Ideas for Assessing the Sustainability Potential of Human- Environmental Auxiliary Systems - The Case of Municipal Solid Waste Landfills -

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Ideas for Assessing the Sustainability Potential of Human- Environmental Auxiliary Systems - The Case of Municipal Solid Waste Landfills -

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Abstract: Although sustainability is a widely accepted guiding idea for the development of our planet, only a few concepts exist on how to specify this idea in the context of human-environmental systems. We understand sustainability as a combination of system limit management with ethical allegiances. Uncertainties given by large timeframes and vague definitions present a major problem when assessing if an object or circumstance is sustainable or not. However, a sound standing assessment is indispensable if sustainability is to be more than a buzzword. In this paper, we present a systemic method for assessing the sustainability potential of anthropogenic systems. This sustainability potential analysis (SPA) is based on the theory that systems are characterized by three core elements: function, context and structure. SPA is organized along these elements, which are specified in six system attributes. These attributes are considered sufficient for the assessment. They define the general system framework, which is crucial for assessing the potential of the observed system and its surroundings to develop sustainably. Rating today's potential to support or stem a sustainable development eludes the above mentioned uncertainties. We present findings of the methods' application on landfills. These man-made systems fulfil specific functions for present generations, which might have short- and most of all long-term side effects on related systems (e.g. vicinal eco-systems or societies). For example, their increased content of heavy metals is expected to endanger groundwater resources for thousands of years. Only an encompassing view on these systems, as provided by SPA, allows a rational assessment in respect of the multitude of intra- and intergenerational problems. The findings reveal the system characteristics and its weak points. Based on these insights decision-makers have the possibility to develop and realize efficient strategies to improve the general conditions for a sustainable regional development.

Keywords: Sustainability potential, Systemic assessment, Human-environmental system, Landfill

1. INTRODUCTION

If the broadly accepted guiding idea of a sustainable development is to be more than just a buzzword, concretisation on different levels is needed (Bosshard, 2000). A prerequisite for this concretisation is to specifically define sustainable development. In this paper, we understand sustainable development as a combination of system limit management with ethical allegiances. This means that the ongoing inquiry process of a sustainable development can only be understood in a systemic context and has to aspire to a well-balanced pareto-optimum[1].

Schneidewind et al. (1997) define reflexivity as a basic strategy to institutionalise sustainability in society. Reflexivity within a system analysis includes: (i) Assessment of the current characteristics; (ii) Evaluation of taken measures; (iii) Evaluation of ongoing processes and (iv) Transparent communication of the results to stakeholders and decision-makers as basis for further planning. According to sustainable development, the major challenges to reach reflexivity are: (i) Representing a complex system accurately; (ii) Evaluating the system with respect to this vaguely defined guiding idea and (iii) Handling the uncertainties given by the large timeframe.

[1] A system-status is called pareto-optimal, if "it is not possible to increase the net benefit by rearranging the allocation. Without an increase of the net benefit, there is no way the gainers could sufficiently compensate the losers; the gains to the gainers would necessarily be smaller than the losses of the losers" (Tietenberg, 1992, p. 28).

In this paper we sketch a method to cope with these challenges. Therefore, the main questions are:

1. How can complex systems be represented accurately and evaluated properly?
2. How can evaluations be carried out transdisciplinary, using stakeholder knowledge and providing transparent information for system optimisation?

The rest of the paper is structured as follows. Firstly, we present different methodological approaches to handle sustainable development. Secondly, we describe our method in detail. Thirdly, we exemplify a part of the method by applying it on landfills. In the end we draw conclusions.

2. METHODOLOGICAL APPROACHES

A major problem in dealing with sustainability is to select appropriate reference states or conditions to assess and optimise the current system characteristics. We distinguish among three different approaches to handle this problem (cf. Figure 1).

Approach 1 constructs a desirable and feasible future state as the reference point. The present system characteristics are assessed and/or optimised with regard to this reference. Examples for scientific methods utilising this approach are formative scenario analysis followed by a strategic planning process (cf. Scholz and Tietje, 2002; Kahn and Wiener, 1967) and the back-casting approach within the natural step framework (cf. Robèrt, 2000).

