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Paul Scherrer Institut

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Renewable Energy Technologies I – Exercise 13.1

Life Cycle Analysis and Multicriteria Decision Analysis

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A zero emissions car

Why is the life cycle perspective important?

- **«Zero emission car»:** Yes, during the use phase. But impacts may just be shifted to another ***life cycle phase*** (production of the fuel; end of life of batteries/other components)

- **«Zero emission car», «Carbon-free product»:** perhaps, but possibly the product performs poorly in ***other environmental impact categories*** such as human toxicity, particulate matter emissions or land use.

- **«Clean and low-energy company»:** Yes, but maybe all energy intensive processes in the process chain have been outsourced to a producer e.g. in China, who does, in addition, not have to follow strict environmental regulations

- Even if it's not a «zero emission car» – how does it **compare** to other car types?

What is Life Cycle Assessment (LCA)?





Environmental impact?

↑ ↑ ↑

Materials, fuels, energy supply,
transport, infrastructure, disposal,…

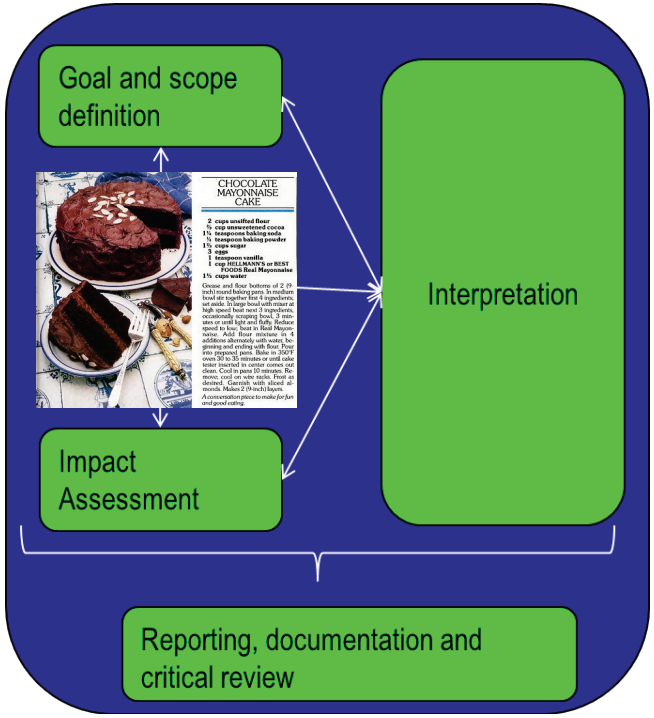
ecoinvent Centre
Swiss Centre for Life Cycle Inventories

«Background»
LCA data

Slide: courtesy of C.Bauer

What is Life Cycle Assessment (LCA)?

LCA according to ISO 14040, 14044



Steps of Life Cycle Assessment (LCA)

Structure / Terminology of LCA is defined by ISO 14040/44:2006

1. Goal **and Scope** (system boundary definition)
2. **Life Cycle Inventory (LCI)**
   Energy and Material Flow inventory into and out of the processes composing the system, within the defined system boundaries
3. **Life Cycle Impact Assessment (LCIA)** (3.1-3.3 mandatory)
   - 3.1 Categorisation (environmental effects and protection targets)
   - 3.2 Classification (burdens/stressors → effects/damages)
   - 3.3 Characterisation of effects (equivalent factors)
   - 3.4 Normalisation (relevance to reference values)
   - 3.5 Grouping (sorting and possibly ranking of the impact categories)
   - 3.6 Weighting (using ethical / subjective elements)
4. **Interpretation**: Sensitivity analysis, Error estimation, Conclusion

Inventory Assessment (LCI)
Quantification of all flows into and out of the system boundaries

Data collection:

a) **Foreground data** from industry etc.

b) **Background data** from databases such as ecoinvent, e.g. for production processes of metals or electricity, etc

Example of a Life Cycle Inventory (Jungbluth et al. 2012)

