Environmental assessment for selected sanitation systems in India, Indonesia, Malaysia and Nepal


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CONTENT

Compilation of data and prerequisites

The environmental assessment was made using information of removal capacities and energy use from data of evaluated technologies (first priority), literature data (second priority) and estimates (third priority). Removal capacities for different technologies are often presented as a range, however, to be able to perform a comparative analysis, assumptions have been made and removal rates have been defined. A classification system has been formulated including removal rates for nitrogen (N), phosphorus (P), organic matter (BOD) as well as cadmium (Cd) in sewage products for use in agriculture (Table 1). The scale consisted of four classes; "low", "moderate", "high" and "very high". The classes low and moderate level were defined with the perspective that low level matches poor technologies and acceptable technologies in this part of the world matches moderate level. High level corresponds to what is acceptable for municipal wastewater management in a European perspective, while very high quality corresponds to what is acceptable where the highest standards are applied, for instance the requirements of large scale wastewater treatment plants in sensitive coastal areas in Sweden.

Table 1. *Classification key*

	Low removal	Moderate removal	High removal	Very high removal
Nitrogen	< 25 %	25-49 %	50-74 %	≥ 75 %
Phosphorus	< 30 %	30-69 %	70-89 %	≥ 90 %
BOD	< 50 %	50-79 %	80-89 %	≥ 90 %
	Low quality	**Moderate quality**	**High quality**	**Very high quality**
Cd (mg/kg DM)	> 40	20-40	3-19	≤ 2

The defined removal rates for selected technologies treating i) black water, ii) grey water and iii) combined wastewater are presented in Table 2-4 respectively. However, it is important to note that the stated removal rates are relating to emissions to the water recipient which significantly impact on the removal rates of dry systems (i.e. systems including the urine diverting toilet) and biogas digesters where most of the substances are trapped and removed with the solid fraction. It should also be noted that, as mentioned above, the classification for cadmium in Table 1 is related to the quality of sewage products, i.e. these levels are not used to classify the removal of cadmium by the sanitation systems regarding discharge to the water recipient. For most technologies, removal rates were taken from literature except for a few cases where data from analysis performed in Malaysia could be used.

Table 2. *Removal rates for selected technologies for black water treatment*

	Septic tank	Upgraded septic tank	Biogas digester[5,6]	Two-pit latrine[8]	Urine diverting toilet[9]	Soil absorption field
Removal of nitrogen	10%[1]	10%[1]	0%	50%	100%	
	Low	Low	Low	High	Very high	
Removal of phosphorus	5%[1]	62%[4]	0%	80%	100%	35%
	Low	Moderate	Low	High	Very high	Moderate
Removal of BOD	62%[2]	77%[4]	50%[7]	80%	100%	35%
	Moderate	Moderate	Low	High	Very high	Moderate
Removal of cadmium	25%[3]	88%[4]	0%	80%	100%	

[1] Swedish EPA (1985); [2] Kamil (2007); [3] Wittgren et al. (2003); [4] Local information from Malaysia concerning the performance of Individual Septic Tanks (IST); [5] Biogas digester is also used for treating combined wastewater; [6] Assumption that 50% of N, 80% of P, 80% BOD and 80% Cd is retained in the solid phase and will not reach the water recipient; [7] Alvarez et al (2008); [8] The stated removal rates are representing the fraction of the substances that are retained in solids, same fractions are used as for biogas digester; [9] No substances are contaminating the receiving water body in a dry system, hence, the removal rate is considered to be very high.

Table 3. *Removal rates for selected technologies for grey water treatment*

	Constructed Wetland[1]	Stabilisation ponds	Storm water filter	Screen chamber[6]	Subsurface sand filter[7]
Removal of nitrogen	50%	60%[2]		0%	50%
	High	High		Low	High
Removal of phosphorus	80%	40%[2]		0%	50%
	High	Moderate		Low	Moderate
Removal of BOD	80%	70%[3]	70%[5]	0%	90%
	High	High	High	Low	Very high
Removal of cadmium	74%	50%[4]		0%	49%

[1] Cui et al. (2003); [2] Mbwele (2006); [3] Picot et al. (2005); [4] Kaplan et al. (1986); [5] According to Malaysian local partners; [6] Only screen solids according to Malaysia feasibility report; [7] Palm et al. (2002), Nilsson et al. (1998); [8] Wittgren et al. (2003).

Table 4. *Removal rates for selected technologies for combined wastewater treatment*

	Settling Tank	Anaerobic Baffle Reactor	Extended Aeration[6]	Imhoff Tank[7]	Sequencing Batch Reactor
Removal of nitrogen	10%[1]	19%[3]	40%	10%	77%[8]
	Low	Low	Moderate	High	High
Removal of phosphorus	5%[1]	15%[3]	50%	5%	95%[9]
	Low	Low	Moderate	Low	High
Removal of BOD	35%[2]	91%[4]	91%	34%	95%[9]
	Low	Very high	Very high	Low	High
Removal of cadmium	25%[1]	25%[5]	90%	25%	90%[8]

[1] Assumed to be comparable to a septic tank; [2] Metcalf & Eddy (2002); [3] Feng et al. (2008); [4] Krishna (2009); [5] Cd assumption absorption to particles, comparable to septic tank; [6] Hellström et al. (2003); [7] Local information from Malaysia concerning the performance of an Imhoff tank (BOD removal: 33.7; other parameters like septic tank); [8] Käppala Environmental report (2004); [9] Bengtsson et al. (1997).