Approach 2 concentrates on impacts of system processes and their significance for sustainable development. In this approach current system in- and outputs are considered and compared with normative reference values or postulates[2]. Methods following this approach are e.g. the ecological footprint (cf. Wackernagel and Rees, 1997) or LCA (life-cycle-analysis) (cf. Goedkoop and Spriensma, 1999). These methods concentrate mostly on ecological aspects and not on the overall sustainability of a system.

Approach 3 focuses on the current system itself. The idea is to understand, evaluate and optimise key mechanisms and principles underlying the system according to system theory. In system theory, a limited number of general principles are derived characterising the "well-being" of a system. Approach 3 assumes that the possibility of a system to develop sustainably is higher the more these principles are obeyed[3]. Methods following this approach are e.g. the Vester sensitivity model (cf. Vester, 1999), the basic orientor theory by Bossel (2000) or Hollings (1987) approach to simplify complexity.

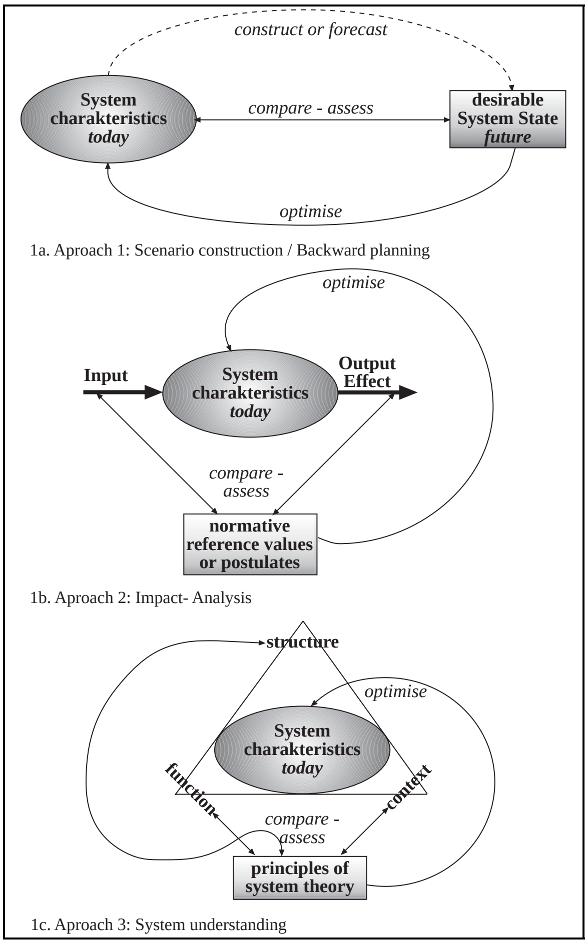

Figure 1: Different approaches to deal with sustainability in a systemic context

Although these approaches overlap in various aspects a prototypic differentiation is important to reveal basic strengths and weaknesses.

Approach 1 constructs a future state based on our present perceptions. This implies two sources of uncertainty: we are firstly not able to construct all possible future system states and secondly we assume, that future generations will have the same needs that we have.

Approach 2 concentrates on impacts that we perceive as being problematic today. It is unlikely, however, to trace all major problematic impacts for the future and that all of the assessed impacts will be considered problematic in the future.

Approach 3 analyses existing system characteristics and their genesis. This evades the above mentioned uncertainties. Obviously the definition of

[2] The latter are fixed on the basis of scientific insights (e.g. CO_2 – equivalents), logically deduced (e.g. the ecological-footprint) or value-based (e.g. public welfare)

[3] It is important to mention, that the liquidation of a system might emerge as its most sustainable development and should therefore be aspired.

general principles based on system theory also hold uncertainties. But system research in different areas[4] reveals coherent general principles, which indicate the "well-being" of an organismic system (cf. Bossel, 2000; Scholz and Tietje, 2002). This coherence provides strong evidence for the existence of such principles.

Because of that, we chose the third approach for assessing the possibility of human-environmental systems to develop sustainably. Up to now Approach 3 is mainly applied on large- scale systems like overall mobility (cf. Vester, 1999). With our assessment method we transfer this complex approach to small scale human environmental auxiliary systems like landfills.

