It is usually needed to transport products until the supermarket shelf. Secondary packaging depends on the primary packaging in terms of volume, shapes, weight, and so on. Secondary packaging was considered in LCA comparative study for liquid food of Tetra Pak and alternative packaging (SEI 2009, Nordic) because the amounts and types of secondary packaging were different between different packaging under study.

It was shown in the same study that secondary packaging gave 40% contribution to the environmental impact during filling phase. This contribution was caused by the raw materials production of secondary packaging.

Secondary packaging was taken into consideration in the LCA study of milk packaging system for United Kingdom market (WRAP 2010, UK) since the goal of the study was to identify the relative environmental impacts of different packaging assessing two different distribution, retail and doorstep.

Secondary packaging may be necessary to be included in LCA of beverage carton since it is a necessary part in transporting both the packaging and the whole product (packaging and the fill products).

3.2.2.9 Fill Product Loss

A product loss was also not assumed in all of the studies, some due to lack of data. Product loss might occur at several points whether in the supply chain or consumption for example during the storage, handling, or filling process.

In making LCA analysis considering the whole product (filling goods together with the packaging), this parameter is important taking into account that the fill product generally composes more than 90% weight of the product. In LCA report evaluating packaging system for wine in Nordic market (BioIntelligent 2010, Norway and Sweden), it was stated that when optimizing the environmental performance of the package, wine wastage must be considered because wine might represent 30-80% of the impact of the product. In one study, fill product wastage was assumed to be accidental. Minimizing product loss should be a key objective to be taken into account to reduce the potential environmental impacts. A correlation between the protection function of the packaging and the loss of product may be established to support an LCA study.

3.2.2.10 Printing Ink

In multi material packaging, printed information is always present whether it’s the product’s brand, nutritional information, and so on. However, only few of the LCA studies took the printing ink into their system boundaries. The LCA study of Tetra Pak and alternative packaging for Nordic market (SEI 2009, Nordic) mentioned about printing ink. However, in this study the printing ink was included in cut-off criteria. There was a missing data for printing ink regarding the type, the production data, and the transportation, hence it was regarded as a data gap limitation. The weight of the ink is less than 0,7% of the beverage carton weight and the mass has been added to the total weight of the beverage carton in this study for posterity.

Printing ink was taken into consideration in three LCA studies for Tetra Pak Italy (Tetra Pak 2002 Italy, Tetra Pak 2002(2), Italy, Tetra Pak 2005, Italy). In this study, there were two types of printing ink : the water based and solvent based ink. The production process of both printing ink was taken into account. The potential impact categories generated from printing ink is the emission of Volatile Organic Compound (VOC) from the production plant, methane generation related to the use of natural gas as energy source in production process. Printing ink is also attributed to water consumption and solid waste generation. However, it was not clearly defined how much the contribution of the printing ink in affecting the potential environmental damage.

3.2.3 Allocation

Allocation procedures were applied in some of the studies evaluated. Allocation can be performed in estimating direct emission, material consumption and transport, electricity energy production, and so on. Allocation is applied based on mass basis. The LCA study for Tetra Pak Italy (Tetra Pak 2002 Italy, Tetra Pak 2002(2), Italy, Tetra Pak 2005, Italy) applied assumptions on the quantity and chemical composition of waste and which based on chemical composition of the treated waste. Some examples of the allocation procedure are presented in the following paragraphs.

Cut-Off criteria

This allocation procedure was performed for Co-product allocation in LCA of Tetra Pak and alternative packaging (SEI 2009, Nordic). It basically works by excluding the effects on the life cycle contributed by an amount of co-products typically less than 1% of the primary packaging weight or when the economic value is very low.

Avoided Burdens or End-of-Life

An example of this allocation approach was the assumption of the percentage of packaging waste disposed in sanitary landfill, incineration with energy recovery, and recycling.

