A procedure for identification of sustainability indicators of urban water systems based on life cycle thinking

Introduction

This paper presents an ongoing case study on operative sustainability indicators. The project is a co-operation between the Department of Environmental Systems Analysis (ESA) at Chalmers University of Technology and Stockholm Water, and forms part of a larger research project, “Indicators for sustainable development of urban water systems”, financed by FORMAS.

Aim

The aim of this case study is to develop a process for the identification of operational sustainability indicators with point of departure in life cycle thinking, and to study the use of sustainable development indicators at organisation level while strengthening and supporting the work towards sustainable urban water systems already initiated by Stockholm Water.

Approach

ESA initiated the project by proposing a co-operative study to Stockholm Water. Stockholm Water serves about one million people in Stockholm and neighbouring municipalities with drinking water and wastewater treatment. Early discussions with Stockholm Water made it clear that one of their greatest concerns was to find a sustainable way of treating sewage sludge. It was thus decided that the case study would aim at identifying sustainable development indicators with general bearing on sewage treatment, but with applicability especially on sewage sludge.

With the process suggested in Figure 1, a procedure for the actual case study was worked out. This resulted in a two-tire procedure, Figure 2, with its analytical basis in life cycle assessment (LCA), combined with economical analysis, risk- and uncertainty assessment. Furthermore, a literature study of the availability of phosphorus was performed on request from Stockholm Water. From this basis a number of indicators at component level (first tier) were to be identified. These were to be used to guide the process of choosing among technical solutions with regard to long-term demands on the system and its function as part of a sustainable society. The process of choosing a technical solution, which would necessarily include valuation of different, sometimes conflicting aspects of sustainability, and a critical examination of the existing system as well as possible alternatives would then lead on to the synthesis of indicators on a system level (second tier) for use in decision-making and communication. The choice of technical solution as such was not considered of prime importance for the identification of indicators, but rather the arguments for making that choice.

During the early discussions between ESA and Stockholm Water four sewage sludge treatment alternatives were selected for further analysis: spreading of hygienised sludge on arable land, co-incineration with household waste, separate incineration and extraction of phosphorus from the ash (Bio-Con), and fractionation with the Cambi-KREPRO-process. These techniques are described in some more detail under “Description and analysis of alternatives”.

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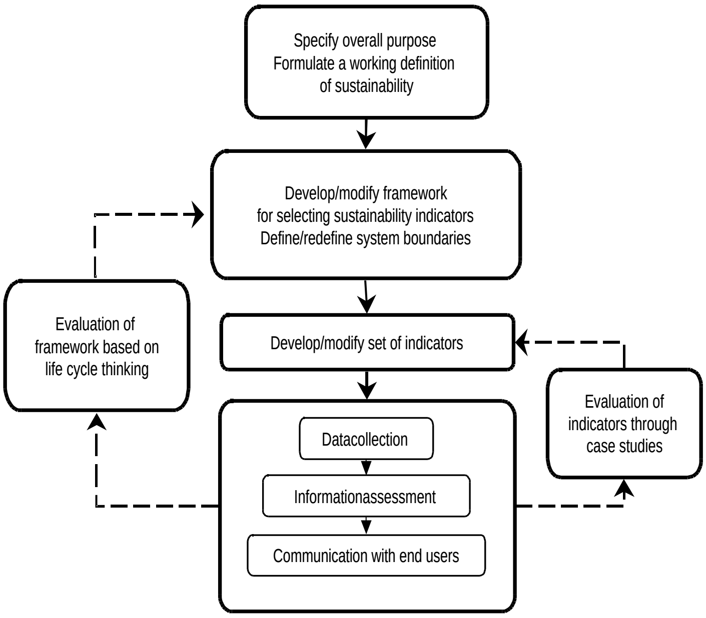

Figure 1. *Iterative procedure for assessing the sustainability of an urban water system, including identification of sustainability indicators (Modified from Lundin(Lundin and Morrison In press)*

Background

Sustainable development

<u>Definition</u>

Sustainable development is basically a question of equal distribution of the resources on earth in space and time. However, *sustainable* and *development* forms no evident combination. There seems to be a conflict embedded in the concept; *sustainable* leads the thought to something quite stationary, *development* suggests a kind of change to the better. Here is a qualitative aspect that makes the concept subjective. The addition of *sustainable* to *development* makes the concept no less subjective; what is to be sustained how and why?

