Life Cycle Management

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Questions

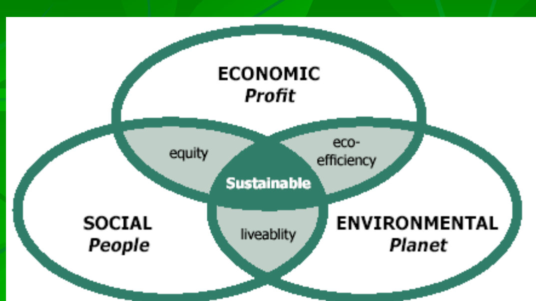
- What is an "Environmentally Friendly" product?
- What is a "Green process"
- What is "Sustainable Development"?

Possible Answers

- Recycled paper?
- Energy-saving appliances?
- A landfill for solid waste?
- Plastic packaging vs paper packaging?

Further Questions

- How far do we look?
- Raw material extraction
- Manufacturing
- Use
- Disposal (end of life)
- Energy consumption?
- Material consumption?
- Emission?



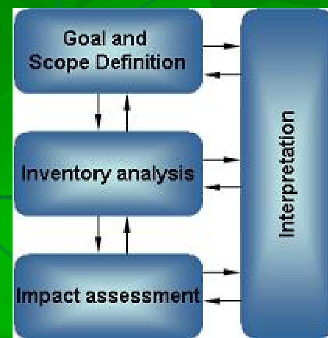
Life Cycle Management (LCM)
Life Cycle Assessment (LCA)

- Life Cycle Management is an integrated concept for managing the total life cycle of goods and services towards more sustainable production and consumption
- Life Cycle Assessment is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle

Brief History of LCA

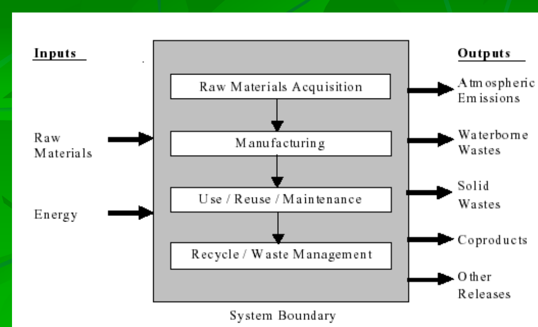
- 1963: World Energy Conference.
- 1969: Coca-Cola performed a study to compare beverage containers
- Early 70's: standard protocols being developed Resource and Environmental Profile Analysis (REPA)
- 1975-early 80's: slow development because of fading threat of oil crisis, Liquid Food Container Directive in 1985 by EC
- 1988: solid waste became global issue, re-surge of LCA
- 1991: concern over inappropriate use of LCA for marketing, lead to development of ISO14040 as a standard approach
- 2002: United Nations Environment Programme (UNEP) and Society of Environmental Toxicology and Chemistry (SETAC) launched the Life Cycle Initiative

The Phases of Life Cycle Assessment



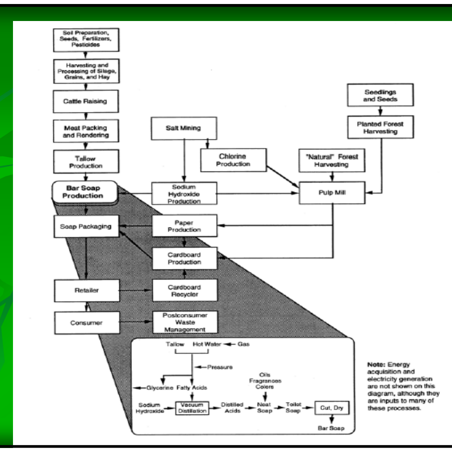
Goal and Scope Definition

- Define and describe the product, process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment.
- Functional unit
- Defining system boundary



Inventory Analysis

- Identify and quantify energy, water and materials usage and environmental releases (e.g., air emissions, solid waste disposal, waste water discharges).



Sources of data

- Meter readings from equipment
- Equipment operating logs/journals
- Industry data reports, databases, or consultants
- Laboratory test results
- Government documents, reports, databases,
- Other publicly available databases or clearinghouses
- Journals, papers, books, and patents
- Reference books
- Trade associations
- Related/previous life cycle inventory studies
- Equipment and process specifications
- Best engineering judgment.