Tab. 10.25 Unit process raw data for "Inverter, 500W, at plant" and "Inverter, 2500W, at plant"

	Name	Location	InfrastructureProcess	Unit	inverter, 500W, at plant	inverter, 2500W, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER			
	InfrastructureProcess				1	1			
	Unit				unit	unit			
product	inverter, 500W, at plant	RER	1	unit	1.00E+0	0			
product	inverter, 2500W, at plant	RER	1	unit	0	1.00E+0			
technosphere	electricity, medium voltage, production UCTE, at grid	UCTE	0	kWh	4.24E+0	2.12E+1	1	1.31	(2,3,4,1,1,5); Literature (Schwarz 1992)
	aluminium, production mix, cast alloy, at plant	RER	0	kg	6.82E-1	1.40E+0	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006), recycled after use
	copper, at regional storage	RER	0	kg	2.00E-3	5.51E+0	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006), recycled after use
	steel, low-alloyed, at plant	RER	0	kg	7.80E-2	9.80E+0	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006), recycled after use
	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	RER	0	kg	1.48E-1	0	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006)
	polycarbonate, at plant	RER	0	kg	6.80E-2	0	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006)
	polyethylene, HDPE, granulate, at plant	RER	0	kg	1.40E-2	0	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006)
	styrene-acrylonitrile copolymer, SAN, at plant	RER	0	kg	2.00E-3	1.00E-2	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006)
	polyvinylchloride, at regional storage	RER	0	kg	2.00E-3	1.00E-2	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006)
electronical components	printed wiring board, through-hole, at plant	GLO	0	m2	5.96E-2	2.25E-1	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006), Calculation
	transformer, high voltage use, at plant	GLO	0	kg	3.10E-1	0	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006)
	connector, clamp connection, at plant	GLO	0	kg	5.00E-2	2.37E-1	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006), Calculation
	inductor, ring core choke type, at plant	GLO	0	kg	7.40E-2	3.51E-1	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006), Calculation
	integrated circuit, IC, logic type, at plant	GLO	0	kg	6.00E-3	2.80E-2	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006), Calculation
	transistor, wired, small size, through-hole mounting, at plant	GLO	0	kg	8.00E-3	3.80E-2	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006), Calculation
	diode, glass-, through-hole mounting, at plant	GLO	0	kg	1.00E-2	4.70E-2	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006), Calculation
	capacitor, film, through-hole mounting, at plant	GLO	0	kg	7.20E-2	3.41E-1	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006), Calculation
	capacitor, electrolyte type, > 2cm height, at plant	GLO	0	kg	5.40E-2	2.56E-1	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006), Calculation
	capacitor, Tantalum-, through-hole mounting, at plant	GLO	0	kg	4.80E-3	2.30E-2	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006), Assumption for Ceramic Multilayer Chip Capacitors
	resistor, metal film type, through-hole mounting, at plant	GLO	0	kg	1.00E-3	5.00E-3	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006), Calculation
processing	sheet rolling, steel	RER	0	kg	7.80E-2	9.80E+0	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006)
	wire drawing, copper	RER	0	kg	2.00E-3	5.51E+0	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006)
	section bar extrusion, aluminium	RER	0	kg	6.82E-1	1.40E+0	1	1.22	(2,3,1,1,1,5); Literature (de Wild 2006)
infrastructure	metal working factory	RER	1	unit	1.04E-9	8.97E-9	1	3.06	(2,4,1,1,1,5); Calculation, based on annual production of electronic component production plant
packaging	corrugated board, mixed fibre, single wall, at plant	RER	0	kg	1.12E+0	2.50E+0	1	1.24	(2,4,1,1,1,5); Calculation, based on estimated dimension of inverse rectifier
	polystyrene foam slab, at plant	RER	0	kg	1.30E-1	3.00E-1	1	1.31	(2,3,4,1,1,5); Literature (Schwarz 1992)
	fleece, polyethylene, at plant	RER	0	kg	3.00E-2	6.00E-2	1	1.31	(2,3,4,1,1,5); Literature (Schwarz 1992)
transport	transport, lorry >16t, fleet average	RER	0	tkm	3.66E-1	2.30E+0	1	2.09	(4,5,na,na,na,na); Standard distance 60km incl. disposal
	transport, freight, rail	RER	0	tkm	1.89E+0	7.11E+0	1	2.09	(4,5,na,na,na,na); Standard distances 200km
	transport, transoceanic freight ship	OCE	0	tkm	8.09E+0	3.63E+1	1	2.09	(4,5,na,na,na,na); Estimation: 18000km
emission air, high pop. dens.	Heat, waste	-	-	MJ	1.53E+1	7.63E+1	1	1.22	(2,3,1,1,1,5); Calculation
disposal	disposal, packaging cardboard, 19.6% water, to municipal incineration	CH	0	kg	1.12E+0	2.50E+0	1	1.25	(2,3,1,5,1,5); Calculation, different geographical location
	disposal, polystyrene, 0.2% water, to municipal incineration	CH	0	kg	1.32E-1	3.10E-1	1	1.25	(2,3,1,5,1,5); Calculation, different geographical location
	disposal, polyethylene, 0.4% water, to municipal incineration	CH	0	kg	3.00E-2	6.00E-2	1	1.25	(2,3,1,5,1,5); Calculation, different geographical location
	disposal, plastic, industr. electronics, 15.3% water, to municipal incineration	CH	0	kg	2.30E-1	0	1	1.25	(2,3,1,5,1,5); Calculation, different geographical location
	disposal, treatment of printed wiring boards	GLO	0	kg	6.90E-1	1.70E+0	1	1.25	(2,3,1,5,1,5); Calculation, different geographical location

