Economic criteria and parameters to evaluate wastewater pond systems

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Abstract: Any serious comparison between alternative, competing solutions for wastewater treatment will lead to results depending on the specific site conditions. Within the frame of an international study and during various project missions, a large number of cost:benefit-analyses has been revised. This paper collects important criteria for the selection, design and strategic evaluation of wastewater pond systems compared to activated sludge systems.
Keywords: Cost:benefit-analysis, selection criteria, wastewater pond, wastewater treatment

INTRODUCTION
Any serious comparison between alternative, competing solutions for wastewater treatment will usually lead to results depending on the specific site conditions. Within the frame of an international study, funded by the German Federal Ministry of Research (BMBF, forthc.), and various project missions funded by donors and private banks, the authors revised a large number of cost:benefit-analyses (CBA) comparing pond systems with other conventional treatment technologies. It was found that many CBA did not sufficiently consider the specific site conditions. This paper collects the important criteria for selection, design and strategic evaluation of wastewater pond systems, compared to activated sludge systems. It describes parameters to be considered for any CBA, and the specifics to be taken into account especially in developing countries.

CORE POND CHARACTERISTICS
To clarify what the authors assume to be a typical wastewater pond system within the following comparisons, table 1 shows three essential characteristics. Number 1 refers to the construction of a pond, usually as earth tank without artificial materials (apart from sealing and wall stabilisation, for which plastic, concrete and other construction materials are used). A second issue is the hydraulic system. Ponds are operated as direct through-flow (designed as mixed reactor, or nearer to a plug flow reactor). Yet, there are advanced pond systems working with e.g. back-feed respectively recirculation to deliver oxygen for odour control in the top layer of anoxic ponds, or algae to enhance anaerobic pre-treatment. The third important characteristic is the bio-process. Activated sludge systems work with bacteria only, whereas ponds use algae and bacteria - even water plants and fish, or the daphnia magna for specific pond systems (Rudolph, Staffel 1998).

Table 1 Basic characteristics of core wastewater pond systems

No	Characteristic	Typical
1	Construction	As earth tanks (apart from sealing and wall stabilisation)
2	Hydraulics	Direct through-flow (apart from oxygen and algae back-feed recirculation)
3	Bio-process	Algae AND bacteria, mainly suspended (plus water plants and fish, sometimes)

Note: Hybrids and combinations using characteristics of activated sludge systems or bio-filters etc. are widely applied, like pond-SBR, PETRO systems, percolation filters etc.

These basic characteristics are for core, typical wastewater ponds (compare Shilton, 2005; von Sperling, 2007). In reality, the number of hybrids or combinations between ponds and other technologies is very high, and leads to reasonable solutions, e.g. pond-SBR, PETRO systems (Shipin et al., 1998), APS (Craggs et al., 2003), ponds plus wetland systems, etc.

SELECTION CRITERIA

A complete and appropriate comparison of the best suitable wastewater treatment technology has to take into consideration all relevant selection and evaluation criteria as well as strategic issues, in every specific case. The following tables comprise the different types of criteria with an exemplarily shown comparison of wastewater pond systems versus activated sludge systems.

Veto criteria within the selection process instantly lead to the exclusion of one of the competing process technologies, depending on prohibitive site conditions. In table 2, examples of such criteria are collated. For example, if there is not enough land available, a compact technical system like activated sludge systems (ASS) will be needed, and ponds with large footprints are not applicable. Or, the effluent standards require low nitrogen concentrations in winter, which is not possible with pond systems.

Table 2 Selection criteria for wastewater pond systems vs. activated sludge systems

No	Key words		Remarks
1	Land requirement	-	Note: up to 40 % of footprint are for infrastructure, not for process reactors.
2	Winter performance	-	N-reduction is practically impossible below 5°C.
3	Storage capacity	+	For reuse water, storm water, peak-levelling etc.
4	Operational skills	+	Requirements for ponds are low, but not negligible!
5	Investment costs	+	Expensive civil works, e.g. for multi-barrier pond sealing, may cause surplus costs for ponds.
6	Evaporation losses	[-]	Due to large surface area; yet, for ASS the intensive aeration causes higher evaporation rates per m².

+ = advantage; - = disadvantage; ( ) = depending on specific process technology and site conditions; [ ] = assumed; further research necessary; GHG = Greenhouse gases; ASS = Activated sludge systems

NOTE: Valid for only far municipal wastewater ponds under "normal" working conditions.

If operational skills onsite are very low, one might conclude that it is not possible to run ASS with more ambitious requirement for skilled staff successfully, and will vote for a pond. Similar, the decision for ponds might be governed by the wish to limit budgets for investments and build cheap pond systems instead of ASS.