Impact Assessment

- Assess the potential human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.
- Impact categories
- Characterisation
- weighting

Impact Category	Scale	Examples of LCI Data (i.e. classification)	Common Possible Characterization Factor	Description of Characterization Factor
Global Warming	Global	Carbon Dioxide (CO_2) Nitrogen Dioxide (NO_2) Methane (CH_4) Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Methyl Bromide (CH_3Br)	Global Warming Potential	Converts LCI data to carbon dioxide (CO_2) equivalents Note: global warming potentials can be 50, 100, or 500 year potentials.
Stratospheric Ozone Depletion	Global	Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Halons Methyl Bromide (CH_3Br)	Ozone Depleting Potential	Converts LCI data to trichlorofluoromethane (CFC-11) equivalents.
Acidification	Regional Local	Sulfur Oxides (SOx) Nitrogen Oxides (NOx) Hydrochloric Acid (HCL) Hydroflouric Acid (HF) Ammonia (NH_4)	Acidification Potential	Converts LCI data to hydrogen (H^+) ion equivalents.
Eutrophication	Local	Phosphate (PO_4) Nitrogen Oxide (NO) Nitrogen Dioxide (NO_2) Nitrates Ammonia (NH_4)	Eutrophication Potential	Converts LCI data to phosphate (PO_4) equivalents.
Photochemical Smog	Local	Non-methane hydrocarbon (NMHC)	Photochemical Oxident Creation Potential	Converts LCI data to ethane (C_2H_6) equivalents.
Terrestrial Toxicity	Local	Toxic chemicals with a reported lethal concentration to rodents	LC_{50}	Converts LC_{50} data to equivalents; uses multi-media modeling, exposure pathways.
Aquatic Toxicity	Local	Toxic chemicals with a reported lethal concentration to fish	LC_{50}	Converts LC_{50} data to equivalents; uses multi-media modeling, exposure pathways.
Human Health	Global Regional Local	Total releases to air, water, and soil.	LC_{50}	Converts LC_{50} data to equivalents; uses multi-media modeling, exposure pathways.
Resource Depletion	Global Regional Local	Quantity of minerals used Quantity of fossil fuels used	Resource Depletion Potential	Converts LCI data to a ratio of quantity of resource used versus quantity of resource left in reserve.
Land Use	Global Regional Local	Quantity disposed of in a landfill or other land modifications	Land Availability	Converts mass of solid waste into volume using an estimated density.
Water Use	Regional Local	Water used or consumed	Water Shortage Potential	Converts LCI data to a ratio of quantity of water used versus quantity of resource left in reserve.

Characterization of Global Warming Impacts

The following calculations demonstrate how characterization factors can be used to estimate the global warming potential (GWP) of defined quantities of greenhouse gases:

Chloroform GWP Factor Value* = 9, Quantity = 20 kg
Methane GWP Factor Value* = 21, Quantity = 10 kg

Chloroform GWP Impact = 20 kg x 9 = 180 kg CO_2 equivalents

Methane GWP Impact = 10 kg x 21 = 210 kg CO_2 equivalents

*Intergovernmental Panel on Climate Change (IPCC) Model

Examples of LCI and LCA Software

- Ecoinvent by Swiss Centre for Life Cycle Inventories
- GaBi by PE Europe GmbH and IKP University of Stuttgart
- SimaPro by PRé Consultants
- US LCI Data National Renewable Energy Lab

Interpretation

- Evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

An example
LCA of Cardboard Box

Environmental impact categories	Unit
Global warming	kg CO_2-equivalents
Acidification	kg SO_2-equivalents
Eutrophication	kg PO_4-equivalents
Smog formation	kg C_2H_4-equivalents
Solid waste generation	kg
Oxygen depletion	kg COD

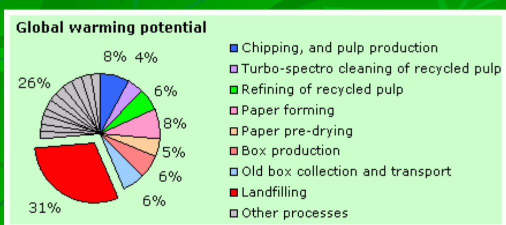
Unit process	Local data	Data from literature and LCA databases	Comments
Material production			
Tree growing and logging		*	L
Chipping and pulp production		*	L
Repulping of virgin pulp	*		I, M, R
Deflaking of virgin pulp	*		I, M, R
Refining of virgin pulp	*		I, M, R
Repulping of old boxes	*		I, M, R
High-density cleaning of recycled pulp	*		I, M, R
Turbo-spectro cleaning of recycled pulp	*		I, M, R
Light-density cleaning of recycled pulp	*		I, M, R
Thickening of recycled pulp	*		I, M, R
Refining of recycled pulp	*		I, M, R
Paper forming	*		I, M, R
Paper pressing	*		I, M, R
Paper pre-drying	*		I, M, R
Paper sizing	*		I, M, R
Paper post-drying	*		I, M, R
Paper calendering	*		I, M, R
Paper reeling and rewinding	*		I, M, R
Board and box production		*	L
Box from other systems		*	L
Use			
Box use		*	L
End of Life			
Landfilling	*	*	L, O
Old box collection	*		I, O
Transportation			
Log transportation	*	*	L, M, O
Pulp transportation	*	*	L, M, O
Paperboard transportation	*	*	L, M, O
Box transportation	*	*	L, M, O
Old box transportation	*	*	L, M, O
Recycled box transportation	*	*	L, M, O

Remark:
I : Interviews
L : Literature
M : Measurements
O : Visual observations
R : Records from the factory