Ecoinvent database

With more than 10’000 LCI datasets for ca. 3’000 products and services in the areas of

- **agriculture**
- **energy** supply, **transport**,
- **biofuels** and biomaterials,
- bulk and speciality **chemicals**,
- construction **materials**, packaging materials,
- basic and precious **metals**, metals processing,
- ICT and **electronics**,
- **waste** treatment,

it is one of the most comprehensive international LCI databases.

Ecoinvent database

- Ecoinvent is one of the world's leading databases with consistent and **transparent**, up-to-date Life Cycle Inventory (LCI) data.
- Ecoinvent was founded by **Swiss Research Institutes** in **1997**.
- PSI has been – and still is - supplying a major part of the data on energy and transports (together with other partners)
- In 2013, **version 3** was released, which represents an overhaul of the structure of the database in order to be able to handle the increasing size and complexity of the database. **Latest version: version 3.3**, released in August 2016.
- **Quality assurance**: All datasets have to be submitted and reviewed by 2-4 experts before they are stored in the database

Ecoinvent database - how to use it

•Not for free, but **guest account** possible
http://www.ecoinvent.org/database/registration/registration-as-guest

•Can be used as such (only by professionals), or – most often – through special **LCA softwares**, such as SimaPro, Gabi, OpenLCA, Brightway2 etc.
http://www.pre-sustainability.com/simapro; http://www.gabi-software.com – license required
http://www.openlca.org/; http://brightwaylca.org/ - for free, but database not included

•These softwares visualise the process trees of the systems under investigation and calculate the LCIA with different methods

Other databases:
- GaBi LCA Databases
- European Life Cycle Database (ELCD)
- U.S. Life Cycle Inventory Database
- and several other national initiatives for LCI databases

Ecoinvent database - example dataset

File Edit Calculate Tools Window Help

Documentation | Input/output | Parameters | System description

Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
Electricity, high voltage//[DE] electricity production, hard coal	1	kWh	Energy	100 %		ecoinvent3test	
(Insert line here)							