Another issue of growing importance is the required storage capacity, e.g. for reuse water, which must be collected and kept in the wastewater plant until the dry season begins, and irrigation water is needed. Similar, the storage of storm water or peak-levelling from industrial sources etc. is much easier with pond systems.

In arid countries like South Africa, ponds have been excluded in various cases, because of the fear that the water losses through evaporation from the large pond surface would be too high and decrease the volume available for wastewater reuse. Yet, little reliable data exist which comprehensively compare evaporation losses from large surface pond systems to small surface ASS tanks, the latter having higher specific evaporation rates per square meter due to high turbulence and intensive aeration.

EVALUATION CRITERIA

For the comparison of generally applicable treatment options, in practice, the most important evaluation criterion applied are the effluent standards to be obtained by the treatment plant. If designed and operated properly, pond systems show similar performance to ASS regarding organic and nutrients removal (when taking into consideration their specific restraints).

Table 3 Evaluation criteria for wastewater pond systems vs. activated sludge systems (ASS)

No	Key words		Remarks
a	Effluent standards, organics	(+/-)	To further reduce COD, BOD, SS, additional stages may be helpful for ponds as well as for ASS.
	Effluent standards, nutrients	(+/-)	Advanced treatment process units available for ponds as well as for ASS.
	Effluent standards, micro-organisms	(+/-)	ASS need additional disinfection. Ponds might need this, too, or for performance guarantee. In average ponds are better, esp. for virus reduction.
	Effluent standards, algae	(-)	Algae may have to be removed from pond effluent through specific measures.
	Effluent standards, biocenosis	(+)	Post-pond-treatment might be demanded near-to-nature to prevent biocenotic shock.
b	Power, net-consumption	(+)	Non-aerated ponds may not need power, except for pumps, screens etc. Bio-gas option available for ponds as for ASS.
	Power, supply sensitivity	(+)	Ponds may continue functioning for some days in case of power failure, whereas ASS fail instantly and need difficult re-start of operations.
c	Carbon footprint, CO_2 balance	(+)	Emissions roughly proportional to BOD reduction; ASS can be covered more easily, but have higher power consumption.
	Carbon footprint, GHG emissions	[-/+]	Uncovered ponds under inappropriate operational conditions may release CH_4 and NO_X. Well operated ponds will probably release less GHG than ASS, under life cycle aspects including power consumption issues.
d	Odours (and VOC)	(+/-)	Odour intensity in well-operated ponds is significantly lower than from ASS. Yet, covering and exhaust air collection is easier with ASS.
e	Mosquitoes, flies, rats	(-)	Can be controlled by proper pond design and operations.
f	Solid wastes	(+)	Sludge production from ponds is lower than from ASS, especially if highly loaded. No difference for waste from screens (both systems should have appropriate ones) and sand grit.

Explanations: See table 2.

Another important evaluation criterion affecting operational costs is the power consumption, which is usually lower for ponds, as explained in table 3. This also influences the carbon footprint. There are materials and technologies available for biogas collection, or collection of volatile organics and greenhouse gases under a pond cover, applicable without major operational problems.

The authors have found a number of ponds, which had been closed down because of odours. Without exception, these odour problems could have been largely eliminated through improved design and/or operations. The same applies to nuisance from mosquitoes etc.

STRATEGIC CRITERIA

Very important, when evaluating pond systems compared to ASS, are strategic criteria. The financial incentives, driving the responsible decision makers, are often stronger for technical equipments and higher investments, pushing pond systems frequently to the looser side. The focus of strong marketing and political lobbying is for systems with more technical equipment installed (e.g. ASS) than in pond systems (Rudolph, 2008).

Technical controllability of the treatment process certainly is an important criterion in the view of operators. ASS (or pure mechanical-physical process technologies) can be steered through buttons and joysticks, whereas pond systems offer fewer possibilities for direct influence. The treatment process within ponds is highly complex and need deep know-how about the hydraulic and bio-chemical processes. On the other hand, ponds are much more flexible regarding inflow conditions because of their large buffer capacity and detention time. And, ponds can be easily upgraded and extended (in some cases, pond systems are understood as the first stage in a development towards combined technical plants on the same footprint for triple capacity).

In addition, the aquacultural potential might be an important issue: promising research is done at various institutes (e.g. see Shilton et al., 2008) on how to increase the growth of plants and algae for harvesting, in combination with CO_2-consumption or even CO_2-scrubbing in ponds.