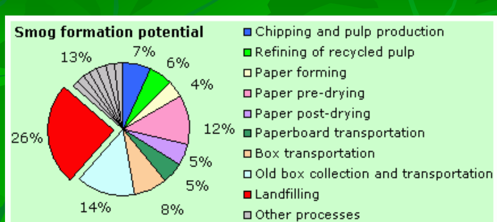
Selected exchanges per functional unit (10 boxes)		
Inputs		
Resource:		
Land use for eucalyptus	2.75	m^2 in one year
Wood (Eucalyptus)	1.80	kg
Material:		
Aluminium hydroxide	76.00	g
Coal	43.30	g
Crude oil	1.80	kg
Glue	7.40	g
Ink	11.30	g
Lignite	0.80	kg
Limestone	33.80	g
Lubricating oil	60.30	g
Natural gas	81.50	m^3
Starch (potatoes)	12.10	g
Water	39.60	kg
Energy use	**164.00**	**MJ**
Outputs		
Product:		
Box	6.60	kg
Emissions to air:		
CO	12.50	g
CO_2	5.10	kg
CO_2 (non-fossil)	0.55	kg
H_2S	41.90	mg
CH_4	0.21	kg
NH_3	2.80	g
N_2O	0.22	g
NO_x	26.60	g
SO_x	15.20	g
NMVOC	5.90	g
VOCs	0.21	g
Emissions to water :		
AOX	63.30	mg
BOD	0.14	g
Chloride	11.30	g
COD	0.57	kg
Fats and oils	16.50	g
Nitrogen	0.43	g
Nitrate	0.58	g
Phosphorus	0.57	g
Sulphate	1.80	g
SS	0.40	kg
TOC	1.20	g
Solid waste generation:		
Plastics packaging	52.90	g
Process waste	0.63	kg
Steel and metal scrap	0.15	kg

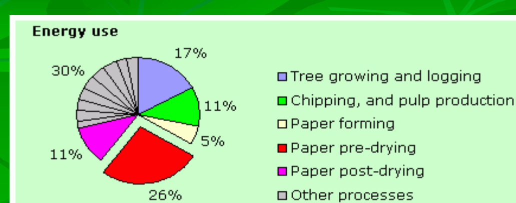
Environmental impact categories	Amount per functional unit	Unit
Global warming	7.47	kg CO_2-eq
Acidification	43.1	g SO_2-eq
Eutrophication	20.2	g PO_4-eq
Smog formation	5.64	g C_2H_4-eq
Solid waste generation	0.91	kg
Oxygen depletion	0.57	g COD

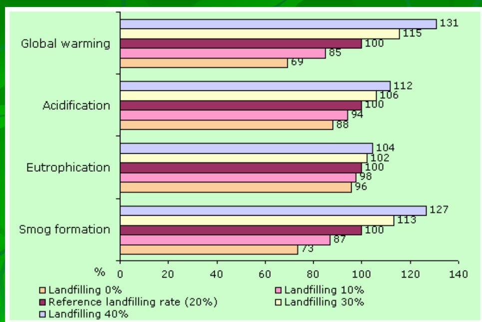
Substance i	Emission Q_i g	Equivalency factor $EF(gw)_i$ g CO_2-eq/g substance	Emission's potential $EP(gw)_i$ g CO_2-eq
CO_2	509	1	509
CH_4	21	11	231
N_2O	0.02	270	5.4
Other substances			1.6
EP(gw) per box			747
EP(gw) per funtional unit			**7470**



Substance i	Emission Q_i g	Equivalency factor $EF(sm)_i$ g C_2H_4-eq/g substance	Emission's potential $EP(sm)_i$ g C_2H_4-eq
CH_4	21.1	0.007	0.148
NMVOC	0.59	0.416	0.245
VOCs	0.0207	0.398	0.0082
Other substances			0.1626
EP(sm) per box			0.564
EP(sm) per funtional unit			**5.64**







LCA of Airbus A380

" The A380 has been designed in order to optimise environmental performance at each stage of the aircraft life cycle. In particular, the high passenger capacity with a 2-deck design and the use of new light weight materials has decreased the energy consumption per passenger dramatically. The A380 is expected to use less than 3 litres of fuel per 100 passengers kilometres."

Benefits of LCA

- Quantifies and pinpoints environmental impact for improvement
- Identifies the transfer of environmental impacts from one media to another and/or from one life cycle stage to another
- Helps decide on product/activity with least overall environmental impact
- Combines with cost and social factors to evaluate sustainability
- Eco-marketing

Ecolabels

Improvement and Management

- Modify unit process with high impacts
- Modify product design
- Mitigation measures
- Compensation e.g. carbon offset

Limitations of LCA

- Resource demanding
- Availability, accuracy and applicability of data
- Does not imply sustainability
- No easy communication to the public (e.g. a single indicator, eco-labels)

- It is better to be roughly right than to be exactly wrong

Thank You