



TÍTULO DEL TRABAJO

“Are Constructed Wetlands a Cost-Effective Alternative to Activated Sludge Systems?
Investigation of Plants in Germany and Mexico”

TÍTULO RESUMIDO

“Economical Comparison of Constructed Wetlands and Activated Sludge Systems”

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ARE CONSTRUCTED WETLANDS A COST-EFFECTIVE ALTERNATIVE TO ACTIVATED SLUDGE SYSTEMS? INVESTIGATION OF PLANTS IN GERMANY AND MEXICO

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SUMMARY

Financial limitation are restricting the implementation of wastewater infrastructure, especially for rural areas with low-income. Constructed Wetlands (CW) are considered to be a cost-effective, low-maintenance technology. Economical data about plants in use are rare; especially when it comes to comparative data with more often used technologies like Activated Sludge Systems (ASS). The study hence surveys investment and operating costs of existing CW and ASS in Germany and Mexico, two countries with different climatic, economical and infrastructural conditions. The result shows that, contrary to the assumption, there is no significant difference of investment for CW and ASS. In opposite, running costs do differ between the technologies, with CW showing up to three times lower costs than ASS. Differences between the countries are tremendously. Plants in Mexico have averagely seven times lower investment and operating costs than German plants.

KEY WORDS: decentralised wastewater treatment, economical comparison, investment costs, operating costs

SON LOS HUMEDALES ARTIFICIALES UNA ALTERNATIVA ECONÓMICA EN COMPARACIÓN CON LA TECNOLOGÍA DE LODOS ACTIVOS? INVESTIGACIÓN EN PLANTAS EN ALEMANIA Y MÉXICO

RESUMEN

Una de las restricciones para la implementación de una infraestructura de aguas residuales son los limitantes de financiación, especialmente en las zonas rurales de bajos ingresos. Los Humedales Artificiales (HA) son considerados como una alternativa económica que requiere poco mantenimiento. Los datos económicos de las plantas de tratamiento son escasos, especialmente cuando se quiere comparar con una de las tecnologías más usadas como es los Lodos Activos (LA). Este estudio incluye los costos de inversión y operación existentes en HA y LA en Alemania y México, dos países con diferentes condiciones climáticas, económicas y de infraestructura. Los resultados muestran que, contrariamente a lo supuesto, no hay diferencias significativas dentro de los costos de construcción para las dos tecnologías. Por otra parte los costes de funcionamiento de los HA son tres veces mas bajos que para LA. La diferencias entre los países son extremas. Los costes de plantas en México son en promedio siete veces mas bajo que las plantas en Alemania.

PALABRAS CLAVE: tecnologías de depuración de aguas residuales descentralizadas, comparación económica, costes de construcción, costes de funcionamiento

1. INTRODUCTION.

The wastewater sector was concentrating on urban areas and centralised concepts for years. Nowadays more rural structured areas excite interest. Beside technical feasibility and operational stability, economical aspects are crucial for choosing a technology above all in the rural sector. Since only few data is available about the investment and operating costs for small plants, information about existing plants were gathered within a doctoral thesis in Germany and Mexico. The two countries with different climatic, economical and infrastructural conditions got chosen consciously. Germany is a country with almost complete connection rate (Federal State Reports 2000), whereas only 15 % of all sewage gets a treatment of Mexico (CNA 2001). The yet non-connected areas in Germany are mostly communities with less than 2.000 inhabitants. According to the EU Municipal Wastewater Directive (91/271/EEG) a solution for small communities is obligatory only since this year (2005). The wastewater problem in Mexico concentrates mainly on agglomeration areas, accounting for three quarters of the population. Still 25 million people are living in rural areas (WHO 2001). Besides missing treatment plants, failure rate of small plants are comparatively high since wrong dimension, overload, insufficient staff training, missing regular maintenance and uncalculated capital for replacement parts (CAMEXA 2002). 60 % of Mexican and 79 % of German plants are smaller than 10.000 p.e. (person equivalents) (Federal State Reports

2000; CNA 2002). The search for appropriate technologies in decentralised regions with bearable burden for the citizen is yet not losing actuality.

Therefore the article compares economical aspects of Constructed Wetlands (CW) with Activated Sludge Systems (ASS). CW considered as an appropriate technology with low costs, collapse rate and maintenance effort, is used comparatively seldom yet. Only 5 % of the German and 2,7 % of the Mexican plants are CW. ASS in opposite is one of the most used technology, with 50 % usage rate in Germany (plants below 5.000 p.e.) and 16 % in Mexico.