In Table 2-4, the assumed removal rates for the individual technologies are presented. In the following environmental assessment (Chapter 2-4), sanitation options consisting of a mix of technologies are evaluated. Although these options have the same name, they might look different from country to country, therefore the classification of the total removal of the options can be different. There were no available local data on the composition of wastewater, grey water, urine and feaces, therefore literature data has been used in the environmental assessment (Jönsson et al., 2005; Morel and Diener, 2006; Schouw et al., 2002).

References used for the energy demand and potential energy production calculations are listed in Table 5. Energy needed is based on the assumption that sludge and urine fractions need to be transported by trucks to their final destination for application or treatment. Based on the nitrogen content, the yearly amount of urine from one person is assumed to fertilise 400 m^2 of crop (EcoSanRes, 2008).

Table 5. *Assumption for energy demand of different steps of O&M of wastewater treatment systems*

Step	Energy needed / produced		Source
Desludging - energy	0.23	MJ/m³ sludge	based on information of Sjöberg (2003)
Driving	15.33	MJ/km	assuming 6 l diesel/km; based on information of Sjöberg (2003)
Urine collection	0.12	MJ/m³ urine	based on information of Sjöberg (2003)
Urine distribution	8.17	MJ/ha	based on information of Sjöberg (2003)
Degradation of organic matter	3.6	MJ/kg O_2	Swedish EPA (2002)
CH_4 produced in a digester	7	m³/person, year	Metcalf & Eddy (2002)
Energy produced in CH_4	22.4	MJ/m³ CH_4	Metcalf & Eddy (2002)

The legal requirements that need to be complied are listed in Table 6. In India and Malaysia legal requirements for domestic wastewater exist, whereas the values in Nepal are not legally binding, but generally used for design. The parameters were established for industrial effluent, but are also applied for domestic wastewater as no other standards are available. In Indonesia, no effluent standards exist so far.

Table 6. *Effluent requirements for treated domestic wastewater*

		INDIA[1]	MALAYSIA[2] Standard A	MALAYSIA[2] Standard B	NEPAL[3]
BOD	mg/l	30	20	50	50
COD	mg/l	250	50	100	250
N	mg/l				
NH_4-N	mg/l				50
P	mg/l				
Cd	mg/l		0.01	0.02	2
Suspended Solids	mg/l		50	100	50
Solids – total	mg/l	100			
pH		5.5 – 9.0	6.0 – 9.0	5.5 – 9.0	5.5 – 9.0
Oil & grease	mg/l	10	not detectable	10	10

[1] Waste Water Management, Shivshankar Ranganathan; www.indiawaterportal.org/tt/wastewater/res/Advanced%20Tutorial.doc); [2] Standard A for discharge upstream of drinking water take-off; Standard B for inland waters http://www.did.sarawak.gov.my/wqis/sgsarawak/water-qua-standard.htm); [3] Reference for Nepal? To be added by Markus

Results of environmental assessment

INDIA

In India, a total of 280 households (HH) are included in the study, with an average of 5 persons per HH. The removal capacity of the existing system is 9.3% nitrogen, 8.4% phosphorus, 8.5% BOD and 12.5% cadmium. Three different options were analysed (Table 7). As described in 3.5.5 there are several options for grey water treatment in India. The mentioned options were analyzed and two of them, consisting of open/closed gutters with stabilization ponds, leach and soak pits, were considered to be best suited for the village based on the emission of nutrients and organic matter to water recipient. Based on this, the grey water treatment for all sanitation options in Table 7 has the mentioned mix of grey water treatment technologies.

Table 7. *Description of options analyzed in India*

Option	Black water	No of HH	Grey water	No of HH
1	Ecological sanitation (Ecosan): Existing Latrines, Ecosan Toilets and open/closed gutters with Stabilization ponds, Leach pits and Soak pits			
	- Existing Latrines - Ecosan toilets	- 77 - 203	- Stabilization ponds - Leach pits - Soak pits	- 100 - 62 - 118
2	Two-pit latrine: Existing Latrines, Two pit Toilets and open/closed gutters with Stabilization ponds, Leach pits and Soak pits			
	- Existing Latrines - Two-pit latrines	- 77 - 203	- Stabilization ponds - Leach pits - Soak pits	- 100 - 62 - 118
3	Biogas digester: Existing Latrines, Biogas digesters and open/closed gutters with Stabilization ponds, Leach pits and Soak pits			
	- Existing Latrines - Biogas digesters	- 77 - 203	- Stabilization ponds - Leach pits - Soak pits	- 100 - 62 - 118

The evaluation of environmental performance is based on the situation of the whole village. Also old systems that were not replaced were considered, which had an impact on the overall performance of each option. The energy demand was calculated for each option in MJ per person and year. To get the average energy demand per person, the total energy demand was divided by the number of people living in the village. Table 8 summarizes the results for option 1 to 3.

