sustainable
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SuSanA fact sheet

Links between sanitation, climate change and renewable energies

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1 Introduction

There are important links between sustainable sanitation, climate change and renewable energy production. For example, sanitation systems can be designed in a way to produce renewable energy sources which in turn may mitigate climate change by reducing greenhouse gas emissions. Sanitation systems may also serve to help people adapt to climate change by reusing energy, nutrients and treated wastewater and thus substituting the use of primary resources.

This fact sheet gives an overview of the possible mitigation and adaptation measures and it explains the additional financial benefit that emission trading may bring (section 2). As one measure for mitigation it describes the possibilities to use sanitation products for renewable energy production (section 3) and draws the conclusions from both (section 4).

2 Climate change mitigation and adaptation potential of sanitation

2.1 Greenhouse effect and responsible gases

The greenhouse effect is the phenomenon where the presence of so-called greenhouse gases (GHG) leads to a warming of the earth's surface: GHG allow solar radiation to enter the earth's atmosphere but prevent heat from escaping back to space. They absorb infrared radiation and reflect it to the earth's surface leading to a warming there.

Many human activities cause GHG emissions which drive the anthropogenic greenhouse effect. According to the Intergovernmental Panel on Climate Change the atmospheric greenhouse effect will cause a rise in the mean global temperature of between 1.1 and 6.4°C by the end of the 21st century (IPCC, 2007a), a change in rainfall patterns, a rising sea level and a weakening of sea currents which will have an additional impact on the global temperature distribution. In order to limit climate change to tolerable levels, global temperature rise has to be limited to 2°C (IPCC, 2007b). To achieve this, GHG emissions would have to be reduced by 50% by 2050 compared to the level in 1990 (IPCC, 2007c).

2.2 Relevant greenhouse gases

In the field of sanitation, the following GHG are climate relevant:

- Carbon dioxide (CO_2) is produced as a result of any fossil or non-renewable wooden biomass combustion. Similarly, the removal of organics and nutrients in wastewater treatment plants requires energy. The same holds true for the production of mineral fertilisers which is a very energy intensive process. Both the removal and the new production of nutrients for fertilisers require the consumption of fossil fuels leading directly to climate relevant CO_2 emissions. For climate protection, it is important to reduce fossil or non-renewable wooden biomass consumption.
- Methane (CH_4) is a potent greenhouse gas with a global warming potential 21 times higher than that of CO_2. In anaerobic processes, organic matter contained in domestic waste and wastewater is decomposed and biogas is formed which contains 60-70% methane. In soak pits, anaerobic ponds, septic tanks and other anaerobic treatment systems where biogas is either not collected or leaking (e.g. many UASB reactors), or even at the discharge of untreated wastewater into water bodies, anaerobic processes take place to different extents and methane is released to the atmosphere. For climate protection, wherever biogas is produced, it should be captured through a controlled anaerobic treatment and used as a renewable energy source. If the biogas cannot be used, then it has to be flared. As an alternative to a controlled anaerobic treatment, methane formation should be avoided through a low-energy aerobic treatment (e.g. dehydration, composting, constructed wetland).
- Nitrous oxide (N_2O) is the most harmful greenhouse gas with a global warming potential 310 times higher than that of CO_2. Nitrous oxide emissions occur during the denitrification process in wastewater treatment, at the disposal of nitrogenous wastewater into aquatic systems and also during mineral nitrogen fertiliser production. For climate protection, nitrogen should be recovered and reused as a fertiliser, or nitrogenous wastewater should be treated for the intended use and reused (e.g. for irrigation or groundwater recharge).

2.3 Mitigation and adaptation in sanitation

Compared to a conventional wastewater treatment system, the use of (decentralized) reuse-oriented sanitation systems can on the one hand lead to energy savings (e.g. in construction, operation, maintenance, demolition and elimination of sewer networks and treatment plants). On the other, reuse-oriented sanitation systems may also result in a higher energy consumption (e.g. for the road-based transportation of sanitation products). Thus, if comparing reuse-oriented with conventional centralized sanitation systems, a careful analysis of the different systems from an energy perspective would be necessary. However, the following considerations focus on reuse-oriented sanitation systems only.