Table 4 Strategic criteria for wastewater pond systems vs. activated sludge systems (ASS)

α	Financial incentives	(-)	Support of equipment manufacturers and consulting fees higher for ASS, which has influence on decision making to the disadvantage of ponds.
β	Technical controllability	(-)	Modification and control of hydraulics and purification processes in ponds may need continuous and more sophisticated skills than for ASS-machines and reactors.
γ	Flexibility regarding inflow conditions + large buffer capacity and detention time; flexibility for upgrade and extension	(+)	Ponds can easily be upgraded/extended stage-wise, and can be combined with conventional and high technologies of all kind.
δ	Aquacultural potential	[+]	Especially algae and plant harvesting for enhanced bio-gas production, nutrient recovery, the production of natural fibres and pharmaceutical agents, are promising.

Explanations: See table 2.

CBA PARAMETERS AND REGIONAL SPECIFICS

The general idea of a cost:benefit-analysis (CBA) is the overall analysis and comparison of costs and benefits of a specific investment project. The result is either the net-benefit (the monetary value by which the benefits exceed the costs) or the cost:benefit-ratio (indicating that the benefits over-compensate the costs by a certain percentage, if the project is profitable).

While the monetary value of project costs is rather easy to assess, valuating benefits in monetary terms is a difficult task as the term "benefits" aggregates all positive effects of an investment on the environment, society, economy, public health etc. Table 5 lists parameters, which need to be included in a CBA for wastewater treatment plants, especially wastewater pond systems. ADB (1999) and Hutton (2004) provide good support for methodologies and good practice for valuating benefits.

Table 5 Basic economic data requirements

Item	Remark
Investment costs	Split up in costs for buildings / excavations, machinery and electrical appliances (→ reinvestments)
Operational costs	Split up in costs for personnel, maintenance, sludge disposal, energy (if applicable)
Interest rate for loans	To calculate capital costs
Inflation rate	Distinguished between energy price, labour prices, etc.

Regional specifics

Especially for developing and transformation countries, cost components must reflect the very specific situation onsite. This particularly applies to labour costs (maybe near-to-zero for low-skilled labour countries or regions with high unemployment), to electric power (in various countries, power is still subsidised and does not reflect the real values), and to natural resources (like land used for plants to substitute water loss reduction).

An example of a cost comparison is shown in table 6. The upper part of the table gives the figures from a consulting engineers cost comparison report. The initial conclusion was that (although expensive land purchase costs were included in the investment) the ponds are still cheaper than the activated sludge plant, but that these cost advantages seem too little compared to the presumed technical disadvantages of ponds (odours and poor effluent quality).

The lower part of the table shows the revised costs. Local labour was calculated at lower unit prices (to acknowledge economic benefits of the regional employment effect). This resulted in reduced investment costs with a relative advantage for the ponds - revised with different percentages of write-off for land (0 %), civil constructions (3 %) and machineries (10 %). Therefore, and due to grants and soft-loans, the revised CAPEX figure was lower than the original calculation.

The revision of operational costs led to higher figures, especially regarding electric power for the activated sludge system. The revised figures were based on full costs instead of the subsidised tariffs (which had been increased significantly in the meantime). Sufficient expenses for structural maintenance to guarantee sustainable wastewater treatment, especially for machineries and plant equipment were added separately, as these had not been included in the original calculation of the engineering consultants.

Table 6 Cost comparison of a wastewater pond system with an activated sludge system

		Wastewater pond system	Activated sludge system	Δ
First draft	Invest (Mio. €) including local labour and land	1.75	2.05	
	CAPEX (k€/a) 11 %	192	225	
	OPEX (k€/a) including electric power	115	164	
	Total (k€/a)	307	389	82
Revised version	Invest (Mio. €) local labour content revised	1.50	1.90	
	(thereof: land purchase)	(0.95)	(0.20)	
	CAPEX (k€/a) 6 % interest, grants deducted 0/3/10 % write-off	72	170	
	OPEX (k€/a) after revision of local labour and electricity costs	110	226	
	Total (k€/a)	182	396	209

The revised cost calculation looks different, the cost advantage of ponds turned out to be much higher. The technical discussion, whether or not ponds tend to create odours and come up with poor effluent quality, remained controversial. But, considering the high cost advantages, the municipality changed its decision.

CONCLUSIONS

Whether wastewater pond systems are advantageous compared to other systems, e.g. activated sludge systems, cannot be said in general. This depends very much on site conditions, and has to be analysed case-wise.

Ponds can be operated free of odours, and can produce very low contaminations in their effluent, fully competitive to other wastewater treatment technologies. It would not be justified to exclude pond systems by arguments claiming that only ASS will guarantee advanced wastewater purification and operation free of odours, although this is often heard in practice.

Unless justified veto arguments dominate the decision (like land requirement or winter performance), any rational decision will need some kind of cost:benefit-analysis (CBA). To provide a reliable and serious statement, whether or not a wastewater pond system is the feasible option for a specific case under discussion, the CBA should be complete and appropriate - taking into account also the regional-specific costs, which may be quite different, e.g. in terms of labour, power, etc.

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