3. METHOD

3.1 Fundamentals

The sustainable potential analysis (SPA) presented in this paper, is based on the bio-ecological potential analysis (BEPA) by Scholz and Tietje (2002). BEPA was originally developed to assess the performance and vitality of ecological systems. But the basic principles indicating system quality can be applied on each kind of organismic system. Figure 1c shows the three core elements constituting a system both in BEPA and in SPA: systems structure, context and function. They establish the basis for the whole assessment process.

SPA is organised according to the Brunswikian lens model (cf. Scholz and Tietje, 2002) (Figure 2).

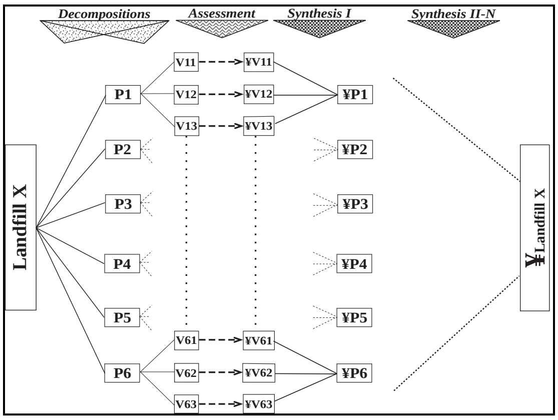

Figure 2: Conceptual outline of SPA. (P_i are Perceptors; V_{ij} are functional key variables and $¥_{i(j)}$ are sustainability- potentials. Explanations follow in the text)

It starts with a detailed *explication* of a system and/or problem. After that in a *decomposition* process, central system attributes (so called perceptors) are defined. Thereafter these are *analysed and evaluated*. Finally the insights of these analyses are integrated within a *synthesis* procedure.

3.2 Decomposition

The decomposition process of SPA takes place in two steps. Firstly, the perceptors for a detailed system analysis are defined according the three core elements: function, structure and context. In the case of SPA we identified six perceptors (Table 1). These are considered sufficient for the assessment.

Performance and efficiency	According to its function, a system should be as effective and as efficient as possible. If not, resources are not optimally utilised, disaccording to sustainability.
Buffer capacity and resilience (Assimilation)	External effects can unsettle systems. Each system has a certain existing capability to equilibrate again.
Ability to accommodate	If the capability to assimilate is exceeded, systems should have the capability to adopt their inherent features to attain a new equilibrium.
Well-structuredness	Two structural properties are important for system quality. Firstly, the system's inherent structure and secondly its contextual embedding into the surrounding system network.
Interdependencies with other systems	Any organismic system is related to other systems. It influences them as well as they influence it. The manner of these interactions determines systems potential to develop sustainability in a crucial way.
Inter- and Intragenerational equity	This postulate is broadly accepted as a requisite for a sustainable development.

Table 1. Perceptors of SPA and their heuristics

Secondly, the abstract perceptors are substantiated by two to four so called functional key variables (FKV). These have to be concrete to such an extent that a comprehensive valuation is possible.

3.3 Valuation (Analysis)

SPA aims to identify the potential of a system to develop sustainably. Therefore a sustainability-potential ¥ is defined. In a first approach we choose this measure ranging from one to five where one stands for impossibility and five for best requisites to develop sustainably (Lang, 2001).

The perceptors are of a different nature. Therefore, approaches to valuate them also have to be diverse. For example productivity and effectiveness could be measured using natural sciences and economics, whereas inter- and intragenerational equity requires more of a so called "soft-valuation". Teams

[4] e.g. ecology, evolution biology, psychology, cultural theory

conducting SPA do not have to be experts in all domains of the assessment. The method lays down the foundation to integrate knowledge of different experts and stakeholders in an inter- and transdisciplinary process. The team takes the role of moderation, methodological support and synthesis within this process.

3.4 Synthesis

Synthesis can take place on different integration levels. The most rudimentary is the integration to ¥$_{Pi}$ of the specific perceptors. The most extensive is the integration to ¥$_{Total}$ of the whole system under investigation.