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Water, cooling, unspecified natural origin	in water	0.035	m3	Undefined				
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Uni					
chlorine, gaseous//[GLO] market for chlorine, gaseous	0.0001	kg					
hard coal ash//[GLO] market for hard coal ash	-0.00263	kg					
hard coal power plant//[GLO] market for hard coal power plant	0.000000000013	n					
hard coal//[WEU] market for hard coal	0.417	kg					
NOx retained, by selective catalytic red//[GLO] market for NOx retained, by	0.00234	kg					
residue from cooling tower//[GLO] market for residue from cooling tower	-0.00005	kg					
SOx retained, in hard coal flue gas desu//[GLO] market for SOx retained, in	0.00616	kg					
water, completely softened, from decarbo//[GLO] market for water, completely	0.06	kg					
water, decarbonised, at user//[GLO] market for water, decarbonised, at user	1.5	kg	Undefined				
light fuel oil//[Europe without Switzerland] market for light fuel oil	0.00017	kg	Undefined				
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Outputs

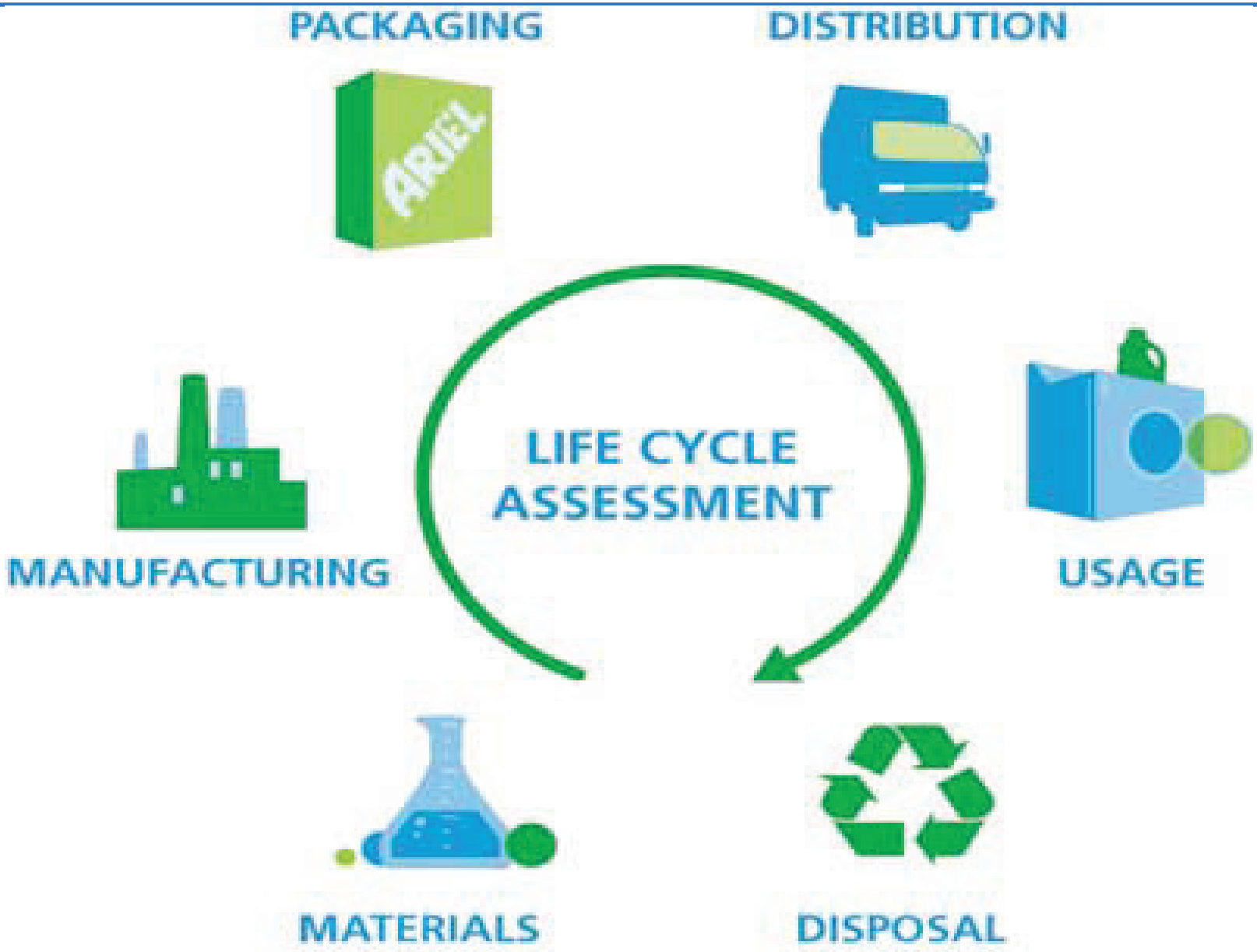
Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Water		0.0009254055	m3	Undefined				
Carbon dioxide, fossil	low. pop.	0.922	kg	Undefined				
Carbon monoxide, fossil	low. pop.	0.00008	kg	Undefined				
Nitrogen oxides	low. pop.	0.000621	kg	Undefined				
Dinitrogen monoxide	low. pop.	0.0000397	kg	Undefined				
Particulates, > 2.5 um, and < 10um	low. pop.	0.00000556	kg	Undefined				
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	low. pop.	0.0000000000	kg	Undefined				
Particulates, > 10 um	low. pop.	0.0000528	kg	Undefined				
Particulates, < 2.5 um	low. pop.	0.0000473	kg	Undefined				
Lead	low. pop.	0.0000000553	kg	Undefined				
Antimony	low. pop.	0.0000000008	kg	Undefined				
Mercury	low. pop.	0.000000041	kg	Undefined				
Cadmium	low. pop.	0.0000000005	kg	Undefined				
Arsenic	low. pop.	0.0000000129	kg	Undefined				
Sulfur dioxide	low. pop.	0.000656	kg	Undefined				