2. MATERIAL AND METHODS.

The data was surveyed in the years 2002 and 2003 via inspection and oral inquiry by a pre-structured questionnaire. Usually the planning and operating authority, being the community, the Wastewater Association (Germany) or the Local Water Committee (Mexico) were questioned. In some cases additional interviews were made with the planning authority, e.g. the Regional Water Council (Mexico) and the maintenance employees about technical details and maintenance effort. The Governmental District of Leipzig in Germany got chosen as area under investigation, since new treatment plants were installed after the newly-formed German states in the last years. Therefore economical data accordingly is newsworthy. In addition, data of CW were collected German-wide via written and telephone interview. Treatment plants got chosen with support of Federal Office for Environment and the German Federal Environment Foundation.

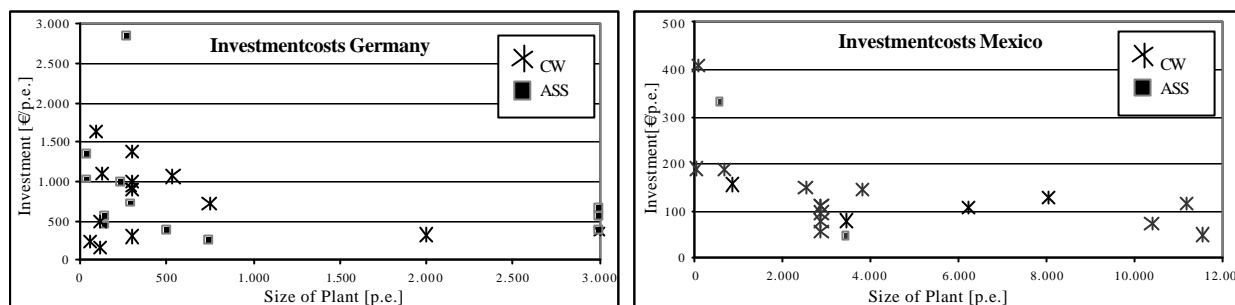
In Mexico the evaluation was centred in the two states of Oaxaca and Michoacán. Plants were selected in assistance with a countrywide statistic of the National Water Commission (CNA 2002) and the Department of Rural Areas and Participation.

In Germany data of 47 treatment plants in the size of 50 to 5.000 inhabitants was collected, whereas 20 were ASS and 13 CW. 4 plants of the ASS were Sequencing Batched Reactors (SBR), the others simple ASS. The CW can be divided in 9 horizontal and 4 vertical beds. In Mexico 34 plants in a size up to 10.000 inhabitants got evaluated, among 6 simple ASS and 20 CW, all horizontal. Beside fundamental data about technical features and general conditions, investment and operating costs, divided into costs for personnel, operating facilities, energy supply, waste- and sludge-disposal got collected. To compare plants of different years as well as between the countries, the investment costs got adjusted for inflation first, using the price-index for Germany (Federal Statistical Office 2003) and the inflation index from 1999 to 2003 for Mexico (Index 2003). Thereafter costs were converted into Euro (using the rates € = MXP 1:11,9 and DM = € 1:0,51). For Mexican plants where size is measured usually in L/s it was necessary to refer data to p.e., assuming a daily water consumption of 150 L/ inhabitant. Since the evaluated operational data refers to 2002 or 2003 inflation adjustment is unnecessary.

Finally the annual costs were calculated on the basis of investment and operating costs. Investment costs get divided by the operating time regardless possible depreciation methods. The operating costs on the basis of the years 2000 or 2001 get simply added, not considering possible price increases. Operating time is considered essential for the calculation.

3. RESULTS

Graphic 1 displays the all over investment costs of the evaluated ASS and CW, including expenses for planning, constructing and installing, ground, adoption and side buildings (data for 13 ASS and 13 CW in Germany, 2 ASS and 17 CW in Mexico). At first the graph shows, that investment costs in Germany disperse in a wide range of 165 €/p.e up to 2.850. Neither for ASS nor for CW appears a clear cost advantage. With increasing size investment costs for ASS are obviously falling up to a size of 800 p.e.. For CW such a trend is not apparent. Investment for Mexican plants is much lower, lying between 48 €/p.e and 410 €/p.e., whereas a falling tendency with larger size is noticeable.



