Chapter 4 Module 9
Environmental systems analysis methodology

Can totally different sanitation systems be fairly compared? How are environmental impacts measured?

After this module should the student be able to understand the concepts of:

System definition and boundaries.

Quantification of environmental effects and resource use.

Indexes and weighing.

Acknowledgements:

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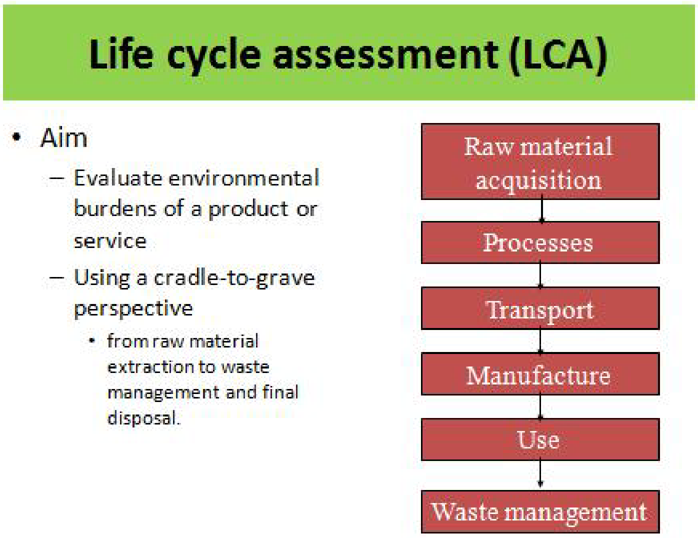
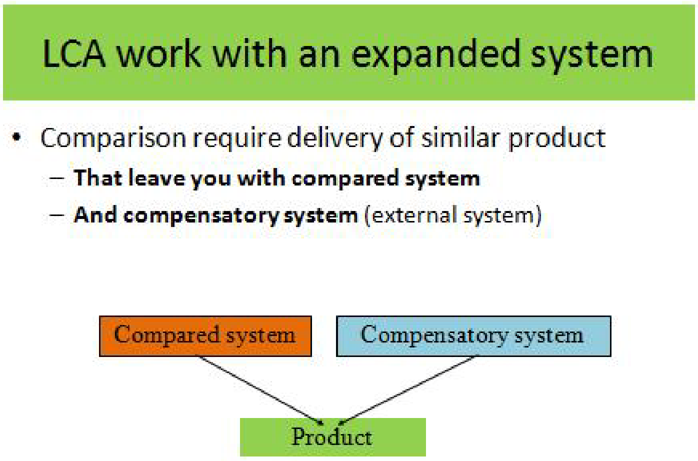


LCA is a standardised tool for evaluation of the environmental burdens that a product or service is associated with.

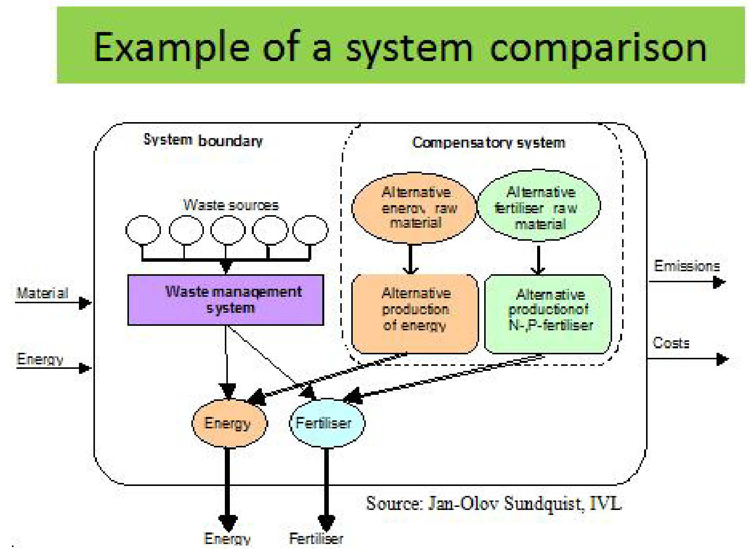
The perspective of the evaluation is from cradle to grave. This means that all parts of the life cycle of the product is included into the system. In the cradle perspective is the collection of raw material included, e.g. if virgin phosphorus is used the effects of the mining should be included in the evaluation. After that should all processing and transportation steps and their environmental impact be incorporated into the evaluation.

The use is then evaluated, this includes effects the material have on the environment or activities associated with the material, e.g. to continue with phosphorus, the effects from the field application such as fuel consumption for the tractor performing the fertilisation.

In the category connected to the grave perspective with the final disposal of the material be included. To continue with the phosphorus example the grave perspective includes several factors such as losses from the field of applied fertiliser, and the emissions from consumed food that is excreted. If the excreta will not be collected and reused as fertiliser the effects from the P that is ending up in the environment need to be considered.