Table 8: Results of environmental assessment in India

India	**Option 1** **Ecosan**	**Option 2** **Two-pit latrine**	**Option 3** **Biogas digester**
Removal of nitrogen	Very high	Moderate	Moderate
Removal of phosphorus	Moderate	Moderate	Moderate
Removal of BOD	Moderate	Moderate	Moderate
Removal of cadmium	73%	63%	63%
Removal of total eutrophication potential (N+P)[1]	62%	47%	47%
Energy demand (MJ/person, year)	18.9	0	1.2
Energy production (MJ/person, year)			154
Quality of recycled product (mg Cd/kg DM)	Very high quality	Very high quality	Very high quality
Average nutrients in side products (kg/person, year)	N: 2.3 P: 0.51	N: 1.32 P: 0.43	N: 1.32 P: 0.43

[1] Total eutrophication potential is expressed in kg PO_4^{3-} equivalent/yr (Guinée, 2002).

Option 1 – Ecosan system

Environmental impact

This option performs best with respect to its environmental impact as no contaminants are polluting the water recipient. No black water is generated and all side products are used in agriculture. Nevertheless, the performance of BOD and phosphorus removal is only moderate due to the existing systems that are still discharging their effluent into the receiving water body. It is worth to note that compared to the other countries all the options in India include a more diverse mix of technologies which affects the removal rate of the total system i.e. the option.

Energy demand

The energy demand of this option results from collection, transport and distribution of urine and compost to farmland.

Option 2 – Two-pit latrine

Environmental impact

Black water infiltrates into the groundwater and only solids that settle in the pits are removed. The same assumption for substance fractions between the solid and liquid phase has been used in the calculation for two-pit latrine as well as for biogas digester. This is based on the assumtion that the pits are allowed to drain properly e.g. that there are no floods during rainy seasons, which should imply that only initial soluble substances leaves the pit. The actual removal rate, i.e. substances that are retained in the pit, is probably lower due to ongoing degradation and flushing while the pit is in use as well as during the resting period.

Energy demand

The idea behing the two-pit latrine is that one pit is resting while the other one is being used. The result is a soil-like material too solid to be removed with a vacuum truck and therefore it needs to be excavated manually. According to local partners the content is distributed on nearby land as fertilizer. In conclusion, there is no need for fossil energy in this option.

Option 3 – Biogas digester

Environmental impact

The water phase is infiltrating into the soil while the slurry from the biogas digester is used as fertilizer on the farmland. Substances remaining in the slurry are considered to be same amount as the substances trapped in the solid phase in the latrine. However in the biogas digester 50% of the organic matter is degraded in the process which increases the removal rate of the system.

Energy demand

This option has the best performance concerning energy demand as much more energy has the potential to be produced in the form of biogas than is needed for operation and maintenance of the systems. Energy production, in the form of biogas collection and usage, is considered in Options 1, 2 and 3 where black water is digested in a fixed dome digester. In option 2 there are 212 HH connected to biogas digester system while in option 1 and 2 there are the existing 9 HH which produce biogas. Energy is needed for desludging of the biogas digester and the transport of the dried sludge to the farmland in 5 km distance, but is highly compensated by the produced energy.

INDONESIA

In Indonesia, a total of 566 households (HH) are included in the study, with an average of 5 persons per HH. The removal capacity of the existing system is 1.1% nitrogen, 0.3% phosphorus, 3.3% BOD and 2.2% cadmium. Four different options were analysed. The evaluation of environmental performance is based on the situation of the whole village. For the on-site systems, old systems that were not replaced were considered, which had an impact on the overall performance of the technology, whereas the decentralised option all households are connected to the constructed wetland (Table 9).

Table 9: Description of options analysed in Indonesia

Option	Black water	No of HH	Grey water	No of HH
1	Pour Flush Toilet (PFT) with Septic Tanks and constructed wetland			
	- Pour Flush Toilet - Septic Tank	- 499 - 499	- Constructed wetland	- 499
2	Public Community Sanitation System			
	- Public toilets - Water from washing and bathing - Anaerobic digester and anaerobic baffle reactor (ABR)			- 6 - 499 - 1
3	Ecological Sanitation and constructed wetland			
	- Urine diverting toilets - Urine application - Faeces utilization	- 50	- Constructed wetland	- 499
4	Decentralised Sewerage System			
	- Pour Flush Toilet - Sewerage system - WWTP (constructed wetland)			- 566 - 499

The energy demand was calculated for each option in MJ per person and year. To get the average energy demand per person, the total energy demand was divided by the number of people living in the village. Table 10 summarizes the results of the calculations for option 1 to 4.