Graph 1: Investment costs of evaluated plants in Germany and Mexico

To make more general statements about the investment costs, the average of the both technologies are presented in Table 1, showing that in *Germany*:

- Average investment costs of ASS and CW are comparable (807 via 783 €/p.e.).
- Simple ASS are clearly favourable as plants using SBR-process (688 versus 1073 €/p.e.).
- Horizontal CW are clearly more expensive than vertical beds (893 versus 537 €/p.e.).

67 % of investment is made averagely for constructing the plant. Excluding the other above mentioned categories there is still no mentionable difference between the all over costs of ASS and CW (560 via 577 € p.e.). If one distinguishes again between processes, vertical CW are most favourable (316 €/p.e.), followed by simple ASS (429 €), ASS with SBR-process (618 €/p.e.) und horizontal CW (693 €/p.e.). On second and third rank are the categories for adoption and side buildings. Ground costs account for less than 10 % for all plants.

As data evaluation is difficult and costs transparency low in *Mexico* investment costs for 17 CW but only 2 ASS was available. In addition it has to be mentioned, that one of the ASS was used for research purposes as well, resulting in higher investment. Thus prohibits comparing statements for ASS. The average costs of CW are 110 €/p.e. The municipal ASS cost 48 €/p.e., the one used for research 330 €/p.e..

Table 1: Average investment and operation costs for ASS and CW in Mexico and Germany

	Germany						Mexico	
	all ASS	simple ASS	SBR	all CW	horizontal	vertical	simple ASS	horizontal CW
investment [€/p.e.]								
allover investment	807	688	1073	784	893	537	190	110
only construction and installation	560	429	618	577	693	316		
operation [€/p.e.*a]								
allover operation	41.50	43.30	35.30	18.30	21.40	13.00	6.50	1.30
personell	16.55			7.18				
disposal/ maintenance of sludge and waste	14.84			4.04				
energy supply	7.53			0.87				
repair and maintenance material	9.62			9.14				

Table 1 includes the overall operating costs. Comparing these costs, the following statements can be made for *Germany* (all costs per p.e. and annum):

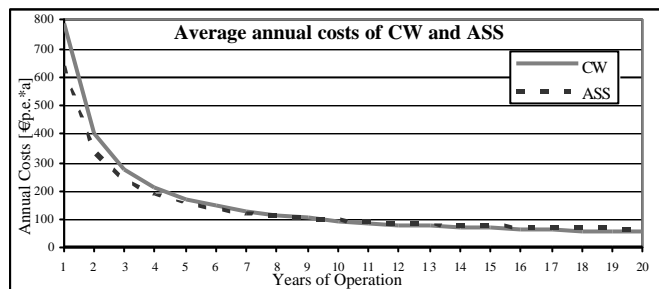
- The average of overall operating costs is three times lower for CW (18,30 versus 41,50 €).
- Simple ASS are more cost-consuming than such in SBR-process (43,30 versus 35,30 €);
- Horizontal CW are clearly more expensive than vertical beds (21,40 versus 13,00 €).

Dividing the costs again in categories as shown in the table, ASS expenses for personnel are the biggest fraction (30 %), followed by costs for sludge and waste disposal (27 %), repair and maintenance material, including external contracts, e.g. for pump control (17 %) and energy supply (14 %). The remaining costs fall on the category „Other Costs“, dominated by fees for wastewater discharge into open water, including sampling and laboratory costs, insurance and tax. Spending on repair and maintenance are comparable for CW and ASS (9,10 versus 9,60 €), but are dominating within the operating costs of CW (35 %) followed by costs for personnel (28 %), sludge and waste disposal (16 %) energy supply (3 %).

In addition Table 1 outlines, that operating costs in *Mexico* are tremendously lower than in *Germany* (all costs per p.e. and annum):

- 6,50 € on the average costs the three ASS, while operating for the 6 CW with detailed operating costs available is as low as 1,60 €
- Nearly half of the costs for ASS is spend for energy supply (43 %), followed by expenses for personnel (23 %), disposal of waste and sludge (11 %), chemicals (8 %) and maintenance and repair material (7 %).
- The evaluated costs for the 6 CW contain averagely 78 % personnel and 15 % energy costs. Only half of the plants are connected to electricity, whilst the others transport the wastewater to the plant and between the processes via free level inclination. 5 % of the costs are spend on chemicals, mainly being chlorine for disinfection. Nearly no expenses accure for maintenance and reparation material, bearing in mind that the plants were not longer than three years in operation. Moreover costs for waste and sludge disposal are marginal, as sludge is only produced during pre-treatment and is mostly disposed in sludge-drying or settlement beds just aside and used as fertilizer on agricultural areas.