…inventory for many products and services, e.g. energy production, freight transport, wheat farming, copper mining, heat production, steel production, etc…

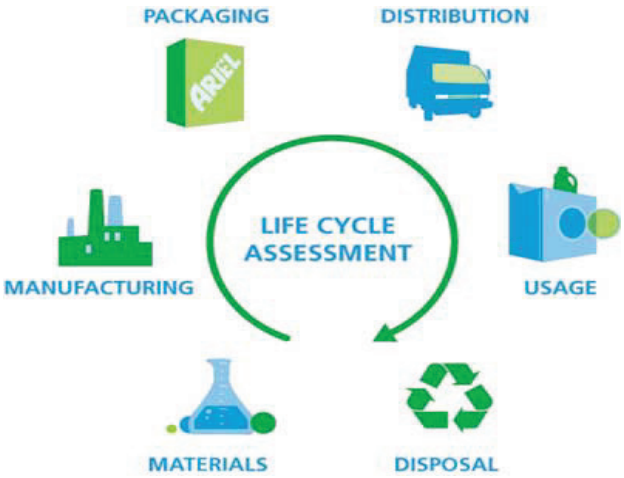
[Ecoinvent online demonstration]

Life Cycle Assessment



http://pgbeautyscience.com/breakthroughs-xix.php

Life Cycle Cost Analysis



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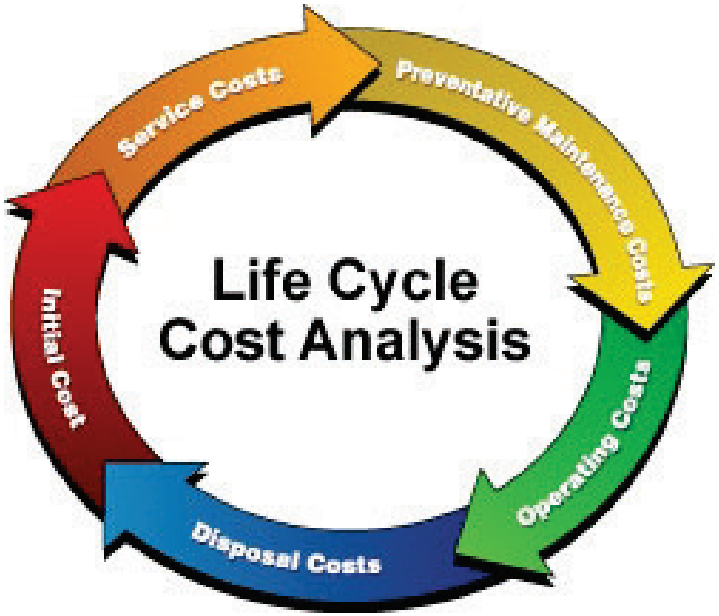
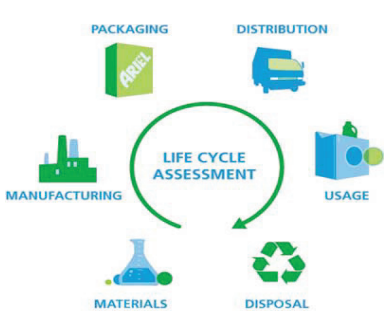


http://www.ramcraft.co.il/Life-Cycle-Cost-LCC.htm

Social Assessment



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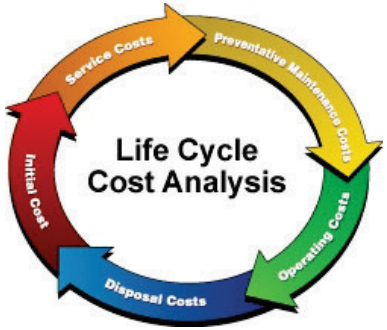

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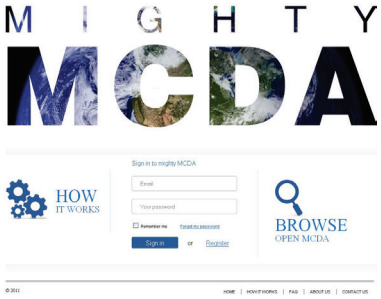
Social etc.

Multi-Criteria Decision Analysis (MCDA)



Tradeoff analysis / Multi-criteria ranking support

Exercise 13: Life Cycle Analysis and Multicriteria Decision Analysis

Exercise 13: A1 - LCA

- **Goal:** Calculate the direct electricity requirements for the construction of a 5 kW_p PV plant throughout the material input chain

- **Example:** inverter

21 $kWh_{ENTSO-E}$ /unit inverter x 2.5 unit inverter / 5kW_p PV plant
= 52.5 $kWh_{ENTSO-E}$ / 5kW_p PV plant
= direct electricity requirement of the inverter per 5 kW_p PV plant

ENTSO-E = European Network of Transmission System Operators for Electricity