Table 10: Result of environmental assessment in Indonesia

Indonesia	**Option 1** **Pour flush toilet with septic tank**	**Option 2** **Public community sanitation system**	**Option 3** **Ecological sanitation**	**Option 4** **Decentralised sewerage system**
Removal of nitrogen	Low	High	Very high	Moderate
Removal of phosphorus	Moderate	Moderate	High	High
Removal of BOD	Moderate	High	High	High
Removal of cadmium	36%	69%	86%	73%
Removal of total eutrophication potential (N+P)[1]	33%	49%	85%	71%
Energy demand (MJ/person, year)	4.8	4.8	18.9	0
Energy production (MJ/person, year)		154		
Quality of recycled product (mg Cd/kg DM)			Very high quality	
Average nutrients in side products (kg/person, year)			N: 2.50 P: 0.50	

[1] Total eutrophication potential is expressed in kg PO_4^{3-} equivalent/yr (Guinée, 2002).

Option 1 – PFT with septic tank

Environmental impact

The septic tank itself has only low removal potential, but as the grey water is treated in a constructed wetland, at least moderate removal rates for phosphorus and BOD can be reached for the system as a unit. This option has the most environmental impact of all the evaluated options.

Energy demand

The energy demand results from desludging and transport of the sludge. The septic tank is desludged every four years and the sludge is conveyed to a sludge treatment plant situated 20 km away.

Option 2 – Public community sanitation system

Environmental impact

This technology has a good technical performance as wastewater is passing through a series of treatment systems (biogas digester, settling tank and ABR) before being discharged into the receiving water body. The good result of phosphorus removal rests on the assumption that 80% of the phosphorus in black water is removed with the solid phase in the digester and thus not contaminating the receiving water body.

Energy demand

The energy demand of this biogas system is comparatively higher than of the on-site biogas systems as the sludge is not applied on the fields, but conveyed to a sludge treatment plant in 20 km distance. Still the potential biogas production is very high, which makes this by far the most energy effective technology of the evaluated options.

Option 3 – Ecological sanitation (urine-diverting toilets)

Environmental impact

This option performs best with respect to its environmental impact as no contaminants from the toilets are polluting the water recipient. All grey water is treated in a constructed wetland and all side products are used in agriculture. Compared to the Ecosan option in India, there are fewer households in Indonesia that are still discharging their wastewater from septic tanks into the recipient and thus this option has lower environmental impact.

Energy demand

The energy demand of this option results from collection and distribution of urine and compost to the farmland. Here a transport distance of 5 km is assumed.

Option 4 – Decentralised constructed wetland

Environmental impact

Due to the connection of all users to the constructed wetland, the removal of phosphorus and BOD is high but the nitrogen removal is only moderate.

Energy demand

As it is possible to run the whole system by gravity, no pumps are needed. A constructed wetland is not aerated and the dried sludge of the pre-treatment does not have to be conveyed to a treatment plant as it can be dried on-site and disposed next to the plant. There results no energy demand from this treatment system.

MALAYSIA

In Malaysia, a total of 183 households (HH) are included in the study, with an average of 5 persons per HH. The removal capacity of the existing system is 5.1% nitrogen, 7.3% phosphorus, 30.4% oBOD and 21.6% cadmium. Four different options were analysed. The evaluation of environmental performance is based on the situation of the whole village. In Malaysia, all system were replaced or upgraded by new systems (Table 11).

Table 11. Description of options analyzed in Malaysia

Option	Black water	No of HH	Grey water	No of HH
1	Upgrade existing traditional septic tanks or replace with prefabricated septic tanks			
	- Low flush and Pour Flush Toilets (PFT) - Replace traditional septic tanks with individual septic tank (IST) - Provide houses without treatment with IST - Soil absorption system	- 183 - 174 - 9 - 183	- Storm Water Filter	- 183
2	Centralize into community treatment plant in Kampung Sepakat Baru area			
	- Low flush and PFT a) communal Imhoff Tanks (IT) to constructed wetland (CW) b) sewer line to small package plant (extended aeration, EA)			- 183
3	Ecological sanitation - Ecosan			
	- Replacement of existing toilets with single-flush toilet (urine diverting) - Urine application - Faeces utilization	- 183	- Screen chamber and sub-surface sand filter	- 183
4	Centralised Sewer System into new wastewater treatment plant			
	- Low flush and PFT - Sewerage system - Sequencing Batch Reactor (SBR)			- 183

The energy demand was calculated for each option in MJ per person and year. To get the average energy demand per person, the total energy demand was divided by the number of people living in the village. Table 11 summarizes the results of the calculations for option 1 to 4.

Table 12: Results of environmental assessment in Malaysia

Indonesia	**Option 1** **Upgrading of existing septic tanks**	**Option 2a** **Centralisation into community treatment plant - CW**	**Option 2b** **Centralisation into community treatment plant – EA**	**Option 3** **Ecosan**	**Option 4** **Centralisation into a new treatment plant**
Removal of nitrogen	Moderate	High	Moderate	Very high	Very high
Removal of phosphorus	Moderate	High	Moderate	High	Very high
Removal of BOD	Moderate	High	Very high	Very high	Very high
Removal of cadmium	65%	81%	80%	87%	90%
Removal of total eutrophication potential (N+P)[1]	38%	74%	47%	81%	90%
Energy demand (MJ/person, year)	4.8	4.8	76.6	18.9	76.6
Quality of recycled product (mg Cd/kg DM)				Very high quality	
Average nutrients in side products (kg/person, year)				N: 2.85 P: 0.57	

[1] Total eutrophication potential is expressed in kg PO_4^{3-} equivalent/yr (Guinée, 2002).