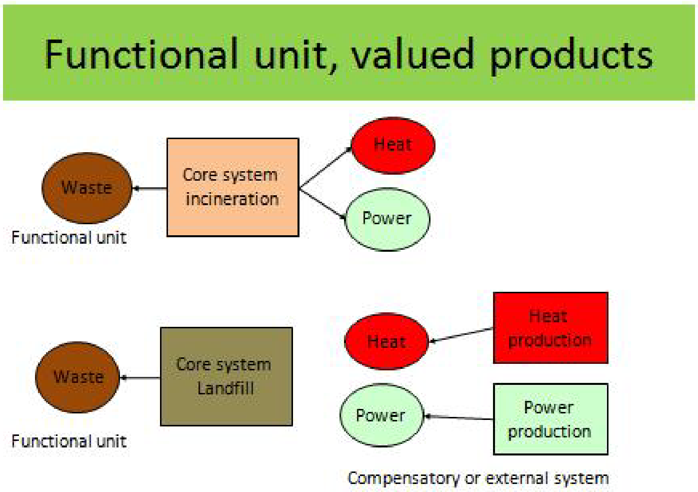


To be able to compare two different systems, e.g. sustainable sanitation and conventional water based sanitation, they need to deliver the same products. The products in the case of sanitation could be fertiliser, biogas etc. To be able to perform this comparison you start with your systems to compare and evaluate the delivered products you have out of the system. Then you put up an extended/compensatory system assuring that all compared systems deliver the same amount of products. E.g. if a dry urine diverting system is compared with a conventional wastewater treatment system, the dry sanitation system delivers fertilisers such as nitrogen, phosphorus and potassium. Then the conventional sewage system needs to be compensated with these products, i.e. the conventional system will be included with the environmental effects from mineral fertiliser production to the same extent as the dry sanitation system delivers.



In this example different treatment systems are compared regarding their consumption of material and energy and the emissions and costs associated to the system.

The different systems alternatives produce different amounts of energy and fertilisers. To be able to compare the alternatives a compensatory system is included compensating all systems up to delivering the same amount of fertiliser and energy. This is then included in the both the consumption, the emissions and the costs. This makes it possible to compare totally different treatment alternatives that deliver completely different products as the sum of products from waste system and compensatory system is equal in all scenarios.



This is an example of the system for waste management comparing incineration and land filling. The core system of incineration is based on Swedish systems where the heat from the incineration is collected and used for production of electricity and of heat, used in a central heating system. When comparing this with the land fill system the land fill need to be compensated with production of heat and of power. How these compensations are selected will have a major effect upon the final results, e.g. the electricity can be either chosen as the electrical mix of Sweden where approximately 45% is hydro power and 45% nuclear power and the remaining is biowaste incineration and other systems such as coal power plant. This can be compared to when Sweden is importing electricity that is mainly coal based electricity. Depending on the selection here, the effect on the environment and production of fossil CO2 differs a lot, so the selection of the compensatory system always need to be motivated.

Impact categories to be considered in an LCA

- Resources - Energy and materials
- Resources – Water
- Resources – Land
- Impacts on human health (toxicological and non-toxicological impacts, excluding and including work environment)
- Global warming
- Depletion of stratospheric ozone
- Acidification
- Eutrophication
- Photo-oxidant formation
- Eco-toxicological impacts
- Habitat alterations and impacts on biological diversity

Upon performing the comparison between the systems what factors to be compared need to be considered.

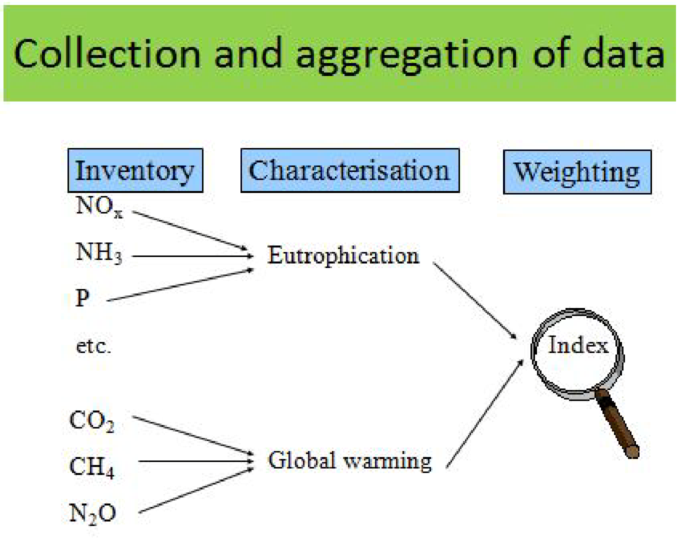
There are a set of groups to be compared, first it is the usage of resources, this include use of energy and material (especially virgin material that need to be newly produced) and water. The final resource is the use of land.

The next category is the impact on human health, both toxic effects other effects and where the effects are related to if it is the work space or other spaces.