Exercise 13: A2 - LCA

- **Goal:** Calculate the cumulative emissions per kWh of electricity produced from PV, due to the direct electricity requirements of the 5 kW_p PV plant

- **Approach:**

1) Calculate the emissions of the ENTSO-E mix
   (e.g. kg CO_2-eq. / $kWh_{ENTSO-E}$)

2) Calculate the total electricity production of the 5 kW_p PV plant over its lifetime
   (kWh / 5 kW_p PV plant)

3) Calculate the cumulative emissions due to the direct electricity requirements of the 5 kW_p PV plant using the result from A1
   (e.g. kg CO_2-eq. / kWh_{PV})

Exercise 13: B1 - MCDA

- **Goal:** Calculate the total sustainability score for the four power generation systems

- **Example:** Score for hydro power in dimension ENVIRONMENT

CO_2-equivalents	40% x 100
Change in unprotected area	30% x 100
Land use	10% x 0
Fatalities in severe accidents	15% x 97
Waste mass	5% x 0
	85

Exercise 13: B2 - MCDA

- **Goal: Establish your own weighting profile**

- The weighting factors in tables 3 and 4 have been determined by evaluation of the opinion of many stakeholders.

- Each of the stakeholder has its own view on what is the most important indicator.

- The outcome of the MCDA (ranking) therefore depends on the weighting factors.

- Change the factors and see how the ranking can change.