Option 1 – Upgrading of existing septic tanks

Environmental impact

Local information about the treatment efficiency could be collected. The removal is slightly better than for the septic tanks in the other countries, still, this is the option with the most environmental impact.

Energy demand

The energy demand results from desludging and transport of the sludge. The septic tanks are desludged every two years, and the sludge is transported to a treatment plant situated 20 km away.

Option 2a – Centralisation into community treatment plant – CW

Environmental impact

The constructed wetland shows better results than the other countries as a communal Imhoff tank is installed as pre-treatment. All households are connected to the system and therefore this option has low environmental impact.

Energy demand

This system has a higher energy demand than the constructed wetlands in the other countries due to the Imhoff tank which has to be desludged and conveyed to a sludge treatment plant 20 km away.

Option 2b – Centralisation into community treatment plant – EA

Environmental impact

This technology provides very good removal of BOD, but only moderate removal of nutrients.

Energy demand

The energy demand of aerated systems is very high compared to non-aerated systems. To decompose 1 kg of BOD, 3.6 MJ is necessary. This option has (together with option 4) the highest energy demand of all options.

Option 3 – Ecosan

Environmental impact

This option performs very good as no contaminants are polluting the recipient. All grey water is treated in a constructed wetland and all side products are used in agriculture. All households will receive this system and this option has the same low environmental impact as the centralised option. Malaysia has the best overall BOD-removal of all Ecosan-options due to sand filter treatment of the grey water.

Energy demand

The energy demand of this option results from collection and distribution of urine and compost to the farmland.

Option 4 - Centralisation into another new treatment plant

Environmental impact

This state-of-the-art technology is the best performing technology and has lowest environmental impact of all options.

Energy demand

This option has the same high energy demand as option 2b as it is an aerated system as well.

NEPAL

In Nepal, a total of 173 households (HH) are included in the study, with an average of 7 persons per HH. The removal capacity of the existing system is 5.8% nitrogen, 1.7% phosphorus, 18.4% BOD and 12.1% cadmium. Four different options were analysed. The evaluation of environmental performance is based on the situation of the whole village. All systems were replaced except for in option 3, the PFT with septic tank, where the existing systems were not replaced (Table 13).

***Table 13**. Description of options analysed in Nepal*

Option	Black water	No of HH	Grey water	No of HH
1	Ecological sanitation (Ecosan) and constructed wetland			
	- Ecosan Toilets	- 173	- Constructed wetland	- 173
2	Pour Flush Toilet (PFT), biogas digester and constructed wetland			
	- PFT - Biogas digester (ind+mult)	- 173 - 95+3 5	- Constructed wetland	- 173
3	Pour Flush Toilet (PFT), septic tank and constructed wetland			
	- Existing PFT with septic tank - PFT (new) - Septic tank (new)	- 113 - 60 - 60	- Constructed wetland	- 173
4	Pour Flush Toilet, Centralized Sewer Line and Constructed Wetland or Waste Water Treatment Plant (WWTP)			
	- PFT - 4a: Constructed wetland (only for ward N°2) - 4b: Centralized WWTP (System in Kathmandu)			- 173 - 173 - 173

The energy demand was calculated for each option in MJ per person and year. To get the average energy demand per person, the total energy demand was divided by the number of people living in the village. Table 14 summarizes the results of the calculations for option 1 to 4.

Table 14. Results of environmental assessment in Nepal

Nepal	Option 1 Ecosan	Option 2 PFT with Biogas digester	Option 3 PFT with Septic tank	Option 4a Decentralised constructed wetland	Option 4b Centralised treatment plant (EA)
Removal of nitrogen	Very high	High	Moderate	High	Moderate
Removal of phosphorus	Very high	High	Moderate	High	Moderate
Removal of BOD	High	High	Moderate	High	Very high
Removal of cadmium	93%	78%	38%	74%	90%
Removal of total eutrophication potential (N+P)[1]	92%	71%	54%	71%	47%
Energy demand (MJ/person, year)	18.9	1.2	4.8	0	74.5
Energy production (MJ/person, year)		154			
Quality of recycled product (mg Cd/kg DM)	Very high quality	Very high quality			
Average nutrients in side products (kg/person, year)	N: 2.78 P: 0.57	N: 1.43 P: 0.46			

[1] Total eutrophication potential is expressed in kg PO_4^{3-} equivalent/yr (Guinée, 2002).

Option 1 – Ecosan

Environmental impact

This option performs best with respect to its environmental impact as no contaminants are polluting the recipient. No black water is generated and all side products are used in agriculture. Nepal has the best overall P-removal of all Ecosan-options due to treatment of all grey water in a constructed wetland.