Finally graph 2 shows the average annual costs of both technologies for a period of one to 20 years in *Germany*. The planned depreciation period of the German plants differ between 5 to 20 years with an average of 17,4 years. With regular maintenance an operating time of 15 years can be seen as realistic for both ASS and CW. The graph shows that average annual costs in the first operating years are slightly more affordable for ASS. When it comes to more realistic operating time a reverse trend can be seen. With an operating time of 9 years annual costs are equal, beyond CW are cheaper. The difference is negligible, with 70 €/p.e.*a for CW and 77 €/p.e.*a for ASS within 15 years operation. Plant size is not addressed in the graph. To proof, if size plays a decisive role to the result, the belonging table categorises the plants in three sizes and shows the annual costs for different running times. The table indicates that for plants below 500 p.e. CW are the more affordable option even at a low operating time. Above this size ASS are more economical for all running times.



Years of operation [costs in €p.e.*a]					
Size of Plant	Techn.	5 years	10 years	15 years	20 years
until 200 p.e.	CW	166	94	70	58
	ASS	203	124	98	85
201 - 500 p.e.	CW	173	95	69	56
	ASS	185	116	93	82
501 - 5000 p.e.	CW	189	100	71	56
	ASS	113	70	55	48

Graph 2/ Table 2: Average Annual Costs for CW and ASS

The data basis for Mexico only allows to calculate the annual costs for one ASS and 4 CW. CW have costs between 5,50 und 8,50 €p.e. per annum (average 7,30 €p.e.*a). Annual costs for the ASS (being the one for municipal use) are 12 €p.e. As the data background for ASS is thin, it has to be repeated, that operating costs of the three ASS were 6,50 €p.e. on average being 4,50, 6,30 and 8,70 €p.e. for the single plants. Consequently the operating costs are only slightly below or even exceed the annual costs of CW, including investment costs on top.

4. DISCUSSION

The decision for a certain wastewater treatment technology and process usually is made from case to case considering climatic, infrastructural, geological, price and other conditions. Statements of the affordability of one or another technology consequently have to be made very carefully. The study consequently did not aim to give precise numbers about investment, operating and annual costs of the two very different technologies ASS and CW, but to proof if one of the technologies is typically more affordable. Even though the costs of the evaluated plants do range widely, the study works with the costs-averages, only dividing into the processes simple ASS and SBR, vertical and horizontal CW.

For overall investment costs no clear advantageousness of one or the other technology gets obvious as expenses are comparable. Ground expenses, contraire to the assumption, played a secondary role in both countries, valid also for the land-consuming CW. An explanation might be, that the option for using a CW is only considered, when ground is not the limiting factor, meaning that ground either is already property of the planning and operating authority or is cheap in the area. If only costs for building and installing the plant get compared, excluding all side costs, vertical CW in Germany are the most favourable option, followed by simple ASS, SBR-process and horizontal CW.

With operating costs the case is more evident, even if conclusions are made diffident. CW is clearly more affordable being 2-3 times cheaper than ASS in Germany, with expenses for personnel and sludge disposal being the driving force. Vertical beds again show a clear cost-advantage. In Mexico, where electricity supply and personnel are the main costs, the advantageousness of CW is even more obvious. CW here is often used in areas, where no reliable electricity net exists, being together with wastewater ponds the only option.

High investment costs dominating the annual costs during the first years of operation. When it comes to longer running periods the operating expenses gains influence. But not only operating time but size is crucial for the cost-effectiveness of the two technologies. For very small and small plants up to a size of 500 p.e. CW are cheaper in overall annual costs. For larger plants ASS still is the considerable option in Germany. Vertical CW show a clear

economical advantage over horizontal beds. This result is contraire to the assumption that vertical beds are more expensive through needing more technical equipment, energy and maintenance.

In Mexico vertical flow CW are not used for municipal wastewater treatment, yet only as pilot plants ((Baumann et al. 2003; CNA 2002; Miranda Ríos & Luna-Pabello 2001). Taking the data of German plants as a basis they might have a larger potential for municipal wastewater treatment in regions where energy supply is no problem.

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