Exercise 13: Reading

- If you want to know more about the **photovoltaic inventory**, read Jungbluth et al. 2012, which is an “ecoinvent report”

- FYI: For v1 and v2 of ecoinvent, extensive reports (sometimes >400 pages) on all energy related technologies (coal, oil, nuclear, biomass, CHP, photovoltaics etc.) have been published. They are accessible here when logging in as a guest user: http://www.ecoinvent.org/support/old-doc/rep/

- If you want to know more about the **single MCDA indicators**, read Hirschberg et al. 2004

Our laboratory at PSI

Laboratory for Energy Systems Analysis (LEA)

- An interdepartmental laboratory in the General Energy Research field under the head of Stefan Hirschberg
- http://www.psi.ch/lea/

- Three groups:
  - Technology Assessment (LCA, costs, accident related risks)
  - Energy Economics (energy scenarios)
  - Risk and Human Reliability (human factor in risks)

Theses and internships in our lab: LCA, cost and risks

Are YOU interested in a thesis/intership with us? We have various open & interesting topics!

TRANSPORT sector:

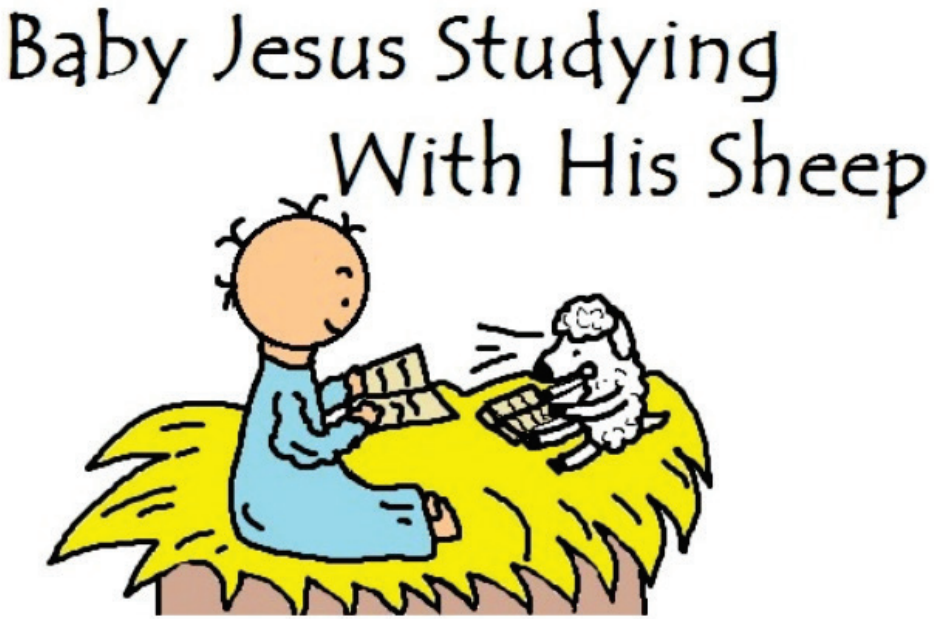
- Costs and environmental impacts of **road public** transport
- LCA of advanced **vehicle power train components** considering size scaling
- LCA of Swiss **transport infrastructure**
- LCA of **Water based transport**
- Optimizing the implementation of Swiss **biofuels in the energy and transport** sectors
- **Accidents** in the Swiss transport sector

VARIOUS:

- Risk assessment of **hydropower**
- Uncertainty in **Electricity Generation Mixes**
- Review of **uncertainty** in LCA
- LCA of **Energy Storage** technologies
- **Automatic classification** of LCA data

Detailed information on:
http://www.master-energy.ethz.ch/studies/thesis/open-positions.html
https://www.psi.ch/ene/master-thesis-openings

Merry Christmas
&
Good luck with your exam(s)!



http://www.churchhousecollection.com/resources/Baby%20Jesus%20Reading%20To%20His%20Sheep%20Printable%20Writing%20Paper.jpg