A classical definition of sustainable development was formulated by WCED in 1987: "*Development that meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations*" (WCED 1987). The concept of sustainability has been much criticised for being too vague and therefore too easy to use as an empty slogan (Leist and Holland 2000). Certain vagueness in a concept may on the other hand be necessary if it is to be accepted and handled by people from different cultures (Bell and Morse 1999). The definition must be sharp enough to unite people towards a common goal, but fuzzy enough to room varying values and interests as well as cultural characteristics. Looked upon it that way the vagueness of the concept is also its strength.

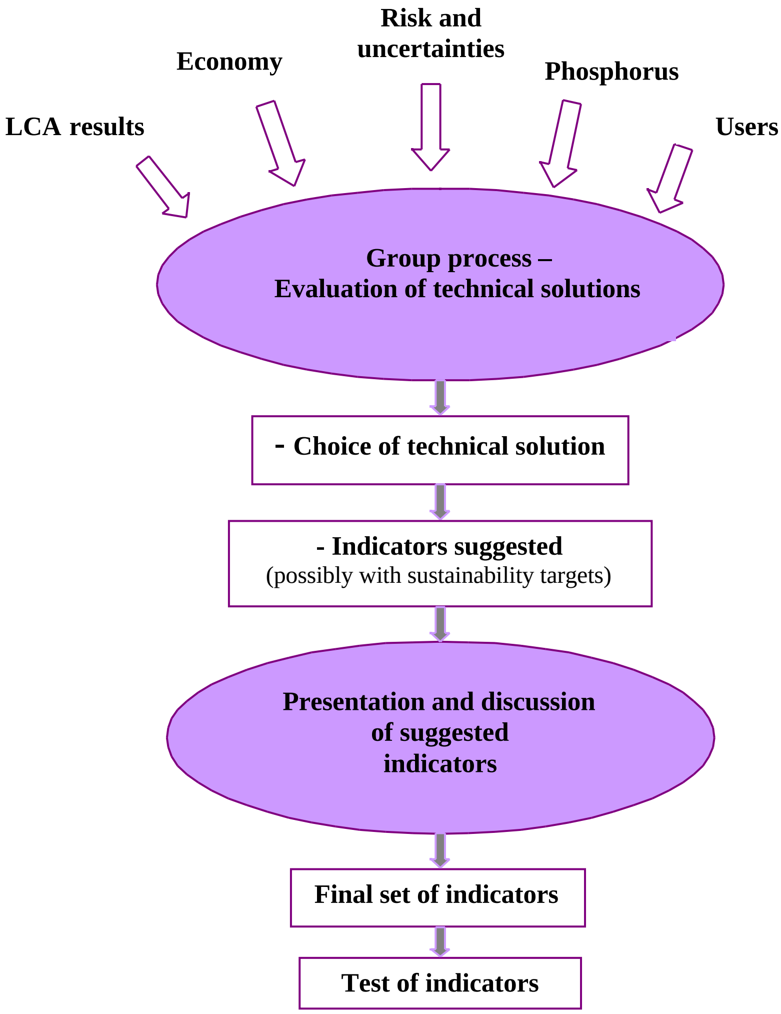

Figure 2. *Procedure for the identification of sustainable development indicators worked out and tested in the case study.*

Multidimensionality

Sustainable development is usually described in three dimensions: an ecological, an economic/technical and a social dimension. Also cultural and institutional dimensions have been suggested. The ecological dimension can be seen as limiting in the sense that earth only holds a certain amount of resources. Economy is partly connected to the natural resources and determines, together with available scientific knowledge, what is technically feasible. In the social dimension are included concepts like equity, democracy and participation. The fundamental idea is that to be sustainable, social solutions cannot be forced upon people from above.