The benefit or drawback of recycling and energy recovery of packaging material largely depends on the assumptions regarding which material and energy type being replaced by the recycling and energy recovery (Oestfold 1999, Sweden). In LCA scenario for Brazil case (ScienceDirect 2007, Brazil) that evaluated the rate of the recycling rate to the GWP and Energy Consumption, increasing recycling rate was assumed to be beneficial for GWP factor because it reduces the methane production from manufacturing process of paper board and polyethylene and from anaerobic degradation of carton process. In comparative LCA for Nordic market (SEI 2009, Nordic), recycling of liquid carton board was modelled as producing white line chipboard, assumed to replace Tetra Brik type paperboard. Consequently, potential environmental impacts associated with the production of virgin material for Tetra Brik was assumed to be reduced.

3.2.4 Life Cycle Impact Assessment phase

The list of impact categories chosen for the studies is shown in table 3-4. All of the impact categories chosen in the reviewed LCA studies are classified as midpoint or problem-oriented approach. Table 3-5 shows other category indicators investigated in some of the studies.

Given the growing concern regarding the climate change issue, GWP was taken into calculation in all of the studies. The importance of this impact category is attributed to the emission released as a consequence of energy use throughout the life cycle of the beverage carton.

Eutrophication (terrestrial and aquatic) and acidification were calculated in all of the studies except two (ScienceDirect 2007, Brazil and Elsevier 2010, Spain) whose objective of the studies were reserved in making comparison in GWP and CED. The impact of eutrophication and acidification is at local or regional level.

Photochemical Oxidant Formation and Cumulative Energy Demand were evaluated in most of the studies (eight out of twelve studies). The geographical scope of the effect of POCP is local or regional. CED is a parameter to quantify the energy consumption of a system.

Human toxicity impact category was calculated in five studies. Currently there is no fixed methodology to quantify this category. Each impact category is attributed to limitations in calculation methodology, assumptions, and so on.

Table 3 - 4 Impact categories studied in LCA report

Impact Categories	Number of study
Global warming Potential	12
Eutrophication	10
Acidification	10
Photochemical Oxidant Formation (POCP)	8
Cumulative Energy Demand (CED); Primary Energy, Cumulative Energy Demand Non Renewable	8
Human toxicity: Respiratory Inorganics, Carcinogen, PM10	5
Ecotoxicity : Terrestrial Toxicity, Freshwater Aquatic Toxicity, Sedimental Toxicity	4
Abiotic Resource Depletion	4
Stratospheric Ozone Depletion	3
Non-Renewable Resource depletion	3
Land Use	2
Minerals and fossil fuel	1
Traffic (Lorry)	1

Table 3 - 5 Other categories investigated in the LCA reports

Other Categories	Number of study
Water consumption	3
Non Hazardous Waste	1
Solid Waste Generation	1

3.2.4.1 Generation of Waste

Two of the studies carried out for Tetra Pak (Oestfold 1999, Sweden and Tetra Pak 2002 Italy), evaluated also the generation of waste in the impact assessment report. Generation of waste does not represent a potential impact category but it is an indicator of the amount of material sent to landfill in mass unit and there is no characterization factors of different types of waste.

3.2.4.2 Waste at Converting phase

The study Investigating the life-cycle environmental profile of liquid food packaging systems for Tetra Brik Aseptic and Tetra Brik (Oestfold 1999, Sweden) mentioned about waste generated at the converting site. According to this study, waste generation in this phase dominated 50% contribution of all impact categories selected. However, further information regarding quantity, waste generation rate, the impacted factors, and waste management option for waste for this phase was not yet available.

3.2.4.3 Water Consumption

Water consumption is not an indicator of environmental impact. There are four studies (Tetra Pak 2002, 2002(2), 2005, Italy, and BioIntelligent 2010, Norway and Sweden) that considered water consumption according to the impact assessment method selected. Water use in this case did not consider water scarcity nor water stress. The life cycle inventory data regarding water use in BioIntelligent, 2010 Norway and Sweden included feed water, groundwater, river water, sea waster, well water with river silt and unspecified water, and excluded water use for hydroelectricity and power plants. This data is expressed in volume unit m^3.

The impact of water consumption depends on local conditions. The report from Wrap UK for the milk packaging system (WRAP 2010, UK) mentioned about the importance of water consumption in LCA study because of the growing importance of water scarcity issue in many countries. Water consumption might be a problem in countries where water source is limited like in arid countries.