Different methods are possible to synthesise the valuations of the specific decomposition levels. In a first setting we choose the weighted sum (Eq.1)[5].

$$X = \sum_{i=1}^{n} k_i Y_i \qquad (1)$$

Y_i represents the valuations to be integrated and X is the valuation on the superior integration level (either ¥$_{Pi}$ or ¥$_{Total}$). k_i is a weighting factor max{0,1}. The factors of a specific integration level have to sum up to one. The magnitude of these factors could be determined by scientific knowledge or within a stakeholder consensus process.

3.5 Discussion

As mentioned FKVs of some perceptors cannot be assessed based on reliable quantitative data gained by methods of natural or economic sciences. Such perceptors require the use of qualitative data. This emerges to be a crucial point. A participative construction of system models with stakeholders and experts, followed by a consensus process to evaluate the uncertain perceptors and their FKVs, seems to be an encouraging approach to gain a reliable database for the assessment.

4. APPLICATION

4.1 Object of investigation

Municipal solid waste (MSW) landfills are auxiliary systems of the anthroposphere. Although they are not genuine organismic systems, their quality can stem or stimulate the sustainability potential of related systems. Therefore, they have to fulfil the same system principles as organismic systems. A sustainability assessment of landfills is particularly interesting and important because of three aspects: (i) Their impact on other systems may last over some thousands of years (intergenerational equity) (cf. Johnson, 1994); (ii) They are the metabolic result of a whole region but most of their impacts only affects a few people (intragenerational equity) and (iii) They represent an actual endpoint of anthropogenic processes (special position in circular flow economy). For their assessment an encompassing (cf. Beccali, et al. 2001)and systemic approach (cf. Voigt, 1996) seems to be most promising.

Newer Swiss landfills mainly contain incineration products besides building wastes, in contrast to untreated MSW in other industrialised countries (cf. Grover and Grover, 2000). This is a result of the Swiss strategy is to incinerate all organic MSW.

4.2 Operationalisation

We want to exemplify the operationalisation of the perceptor "Performance and Efficiency". For its concretisation four FKVs are defined (Table 2). In the following the analysis of FKV "transformation of disposals to resources or natural areas"[6] is presented in detail. The others are comparably analysed.

V_{11}	Transformation of disposals to resources or natural areas
V_{12}	Control of pollutant release
V_{13}	Time to achieve ultimate disposal quality
V_{14}	Economical efficiency

Table 2. FKVs of the perceptor "Performance and efficiency

The first step of the operationalisation is to distinguish between ore-like and earths crust like disposals. Ore-like are compared with resources and earths crust like with natural areas. In this paper we present the approach for ore-like disposals and its application on two specific kinds of residues.

For the valuation, a specific indicator F_{11k} max{0,1} is defined and calculated (Eq.2).

$$F_{11k} = 1 - \frac{C_{kExhaustion} - C_{kDisposal}}{C_{kExhaustion}} \qquad (2)$$

In (2) k indicates a specific heavy metal, $C_{kExhaustion}$ is the minimum ore-concentration exhausted today and $C_{kDisposal}$ is the current metal concentration of the disposal under investigation. F_{11k} represents the

5 Independently of the applied method, each integration step also implies valuing aspects. To raise the assessment quality these aspects have to be transparent.

6 The "Leitbild für die Schweizerische Abfallwirtschaft" (Swiss overall concept of waste management) (Eidgenössische Kommission für Abfallwirtschaft, 1986) demands for a sustainable waste management that waste disposal systems should generate only two groups of waste materials, namely those which can be recycled and those which are suitable for depositing on final disposal sites. Baccini et.al.(1992) specify the suitability for depositing demanding that solid residues have to be ore- or earths crust-like.

normalised difference of heavy metal concentration in ore and in the disposal. If $C_{kDisposal} = C_{kExhaustion}$ F_{11k} is rated with one, then this means the best prerequisite for a sustainable development. In cases where $C_{kDisposal}$ exceeds $C_{kExhaustion}$, F_{11k} is also stated one because higher values are excluded of the assessment.

For evaluating the sustainability potential $¥_{11}$ of FKV "transformation of disposals to resources or natural areas" the three metals with highest F_{11k} were considered. To calculate $¥_{11}$ equation (3) is used.

$$¥_{11} = 1 + \sum_{k=1}^{3} F_{11k} * \frac{4}{3} \quad (3)$$

This is the indicator sum normalised to values of one to five corresponding to the codomain of ¥.