Sustainability at different levels

At a global level aims and goals of sustainable development are formulated by international organisations and at international meetings. These goals are often more or less loosely formulated, as a consequence of being compromises between the many

stakeholders involved. The implementation of these larger goals must take place, if at all, at a local level, where the demand for precision is considerably higher. The larger goals of sustainable development have to be translated into a form that makes sense and is operational within organisations and companies, without loosing their meaning. At this level there are fewer stakeholders involved, but still many enough to make decisions complicated. Also the conflict between the different dimensions in sustainable development becomes painstakingly evident at the implementation stage. The prevailing value-systems of economy on the one hand and environmental and human considerations on the other, are often contradicting.
The achievements possible to make at local level, in spite of all difficulties involved, may seem like small contributions to the larger goals of sustainability, but that is the one and only way to reach those goals. To lessen the difficulties and make sustainable development more operational more research within this field is needed.

Sustainability indicators

Indicators are used as tools in many different areas to give simplified but accurate information for mainly two intertwined purposes: planning and communication (Verbruggen and Kuik 1991). An indicator generally has a wider significance than its immediate meaning (Bakkes, van der Born et al. 1994). For example within ecology the presence of certain so called indicator species is used to judge the state of the ecosystem, as the latter as such is difficult to measure. Correspondingly it is very difficult to measure sustainable development *per se*. Instead parameters related to sustainable development are identified and used as the basis for the construction of indicators of sustainable development.
Sustainable development indicators need to cover the different dimensions of that concept by linking different areas of society, *e.g.* life styles, economy and environmental problems, or by relating to a sustainability target. System level, sustainability targets and how the indicators are to be used by whom, and for whom, once in operation needs to be considered when identifying them in order to gain acceptance for the indicators and make them operational. This makes co-operation between researchers and practitioners necessary (Lundin 1999). Lundin has suggested a procedure for this process with life cycle thinking as one important component (Fig 1) (Lundin and Morrison In press).

Sustainability of urban water systems

The water system forms an important part of urban infrastructure. Fresh water is cleaned and supplied to the urban population. Sewage water is collected and purified to different degrees before it is let out in receiving waters. How would a sustainable urban water system be defined? This question cannot be answered here, but obviously many different aspects such as access to water, water quality, use of energy and resources, environmental effects, health effects, recirculation of nutrients and many more have to be taken into consideration (Lundin, Molander et al. 1999).
In the case study and in this paper focus is set on treatment of sewage sludge.

Sustainable handling of sewage sludge

From a sustainability perspective, the management of sewage sludge is strategic. It contains valuable resources such as phosphorus and soil-conditioning substances, but also harmful substances such as heavy metals and persistent organic compounds.

Ideally the phosphorus in sewage sludge would go back to the agricultural sector to close the circle, as was done in preindustrial society. Still in 1992 40% of the sewage sludge in Sweden was used in agriculture. In 1998 this number had fallen to 25% (Ramirez and Frostell 2001).
The major sludge disposal alternatives, in addition to spreading on arable land, are incineration and landfill. In Sweden the latter will be prohibited from the year of 2005. The former is comparatively expensive and not in agreement with the aim of phosphorus recovery expressed in the Swedish environmental goals (2000). By incinerating sewage sludge the phosphorus content is lost. A benefit as compared to landfill is that the energy content of the sludge is utilized. At present there is however no need of more fuel to the waste incineration plants in the country. Their incineration capacity is too low as it is.
As an answer to the dilemma of whether to prioritise recirculation of phosphorus or avoid contamination of arable land with potentially hazardous elements and substances, techniques have been developed that make it possible to recover phosphorus from the sludge. Phosphorus can be recovered by fractionation through hydrolysis and precipitation, or phosphorus can be extracted from the ash after incineration of sludge. These methods are comparatively new and as for economy and running operation uncertainties remain.

Description and analyses of alternatives

Description of sewage sludge treatment alternatives selected in the case study

At an early stage of this case study four sludge treatment alternatives were selected for further analysis. These are given a short description here.

Spreading on arable land

European sludge regulations expected to apply from 2003 demand that sewage sludge be hygienised before utilization as fertilizer on arable land. This hygienisation can be performed by drying the sludge or by various treatments including high temperature to limit the number of pathogens. In this case pasteurisation at 70 ˚C for one hour was chosen (as the hypothetical technical solution).
After hygienisation the sludge is stored at the sewage treatment plant for quality control before it is dewatered and delivered to the farm (in this case assumed to be 80 km on way). Fertilizing with sewage sludge is normally done every 5th to 7th year.