In 2009, some researchers from ETH Zurich developed an integration of a model for assessing the environmental impacts of freshwater consumption into Eco-indicator-99 (EI99) method. The method considers damages to three area of protection: human health, ecosystem quality, and resources (Cooney, 2009).

3.2.4.4 Land Use

Only two studies regarded Land Use in their impact categories: the comparative LCA on milk packaging using life cycle assessment: from PA-PE-Al laminate and polyethylene in China

(Elsevier, 2011, China) and Combibloc cb3 and cb3 ecoplus comparative study (IFEU 2010, EU). However, the type of the land use in the first study was not specified. The method applied in estimating land use in the first study was EI99. The impacts of land use are given as a damage in ecosystems in unit as PDF (Potentially Disappeared of Affected Fraction) expressed in m^2 year.
The second study selected forestry to specify the land use category. Land use was also mentioned in LCA study of Tetra Pak for Nordic Market (SEI 2009, Nordic), but since there was lack of time and data it was omitted from the work.

3.2.4.5 Environmental Performance of Multi Material Packaging

In all of the studies evaluating the packaging system without fill products, the production process of multi material packaging was highlighted to be the most contributing phase in generating potential adverse effect to the environment. The production of raw materials mainly include the production of carton, the production of polyethylene part, and, in some packaging types, included the production of aluminium layer which is a very energy intensive process.
One important contribution comes from the forestry activity which resulted a disadvantage in natural resource depletion, since a high quality virgin paper is required for the production of paper for multi material packaging. However, this factor was not reported in all of the studies. Paper percentage in multi material packaging is in average 75% by weight. One option suggested in some studies to overcome this problem is by designing a more light-weight packaging to reduce material consumption. This light-weight packaging would have to be designed without compromising the proper protective and preservative function of the packaging.

Generally, higher capacity packaging has a better performance than the smaller one within a same packaging system. This is due to the quantity of the material used in producing the packaging, which is less in the case of bigger packaging. The packaging trend in types and size is influenced by the consumption. The packaging trend in the sense of the types of the material used, quantities, and their recyclability is influenced by the change in the lifestyle. As an example, nowadays there are few number of people per household, less time to prepare food, and the need of eat-on-the-go foods therefore smaller packages are more requested.

3.2.5 Sensitivity Analysis

Among twelve studies reviewed, only three did not mention about sensitivity analysis. Sensitivity analysis aims to identify which parameters of a beverage packaging system gives the strongest influence on the results of an LCA when variations in the parameters are made within certain limits.

Among some parameters mentioned in the sensitivity analysis are as follow:

- Weight of primary packaging
- Transportation distance
- Post consumer recycling rate
- Allocation approach
- Fill products loss

The results of sensitivity analysis are specific for particular condition and assumptions of each LCA study.

3.2.6 Limitation

There were some limitations encountered in doing the LCA studies. Each of them is specified in the following section.

3.2.6.1 Uncertainty associated with the raw data gathered/ measured

In most studies, limitation comes from the availability of the data. An example comes from the Life Cycle Assessment study of milk packaging systems in UK. The whole data required to accomplish the study was not available by the supply chains, for example the data of milk wastage. Therefore a lot of assumptions were made to overcome the data gaps. In the end it did reflect the actual UK market condition (WRAP 2010, UK). Another example was the LCA study conducted in China regarding beverage carton and plastic based packaging comparative study (Elsevier 2011, China). Lack of local database was mentioned as a the first difficulty that encountered in uncertainty analysis.

The quality of the collected data was also a factor that was mentioned in several studies as one of the limitations. One example was from the comparative study of wine packaging for Nordic market (BioIntelligent 2010, Norway and Sweden). The data for glass production only considered the raw materials production, but not the bottle formation. Thus, the impacts associated with its life cycle was estimated and the data used at the time was said to be outdated.

The precision of an LCA analysis depends on the availability and the accessibility of the data. Participation and transparency of all elements in supply chain is needed in order to support a more reliable LCI database.