Below $¥_{11}$ is calculated for two typical land filled incineration products: (i) MSW bottom ash and (ii) Cemented filter ashes[7]. Figure 3 shows $C_{kDisposal}$ vs. $C_{kExhaustion}$ of different heavy metals for both products. Pb, Mn, Al and Fe lay outside the diagrammed sector.

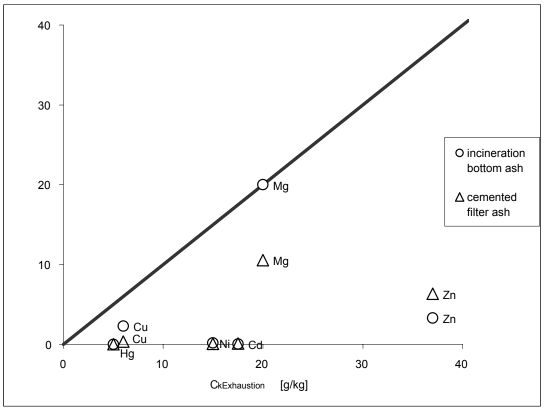

Figure 3: Concentrations of heavy metals in incineration products vs. concentrations in mined ore (sources: AWEL, 1992; Baccini et al., 1992; BUWAL, 1995; Wilmoth et al., 1991)

Dots lying on or above the bisecting line have a F_{11k}-value of one, hence underneath the line between zero and one.

Table 3 and Table 4 show the data used for calculating $¥_{11}$ of the two products and its value.

Metal	$C_{kExhaustion}$[g/kg]	$C_{kDisposal}$ [g/kg]	F_{11k}
Mg	20	20	1.00
Cu	6	2.3	0.38
Al	300	55	0.18
		$¥_{11}$	**3.09**

7 For the analysis a filter ash/cement ratio of 70/30 is assumed (AWEL, 1991)

Table 3. $¥_{11}$ of MSW bottom ash and data for its calculation[8].

Metal	$C_{kExhaustion}$ [g/kg]	$C_{kDisposal}$ [g/kg]	F_{11k}
Mg	20	10.52	0.53
Zn	37	6.3	0.17
Al	300	33.8	0.11
		$¥_{11}$	**2.08**

Table 4. $¥_{11}$ of cemented filter ashes and data for its calculation[8].

The values of $¥_{11}$ show that MSW bottom ash shall be deemed to be neutral, cemented filter ashes in contrast to slightly stem sustainable development only regarding this FKV.

4.3 Discussion

At first glance the presented application seems to be very specific and to neglect important issues essential for a sustainable development. With regard to this argument two aspects should be taken into account: (i) Not a single perceptor and less than a single FKV can and ought to represent a system's overall potential to develop sustainably[9]. Considering all perceptors is mandatory for determining the sustainability potential of a system. (ii) As mentioned above the goal of the perceptors is to grasp the system sufficiently. This means not all system aspects have to be considered for a holistic understanding.

5 CONCLUSIONS

1. This paper presents how the method of SPA can be applied to evaluate systems (i.e. landfills) according a sustainable development. We consider the method appropriate for this valuation because:
   i. It utilises a sufficient representation of the system rather than complex system models;
   ii. It evaluates the current system characteristics in its ability to manage future situations.
2. SPA facilitates transdisciplinary processes by:
   i. Integrating stakeholder knowledge in the valuation;
   ii. Paving the way for decisions by consensus;
   iii. Allowing decision-makers to develop and realise efficient strategies to improve the general conditions of the system to develop sustainably by providing transparent information;

8 Sources cf. Figure 3

9 E.g. one FKV of the perceptor "ability to accommodate" concerns the possibility to isolate metals out of disposals. Only a combination of this FKV with metal concentrations assessed by $¥_{11}$ permits propositions regarding landfills as potential stocks of resources.

iv. Making it possible to valuate the benefit of taken measures uniformly.

Further investigations should: (i) Elaborate and implement participative stakeholder processes; (ii) Evaluate the method by applying it on other objects; (iii) Test other valuation and synthesis approaches to be more appropriate; (iv) Analyse the general system principles used in more detail.

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