Energy demand

The energy demand of this option results from collection and distribution of urine and compost to the farmland.

Option 2 – PFT with Biogas digester

Environmental impact

The water phase is infiltrating into the soil while the slurry from the biogas digester is used as fertilizer on the farmland.

Energy demand

This option has the best performance concerning energy demand as much more energy is produced in the form of biogas than is needed for operation and maintenance of the systems.

Energy is needed for desludging of the biogas digester every two years and the transport of the dried sludge to the farmland in 5 km distance, but is highly compensated by the produced energy.

Option 3 – PFT with septic tank

Environmental impact

The septic tank itself has only low removal potential, but as the grey water is treated in a constructed wetland, at least moderate removal rates for all parameters could be reached. This option has worst environmental impact of the evaluated technologies.

Energy demand

The energy demand results from desludging and transport of the sludge. The septic tank is desludged every four years and the sludge is conveyed to a WWTP in 20 km distance.

Option 4a – Decentralised constructed wetland

Environmental impact

Due to the connection of all users to the constructed wetland, proper treatment of wastewater is ensured. The removal of phosphorus and BOD is high and the environmental impact low.

Energy demand

As it is possible to run the whole system by gravity, no pumps are needed. A constructed wetland is not aerated and the dried sludge of the pre-treatment does not have to be conveyed to a treatment plant as it can be dried on-site and disposed next to the plant. There results no energy demand from this treatment system.

Option 4b – Centralised treatment plant in Kathmandu

Environmental impact

This technology shows moderate removal results for nutrients and very high removal of BOD.

Energy demand

The energy demand of this option is very high due to energy necessary for aeration of the system. The effluent should observe the standard of 50mg/l BOD (compared to 20mg/l in Malaysia), however, the difference in energy usage is very small between the countries due to the higher water usage in Malaysia which dilute the concentration in the influent, i.e. almost the same amount of organic matter needs to be removed in the two options.

Energy calculations

In this chapter, the annual energy demand for the different options is presented as MJ/person. Table 15 shows a summary of the energy use per option and country. The calculations can be found in the following subchapters. Options that include several different treatment components might have the same energy use since only some technologies require energy. Therefore, the names below are based on the energy requiring component of the treatment option that is the same for all countries.

In general, all transport between the different technologies in a system is by gravity. There are several components and options that require no energy. Stabilisation ponds, constructed wetlands, storm water filters and soil absorption fields are used for grey water treatment and require no energy. In addition, constructed wetlands are also used in Indonesia and Nepal as a decentralised solution for treatment of all wastewater. Since there is no energy associated with transport this option is also not included here. The two-pit latrine option used in India is emptied manually and the material is used locally, hence, no energy use.

Table 15. *Annual energy use for the system options [MJ/person, year]*

Options	India	Indonesia	Malaysia	Nepal
PFT with septic tank[1]		4.78	4.78	4.78
Biogas digester[2]	1.20	4.78		1.20
Ecosan option[3]	18.89	18.89	18.89	18.89
Community IT[4]			4.78	
Aerated WWTP			76.57	74.47

[1]Sludge removal from septic tank and transport to sludge treatment plant (20 km); [2]Sludge removal from digester and transport to farmland (5 km or 20 km); [3]The relatively high energy demand is due to assumed transport and distribution of urine by truck from storage to agricultural land; [4]Sludge removal from communal septic tank and transport to sludge treatment plant (20 km).

From one technology a potential energy production has been calculated, this is the biogas digester which is included in one option in all countries besides Malaysia (Table 16).

Table 16. *Potential energy production for the system options [MJ/person, year]*

Options	India	Indonesia	Malaysia	Nepal
Biogas digester	154	154		154

Pour Flush Toilet with septic tank

The assumed annual sludge production is 0.035 m^3/person in all countries, hence, the calculated energy for desludging is the same in the three countries with septic tank options. By chance, the average distance from the settlements to the sludge treatment plants is also the same. Therefore, the total energy per person for this option is the same in all countries.

	sludge m^3/pers, yr	desludging MJ/m^3 sludge			Energy use MJ/pers, yr	**Nepal & Indonesia & Malaysia**
Desludging of septic tanks	0.035	0.23			**0.0079**	
	distance km	driving MJ/km	size truck m^3	trips/yr	Energy use MJ/pers, yr	
Transport of sludge to WWTP	20	15.33	4.5	0.008	**4.77**	

Option with a biogas digester

The assumed annual sludge production in the biogas digester is the same in all options. In India and Nepal the dried sludge is used as fertilizer on farmland close to the system (average 5 km) compared to Indonesia where longer transport is required (average 20 km). Therefore, the energy use in Indonesia is higher than for the other two options.