3.2.6.2 Uncertainty related to space and time boundary

Reference period in one LCA study can be valid only for the indicated time scope and it can not be assumed to be valid at different point in time. Results of LCA at regional or global level sometimes can not be applied locally and vice versa.

3.2.6.3 Limitation regarding impact assessment phase

Another limitation in conducting LCA of beverage packaging was that the impact assessment method only addresses the issues specified in goal and scope definition. It is therefore not a complete assessment of all environmental issues under study. The LCA study made for beverage packaging scenario for the Nordic market (SEI 2009, Nordic), for example, did not take into account the impact category land use and biodiversity due to the time constraint in conducting the LCA study. Later it was mentioned in the sensitivity analysis that the involvement of these categories might give a contradictory result to the conclusion of the report.

3.3 LCI Dataset for Beverage Carton Conversion

The following is an example of input data for life cycle inventory phase of beverage carton converting process. The LCI data set represented 13 out of total of 19 European plants in the year 2005. The reference functional unit used was 1000 kg of aluminium-coated liquid packaging board ready to be sent to the fillers.

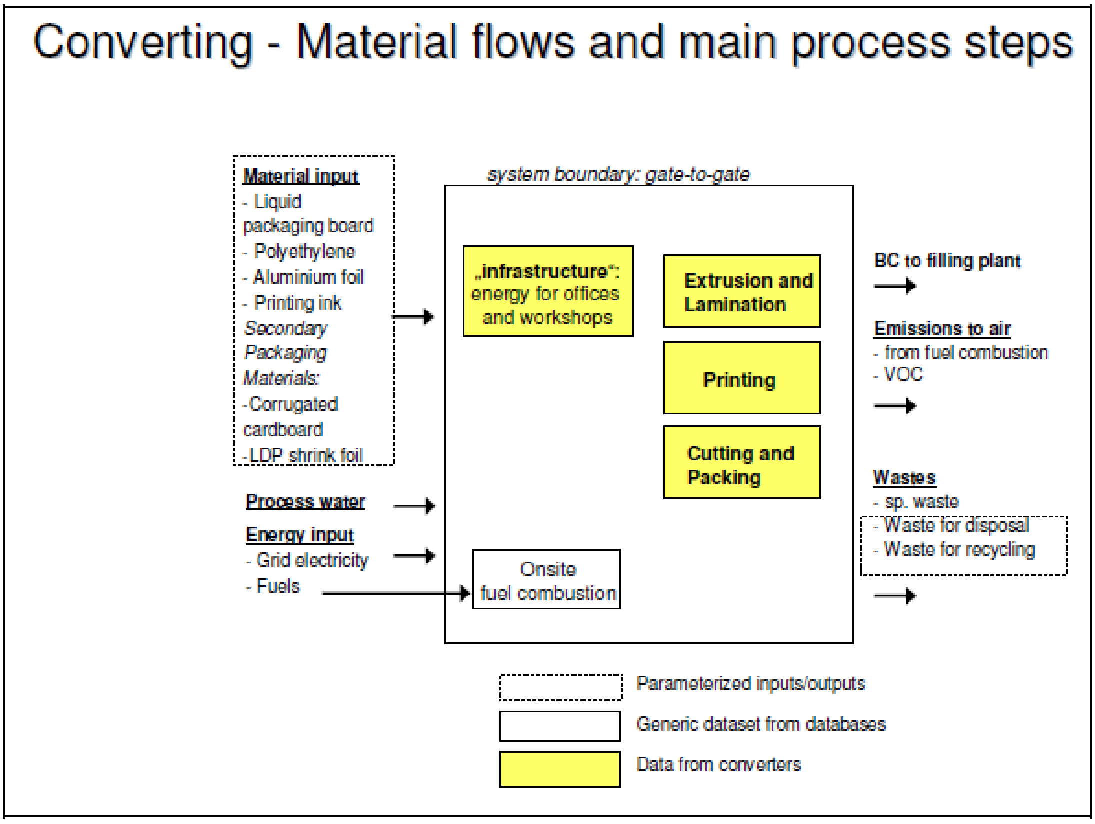

Figure 3 - 2 System Boundaries of Converting Step in Multi Material Packaging
Source : ACE

The system boundaries considered in this dataset is shown in figure 3-2. The gate-to-gate approach was used in this data. The LCI dataset for beverage carton converting phase is shown in table 3-9. At this phase, the material inputs like paper, polyethylene, and aluminium are laminated together and converted into a roll of multi layer packaging. The composition of the packaging depends on the requirement; the type of fill products, the protection function, size, and so on. In the input of the dataset, Polyethylene, Aluminium, and Liquid Packaging Board quantity is left to be filled by the user of the database, depending on the packaging type.