Co-incineration with household waste

The energy content of sewage sludge is comparable to that of bio fuels (12-13 MJ/kg dry substance). Incineration of sewage sludge has been suggested as a way of getting rid of, or at least keeping better control over, contaminants while making use of the energy content in the sludge. An admixture of up to 20 % sewage sludge has been shown to work well in the process when co-incinerating it with household waste.
The phosphorus content of the sludge ends up in the ashes together with the main part of the metals. The ashes go to landfill. Most organic compounds are incinerated completely, but dioxins and other persistent organic compounds are found in the flue gases, as are acidifying gases, particles and heavy metals. The flue gases are thoroughly cleaned by passage through filters and scrubbers, but some discharge is inevitable.

Separate incineration and extraction of phosphorus from the ash – Bio-Con

Bio-Con is a method where the sludge is dried to 90 % dry substance content and incinerated separately with energy recovery. Phosphorus is extracted from the ash through dissolution in sulphuric acid and a series of ion exchange processes, requiring further addition of chemicals, and recovered as phosphorus acid. Phosphorus acid is a source of phosphorus with high plant availability, and is thus an excellent fertilizer. Also iron sulphate (precipitation chemical) is recovered in the process.
As this process requires separate incineration, the hypothetical plant would be smaller and thus the flue gas cleaning was assumed to be less efficient in this case than in the case of co-incineration with household waste or the Cambi-KREPRO method (Pettersson 2001; Zetterlund 2001).

Fractionation with the Cambi-KREPRO-process

In the Cambi-KREPRO method dewatered sludge (25 % dry substance content) is fractionated by use of hydrolysis, yielding four different fractions: iron phosphate, organic material, heavy metal sludge and a carbon source. The organic fraction goes to incineration at a waste incineration plant with energy recovery. The heavy metal sludge is treated as hazardous waste. The carbon source can be recirculated back to the wastewater treatment plant. Iron phosphate can be used as a fertilizer, although it is a phosphorus source with lower plant availability than phosphorus acid. The process is partly performed under high pressure and at high temperature, and it requires the addition of several chemicals (Pettersson 2001; Zetterlund 2001).

Life cycle assessment

A life cycle assessment was made on the four sludge treatment alternatives including effects on adjacent technical systems (Fig 3). This work was performed as a master thesis under supervision of one of the researchers in the project and in close contact with Stockholm Water. This work resulted in the documentation of 200 parameters regarding resource consumption, energy use and environmental effects, all related to the functional unit “1000 kg of sewage sludge” (Pettersson 2001).

Economic analysis

In parallel with the LCA-study, an economic and technical evaluation of the four alternatives was performed as another master thesis with the same functional unit and under supervision from the Energy Systems Technology Group at Chalmers University of Technology (Zetterlund 2001).

Risk assessment and uncertainty evaluation

A general procedure for risk assessment of hazardous compounds in sludge was suggested and exemplified with cadmium. Apart from this, risk and uncertainty were dealt with mainly in a qualitative manner.