Then it is global effects such as global warming and depletion of stratospheric ozone.

This is followed by more local environmental effects such as acidification, eutrophication, photo oxidant formation, eco-toxicological impacts. All these effects are from emission of chemical substances.

The final effect included is habitat alterations and impact on biological diversity, this can be from chemical, physical as well as biological origin.



When the data has been collected, in this case emissions from a system it has to be aggregated into groups where the different substances are grouped together and calculated as one emission. After this grouping the groups are weight to be able to compare the different impact factors.

Which environmental effect is most important?

- Global vs local
- Long-term vs short-term

- Importance of the impact
  - Compare the system impact with total national emissions

When comparing the different impact factors there are several things to have in mind during the comparison, several weighing factors will be presented later in this module. Statements had to be made regarding local and global effects, this will also have political implications for a system as the local effects are more visible for the people nearby, while the global effects are less noticeable for that group. The same is for comparison of long term and short term effects where the short term can be seen here and now while the long term effect will not appear until later.

One good way of evaluating the effect from a system is to relate/normalise that special effect to the same effect, either on national level or on global level. Hereby it is possible to have an objective weighting factor of each specific impact as you get that impacts contribution compared to the same impact on national or global level. When comparing effects it will be possible to estimate the percentage of the effect in the environment.

Weighting of global warming

Global Warming Potentials (GWP) as CO_2 –equivalents for different trace gases and time-frames (IPCC, 2001)

Trace gas	GWP, 20 years	GWP, 100 years	GWP, 500 years
Carbon dioxide, CO_2	1	1	1
Methane, CH_4	62	23	7
Nitrous oxide, N_2O	275	296	156

The global warming is given as CO2 equivalents with different time spans. The carbon dioxide of fossil origin result in one equivalent in all age categories. For methane and nitrous oxide the impact will be considerably higher as the effect of the gas on global warming is considerably higher. Over time will the effect decrease as some of the gas is degraded and thereby less gas will be available causing global warming.

Weighing of acidification

Weighting factors for acidification for two scenarios, min and max (Lindfors et al., 1995).

Substance	Min [mol H+/g]	Max [mol H+/g]
SO_2	0.031	0.031
HCl	0.027	0.027
NO_x	0	0.022
NH_3	0	0.059

For acidification is the effect not varied over time but rather connected to how the substances are utilized. Sulphate and hydrochloric acid will always have the same potential while ammonium and nitrates will vary in their effect depending on if the nitrogen is ending up as an acidifier in the environment or if it is taken up by plants, then the effect is less. Upon uptake by plants of the nitrate it will be ion exchanged into hydroxide and thereby will the pH remain. When doing an estimation of the acidification these min and max scenarios needs to be taken into account.

- $2\ NH_3 + 4\ O_2$ $\quad$ $2\ NO_3^- + 2\ H_2O + 2H^+$
- $2\ NO_2 + ½\ O_2 + H_2O$ $\quad$ $2\ NO_3^- + 2H^+$
- $2\ SO_2 + ½\ O_2 + H_2O$ $\quad$ $2\ SO_4^{2-} + 2H^+$

NH_3 and NO_x are not acidifying if they are taken up by plants instead of being oxidized to NO_3^- or if the NO_3^- is taken up, because when taken up by the root it is exchanged for OH^-.

Weighting of eutrophication

Substance	Maximum (g O_2 per g)	Minimum (g O_2 per g)
N to air	20	
NO_x to air	6	
NH_3 to air	19.8	3.8
N to water	20	
NO_3 to water	4,4	
NH_4 to water	18.6	3.6
P to water	140	140
PO_4^{3-}	46	46
COD	1	1

Euthophication (overfertilisation) is measured as di-oxygen equivalents. This is measured as COD (Chemical oxygen demand) and the effect from other eutrophying substances will be measured as the amount of organic material they can support the growth of leading to a secondary measurement as COD. Here as well as for the acidification the effect of nitrogen depends upon how the substance is utilized. If the nitrogen is taken up by biological growth then it will increase the eutrophication while if it is just oxidized and degraded it will result in acidification. The different in the emission to water or air depends upon that in water nitrogen is seldom the limiting substance for biological growth. Then the nitrogen emitted will not have eutrophying effects but rather be an acidifier as the nitrogen will not be utilized.

Remember…

It is a **great difference between potential and actual** environmental impacts.

When doing an environmental systems analysis or an LCA you have a good tool for comparing several different systems. The actual numbers that the analysis comes up with will not be possible to utilize in other evaluations as all analysis are very place and situation specific.

The impact proven by a system is the potential impact and this is a large difference to the actual impact. One good example is that ammonia can in the impact be calculated in a max scenario to have both acidifying and eutrophying effects while in reality it can only have one of them and if the nitrogen are taken up by growing plants, e.g. from air emission to a plant there is neither any acidification nor euthrophycation.

However, the evaluation is a very good too to understand and compare what are the potential environmental effects from a system.