At the converting phase, the main elements of inputs include energy use, water, printing ink, the packaging main composition : paper, aluminium, and polyethylene. Converting phase generates solid waste and emission to air related to the processes and energy use.

Table 3 - 6 LCI dataset for beverage carton converting phase
Source : ACE

Inputs:		
	Quantity:	Unit:
Grid electricity	360	MJ
Natural Gas*	114.6	MJ
Fuel oil light*	0.367	MJ
LPG*	22.7	MJ
Water	0.105	m^3
Printing ink	1.7	kg
Polyethylene	Specified by user	
Aluminium foil	Specified by user	
Liquid Packaging Board	Specified by user	
Secondary Packaging Materials:		
corrugated cardboard	10	kg
LDPE shrink foil	0.6	kg
Outputs:		
	Quantity:	Unit:
Product:		
Converted board (BC)	1000	m^2
Waste:		
special waste	3.08E-01	kg
Emissions to air from process:		
VOC	5.,93E-02	kg
Emissions to air from on-site fuel use:		
CO_2, fossil	7.60E+00	kg
N_2O	1.39E-04	kg
CO	2.89E-03	kg
CH_4	6.94E-04	kg
NMVOC	6.94E-04	kg
NO_x	7.70E-03	kg
SO_2	8.71E-05	kg
dust	1.96E-05	kg
Product waste:		
Product waste	7.1	%**

* lower heating value used for calculation
**: % of input materials, thereof >96% are sent to recycling (~3% landfill/ ~1% incineration)

CONCLUSION

Life Cycle Assessment application in multi material packaging industry involves quantifications of energy and materials in the life cycle of packaging.
The complexity of an LCA study depends on where the system boundaries are drawn, the range of activities to be involved, the level of the details of the inputs and outputs.
The LCA studies reviewed in this work had various system boundaries, but they shared common main processes. These common processes are listed below:

1. Extraction of raw material
2. Production of the packaging (Converting)
3. Filling phase
4. End of Life phase
5. Transportation that connects among the first four processes

There are a total of 25 impact categories identified from the studies. The most frequently analyzed impact categories are:

1. Global Warming Potential
2. Eutrophication
3. Acidification
4. Photochemical Oxidant Formation Potential
5. Cumulative Energy Demand

Moreover, experts judgement might give an important influence in deciding which impact categories to be taken into account. For example, even if it was not specified from the studies, water consumption and land use might be a relevant impact indicator in the life cycle of beverage carton, based on local conditions.

The unavailability of a standardized method in conducting an LCA study might yield a questionable outcome. LCA as a tool faces several crucial limitations that might generate arguable results, such as the availability and the quality of the data, the setting of system boundaries, allocation procedure and assumptions that often have to be made due to lack of reliable data, methodology and choices of impact categories, time-coverage and geographic-related issue. The results of an LCA study in one place can not be applied to other places, due to the dependency of LCA study on local situations such as geographic, time reference, and the current waste management practice.

Conducting a full LCA study can be time and resource consuming, therefore a simplified LCA for beverage carton system could be a subject for future development. The practice of simplified LCA is known as Streamlined LCA.

The five common processes above mentioned might be proposed as the core of the simplified LCA for beverage carton. However, additional research is required to understand which of these processes could be safely omitted for a further simplification of the streamlined LCA without greatly affecting the results

In the future development of packaging system, LCA would be a necessary tool to be integrated in the design process. It is important to design a packaging adapted to the specific local condition, to give more focus on which phases should be subjected to improvements.

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