Biogas is produced in the biogas digesters, and the potential energy production is calculated based on the assumed amount of CH_4 that can be used as an energy source. Energy produced per person is the same in all options. However, it should be noted that the amount of people connected to this technology in the different biogas options varies.

	sludge m^3/pers, yr	desludging MJ/m^3 sludge			Energy use MJ/pers, yr	
Desludging of biogas plants	0.035	0.23			**0.0079**	**India & Nepal**
	distance km	driving MJ/km	size truck m^3	trips/yr	Energy use MJ/pers, yr	
Transport of dired sludge to farmland	5	15.33	4.5	0.008	**1.19**	
	Biogas produced m^3/pers, yr	Energy MJ/m^3 CH_4			Energy produced MJ/pers, yr	
Potential energy production	7	22			**154**	

	sludge m^3/pers, yr	desludging MJ/m^3 sludge			Energy use MJ/pers, yr	
Desludging of biogas plants	0.035	0.23			**0.0079**	**Indonesia**
	distance km	driving MJ/km	size truck m^3	trips/yr	Energy use MJ/pers, yr	
Transport of sludge to WWTP	20	15.33	4.5	0.008	**4.77**	
	Biogas produced m^3/pers, yr	Energy MJ/m^3 CH_4			Energy produced MJ/pers, yr	
Potential energy production	7	22			**154**	

Ecological Sanitation Option

In the Ecosan option, urine diverting toilets are installed. Urine is collected and stored before being used as fertilizer on crop. In the energy calculations, a truck is used for urine collection from storage, transport and distribution on farmland. Due to large volumes, compared to sludge, the energy demand for transport is relatively high. This can be significantly reduced if the urine is applied closer to the source. In Malaysia flush toilets are installed, and although the small flush is only about 0.1 litre, this additional water will add to the transport energy demand. However, this demand is not considered in the calculations.

	urine m^3/pers, yr	collection MJ/m^3 urine			Energy use MJ/pers, yr	
Collection from storage	0.54	0.12			**0.067**	
	distance km	driving MJ/km	size truck m^3	trips/yr	Energy use MJ/pers, yr	
Transport storage to agriculture	5	15.33	4.5	0.12	**18.49**	
	fertilizing m^2/pers, yr	cover area ha/pers, yr	Distribution MJ/ha		Energy use MJ/pers, yr	**India & Indonesia & Malaysia & Nepal**
Urine distribution	400	0.04	8.17		**0.33**	
	compost m^3/pers, yr					
Dehydration chamber	0.035					
	distance km	driving MJ/km	size truck m^3	trips/yr	Energy use MJ/pers, yr	
Compost to agriculture	5	15.33	4.5	0.008	**1.19**	

Faeces are left to dry in a dehydration chamber. The amount of compost is assumed to be approximately the same as the total sludge production on a yearly basis. The dry compost is used as soil conditioner on agricultural land within the same area as for the applied urine.

Community Imhoff Tank

In this option, a community septic tank is used for collection or wastewater before the liquid part is transported by gravity to a constructed wetland for further treatment. The energy use is for desludging of the septic tank and transport to a sludge treatment plant. The transport distance is in average 20 km.

	sludge m^3/pers, yr	desludging MJ/m^3 sludge			Energy use MJ/pers, yr	
Desludging of septic tanks	0.035	0.23			**0.0079**	
	distance km	driving MJ/km	size truck m^3	trips/yr	Energy use MJ/pers, yr	**Malaysia**
Transport of sludge to WWTP	20	15.33	4.5	0.008	**4.77**	

Aerated treatment plant

Energy is needed for the aerated processes. Malaysia has two aerated options:1) decentralised option with an Extended Aeration system, and 2) centralised option with a combination of a Sequencing Batch Reactor and a Membrane Bioreactor. However, the organic load to the treatment plants are the same, therefore only one calculation is performed. The centralised treatment plant in Nepal is also based on the extended aeration process. Even though the effluent requirements are higher in Malaysia the amount of organic material that needs to be removed is about the same. This is due to the high water consumption in Malaysia which dilute the influent concentration to the treatment plant.

	influent lpcd	influent mg/l	effluent mg/l	influent l/pers, yr		**Malaysia**
Organic load to WWTP	170	362.77	20	62050		
	removed kg O_2/pers, yr	Energy use MJ/kg O_2			Energy use MJ/pers, yr	
Energy for organic degradation	21.27	3.6			**76.57**	

	influent lpcd	influent mg/l	effluent mg/l	influent l/pers, yr		**Nepal**
Organic load to WWTP	100	616.71	50	36500		
	removed kg O_2/pers, yr	Energy use MJ/kg O_2			Energy use MJ/pers, yr	
Energy for organic degradation	20.69	3.6			**74.47**	

REFERENCES

Álvarez, J. A., Armstrong, E., Gómez, M. & Soto, M. (2008) Anaerobic treatment of low-strength municipal wastewater by a two-stage pilot plant under psychrophilic conditions. *Bioresource Technology,* 99(15), 7051-7062.

Bengtsson, M., Lundin, M & Molander, S. (1997) *Life cycle assessment of wastewater systems. Case studies of conventional treatment, urine sorting and liquide composting in three Swedish municipalities.* Report 1997:9, Chalmers University of Technology, Göteborg, Sweden.

Cui, L. H., Luo, S. M., Zhu, X. Z. & Liu, Y. H. (2003) Treatment and utilization of septic tank effluent using vertical-flow constructed wetlands and vegetable hydroponics. *Journal of Environmental Sciences China,* 15(1), 75-82.