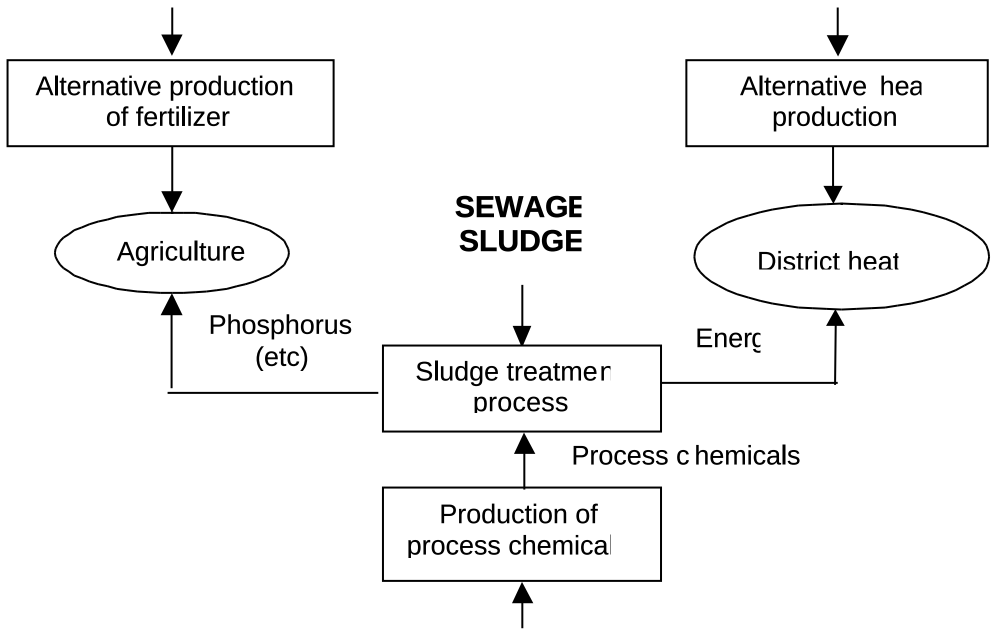

Figure 3. *Technical systems included in the LCA and the economic analysis. Systems within oval frames have not been modelled.*

Multi-criteria decision process

To proceed from the different analyses of the four sludge treatment alternatives to a choice of preferred solution, a multi-criteria decision process (Clemen 1996) (Guitouni and Martel 1998; Stirling and Mayer 1999) was arranged.

Identification of criteria

A number of criteria to be used when evaluating the different sludge treatment alternatives were selected from the analyses performed and from discussions with representatives of Stockholm Water. The criteria finally used in the multi-criteria decision process were economy, resources, energy, emissions to air, emissions to soil, acceptance, reliability of service, working environment and hygiene (Table 1).

Process

Two persons from ESA ran the multi-criteria decision process with eight participants from Stockholm Water, seven persons representing technical and economic departments and one member of the board. The whole meeting was recorded for full documentation.
The meeting was started by a presentation of the results from the analyses of the four technical solutions (written material had been distributed on beforehand), followed by a long discussion around the different criteria and the data presented under each (Table 1). The criteria *acceptance*, *reliability of service*, *working environment* and *hygiene* where not accompanied by any data or facts from the start, as the experience of Stockholm Water staff was considered necessary in these cases, and thus comments on these criteria were added during the meeting.

Table 1*. Spreadsheet used in the multi-criteria decision process with criteria and data as they were at the start of the process.*

	Spreading		Co-incineration		Bio-Con		Cambi-Krepro		
Criteria	Score	Data	Score	Data	Score	Data	Score	Data	Weight
Economy		685 SKR		2 445 SKR		1 379 SKR		1 796 SKR	
Resources		-18 kg P Soil conditioning subs.				-21 kg P 73 kg S		-15 kg P 91 kg S	
Energy		-36 kWh el 947 kWh fossil fuel		-329 kWh el 29 kWh fossil fuel -2 986 kWh combustion		202 kWh el 17 kWh fossil fuel -1 916 kWh combustion		328 kWh el 80 kWh fossil fuel -956 kWh combustion	
Emissions to air		47 400 g CO2 2 020 g NOx -520 g SOx		-306 000 g CO2 960 g NOx -349 g SOx 0,1 g Hg Dioxins?		-336 000 g CO2 1 080 g NOx -312 g SOx 0,5 g Hg About 1 mg of dioxins		-151 000 g CO2 639 g NOx -211 g SOx 0,1 g Hg Dioxins?	
Emissions to ground		Heavy metals to soil Org. compounds to soil		Heavy metals to landfill		Heavy metals to landfill		Heavy metals to landfill and to SAKAB*	
Accep-tance									
Reliability									
Work. env									
Hygiene									
Sum:									

*Formerly State-owned company responsible for the treatment of industrial waste.

After the discussion the Stockholm Water participants worked individually with scoring the different criteria under each alternative.
Weighting of the criteria was discussed and unanimously considered necessary. The group agreed on setting a weight of 100 on economy, and judging the other criteria proportionally to this. It was also agreed on that the criteria should be weighted with regard paid to their contents and the whole situation, not per se and detached from the situation. The weighting procedure was first attempted in group, but this lead to such lengthy discussions that it had to be interrupted and replaced by individual weighting.

Results

Results on the way

One type of results from this study has already been mentioned, interwoven in the text above, as it forms part of the approach and method. This includes the chosen aim and focus of the case study, the approach to the case study (Fig 2), the choice of sewage sludge treatment alternatives to be considered, the criteria included in the multi-criteria decision process and, to a certain extent, how this process was performed.

Results of multi-criteria decision process

The preferred alternative in the multi-criteria decision process turned out to be spreading on arable land, in spite of the presently poor acceptance. This was neither very surprising, nor very important as a result in the process of identifying indicators. The discussion towards this result, however, was substantial, and the way scores and weights were set was revealing:

Technical matters:

- Whether phosphorus is regarded as a limited resource or not is decisive for how the resource criterion is weighted. In a sustainability perspective it is not only the question of how much phosphorus that remains, but also what the costs and the environmental consequences are from extracting virgin phosphorus as compared to recycling it.
- In the LCA, alternative energy production was assumed to be combustion of coal and oil. This is not unquestionable and may give disproportionately large benefits to the incineration alternatives in the study. The avoided environmental effects would be considerably smaller and of a different character if *e.g.* natural gas or some other waste fraction was assumed to be the alternative energy production instead.
- How the spreading of sewage sludge on arable land is actually performed need to be investigated more thoroughly. In the LCA sewage sludge has been equalled to semi-fluid manure. Equalling it to solid manure instead would mean lower energy expenditure in this alternative.
- Poor acceptance is a problem related to both spreading of sludge on arable land and co-incineration of sludge with household waste. In the first case people are afraid of contaminants, but also find the thought of their food being grown in sewage disgusting. In the latter case it is the employees at the waste incineration plants that prefer not to handle sludge, which they find to be both more difficult to handle and more repulsive than household waste.
- Both incineration methods with extraction of phosphorus (Bio-Con and Kambi-CREPRO) contain operations that are judged comparatively risky when reliability of service and working environment is considered.

Procedural matters:

- It was considered unfair with four criteria relating to environment and only one relating to economy. Different ways of grouping the criteria for increased transparency were suggested.
- The possibility of entering threshold levels in some criteria was discussed. If such a level or value is exceeded the alternative in question need not be further discussed.
- The variability between scores set by different persons under the same criterion and alternative is in the same order of magnitude as the variability between the scores summed up under each treatment alternative (before weighting). The variability in individual scoring partly reflects the different views that people have, but also different approaches to the scoring procedure.

Expected results

With the results from the multi-criteria decision process, including the arguments brought forward in it, and the already existing key indicators of Stockholm Water as a basis, sustainable development indicators of sewage sludge treatment will be suggested to Stockholm Water. It is the intention that at least some of these indicators will be applicable to sewage treatment in general.

Discussion and conclusions

One important question that remains unanswered at this stage is whether it is possible to identify sustainable development indicators on a low system level (sewage sludge treatment in this case) with bearing on a higher system level (*e.g.* sewage treatment in this case). If the answer to this question is no, the case study has to be placed on a higher system level. This will make the process more complicated, as a larger case study will require more data and more comprehensive modelling.

This case study was started with an open-minded attitude. The case was allowed to lead its own way (within reasonable limits). The broad outline of the approach (co-operation between researchers and practitioners, the analytical tools applied and the use of a multi-criteria decision process) appears to be a practicable way for identifying sustainable development indicators. Looking back, however, there are a number of lessons that have been learnt from this case study about what could preferably have been done differently:

- More knowledge gathered about the structure of the organisation before starting the project.
- More knowledge gathered about the use of key indicators within the organisation before starting the project.
- A preparatory meeting before the multi-criteria decision process aiming at selecting criteria and identifying data needed in the process.

These changes would hopefully help in shifting the centre of attention from the purely environmental questions to a more even distribution of interest between economic/technical, social and environmental questions: a better whole.

Continued research

Some important questions have been identified: Will the indicators selected in this case study be operational? Will they be useful for communicating sustainability issues within and/or outside the organisation? Will they help the organisation to move in the direction of sustainability? If so, would the process, in broad outline, of identifying indicators applied in this case study be applicable in other cases? The continuation of this project is intended to include the follow-up of the identified sustainable development indicators and their use within the organisation.

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