EcoSanRes (2008) *Guidelines on the use of urine and faeces in crop production*. EcoSanRes Factsheet 6. Available from: http://www.ecosanres.org/pdf_files/ESR-factsheet-06.pdf [Accessed 5 May 2009].

Feng, H., Hu, L., Mahmood, Q., Qiu, C., Fang, C. & Shen, D. (2008) Anaerobic domestic wastewater treatment with bamboo carrier anaerobic baffled reactor. *International Biodeterioration & Biodegradation*, 62, 232-238.

Guinée, J.B. (Ed.) (2002) *Handbook on Life Cycle Assessment*. Kluwer Academic Publisher.

Hellström, D., Jonsson, L. & Sjöström, M. (2003) *Good small wastewater systems: evaluation of 15 onsite wastewater treatment systems* [Bra små avlopp. Utvärdering av 15 enskilda avloppsanläggningar] Report 13, Stockholm Vatten, Stockholm, Sweden. In Swedish.

India Feasibility Study (2009) Dim-Sum Project.

Indonesia Feasibility Study (2008) Dim-Sum Project.

Jönsson, H., Baky, A., Jeppsson, U., Hellström, D. & Kärrman, E. (2005) *Composition of urine, faeces, greywater and biowaste for utilisation in the URWARE model.* Report 2005-6, Urban Water, Chalmers University of Technology, Göteborg, Sweden.

Kaplan, D., Abeliovich, A. & Yaakov, S. B. (1986) The fate of heavy metals in wastewater stabilization ponds. *Water Research*, 21(10), 1189-1194.

Krishna, G.G.V.T., Kumar, P. & Kumar, P. (2009) Treatment of low-strength soluble wastewater using an anaerobic baffled reactor (ABR). *Journal of Environmental Management*, 90, 166-176.

Käppala Environmental report (2004) [Käppala miljörapport (2004). Miljörapport enligt miljöbalken]. Käppala förbundet, Lidingö, Sweden. In Swedish.

Malaysia Feasibility Study (2008) Dim-Sum Project.

Mbwele, L. A. (2006) *Microbial Phosphorus Removal in Waste Stabilisation Pond Wastewater Treatment Systems*. Licentiate Thesis. KTH, The Royal Institute of Technology, Stockholm, Sweden.

Metcalf & Eddy (2002) Treatment, Reuse, and Disposal of Solids and Biosolids. In: Tchobanoglous, G., Burton, F. L. & Stensel, H. D. (eds.) *Wastewater Engineering: treatment and reuse.* 4th edition. New York, McGraw-Hill, pp. 1505-1523.

Morel, A. & Diener, S. (2006) *Greywater Management in Low and Middle-Income Countries, Review of different treatment systems for households or neighbourhoods*. Report 14/06, Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland.

Nepal Feasibility Study (2008) Dim-Sum Project.

Nilsson, P. Nyberg, F. & Karlsson, M. (1998) *The function of filter beds– monitoring and evaluation of filter beds.* [Markbäddars funktion: kontroll och utvärdering av markbäddar] Report 4895, Svenska naturvårdsverket SNV (Swedish EPA). In Swedish.

Palm, O. Malmén, L. & Jönsson, H. (2002) *Robust, sustainable small sewage systems: a review.* [Robusta, uthålliga små avlopp: en kunskapssammanställning] Report 5224, Svenska naturvårdsverket SNV (Swedish EPA). In Swedish.

Picot, B., Andrianarison, T., Gosselin, J. P. & Brissaud, F. (2005) Twenty years' monitoring of Meze stabilisation ponds: part I - removal of organic matter and nutrients. *Water Science and Technology,* 51(12), 23-31.

Schouw, N. L., Danteravanich, S., Mosbaek, H. & Tjell, J. C. (2002) Composition of human excreta-a case study from Southern Thailand. *The Science of the Total Environment*, 286(1-3), 155-166.

Sjöberg, C. (2003) *Recirculation of sewage products from on-site systems within the Oxundaån watershed area* [Lokalt omhändertagande av restprodukter från enskilda avlopp i Oxundaåns avrinningsområde]. M.Sc. Thesis. Swedish University of Agricultural Sciences, Uppsala, Sweden. In Swedish.

Swedish EPA (1985) *Wastewater infiltration – Presumption, function, environmental effects.* [Infiltration av avloppsvatten: förutsättningar, funktion och miljökonsekvenser] Nordisk Samproduktion, Svenska naturvårdsverket SNV (Swedish EPA). In Swedish.

Swedish EPA (2002) *Systems for reuse of phosphorus from wastewater* [System för återanvändning av fosfor ur avlopp]. Nordisk Samproduktion, Svenska naturvårdsverket SNV (Swedish EPA). In Swedish.

Wittgren, H. B., Baky, A. & Palm, O. (2003) *Environmental systems analysis of small-scale sanitation solutions.* In: proceedings of 2nd international symposium on ecological sanitation, Lübeck, Germany, 7-11 april 2003.