By using appropriate reuse-oriented sanitation systems with energy, nutrient or wastewater recovery and reuse, anthropogenic greenhouse gas emissions can be reduced (mitigation) as well as people's capacity to cope with climate change impacts can be increased (adaptation). In the field of sanitation, possible measures to mitigate or adapt to climate change impacts are described in sections 2.4 and 2.5.

2.4 Mitigation measures

2.4.1 Energy recovery

Besides the avoidance of energy intensive aerobic treatment systems, sanitation systems can be operated in a way to produce renewable energy in the forms of either biogas or biomass and thus reduce the primary energy consumption:

1. Biogas production or its avoidance (see below and section 3.1).
2. Biomass production (see section 3.2).

Wherever biogas is produced, it must be captured and preferably used either for simple heat generation (Figure 1) or for a combined heat and electricity generation, e.g. by means of a combined heat and power plant (Figure 2) or by a fuel cell. This can substitute the use of fossil or non-renewable energy sources. If the biogas cannot be used, then it has to be flared (this converts methane to carbon dioxide which has a 21 times lower GHG potential than methane, see section 2.2). This results in the following recommendations:

- Where treatment size allows for it, replace existing (facultative) anaerobic ponds (also called "lagoons") and septic tanks by a controlled anaerobic treatment system (e.g. biogas plant, UASB reactor, anaerobic baffled reactor).
- Design and build any new anaerobic treatment system as a closed gastight construction with biogas capture.
- Close existing open UASB reactors as well as leaky biogas plants gastight and avoid venting by restoring the flares.

If neither the use nor the flare can be realised, uncontrolled biogas production should be avoided. Therefore, where septic tanks are too small for a controlled anaerobic treatment (i.e. generally household level), aim at replacing septic tanks by appropriate, low-energy, (partially) aerobic treatment methods (e.g. dehydration, composting, constructed wetland systems).

Figure 1: Biogas stove in kitchen, India, 2008 (source: David Fulford)

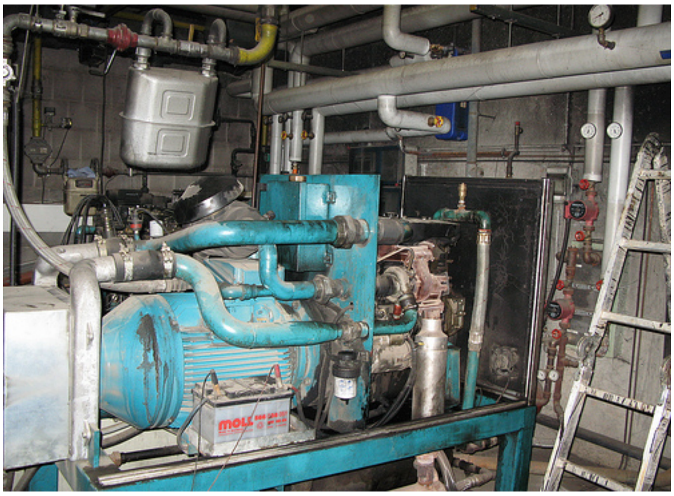

Figure 2: Combined heat and power (CHP) unit, Germany, 2008 (source: GTZ ecosan)

Another possible measure is the heat recovery from:

- wastewater (e.g. from greywater or wastewater running in sewers or from the effluent of wastewater treatment plants) and its use.
- the heated pressurized air for the aeration of activated sludge tanks and its use.

Since these measures represent very local options for conventional centralised systems, they are not further discussed here.

2.4.2 Nutrient recovery

The macronutrients nitrogen (N), phosphorus (P) and potassium (K) contained in human and animal excreta can be locally recovered and safely used as fertiliser in agriculture. In this way they can substitute the energy intensive production of manufactured mineral fertilisers and their transport over long distances. Further information on the safe use of excreta for fertilisation can be found in (WHO, 2006) and (SuSanA, 2008).

Since N-fertilisers require more energy (Remy et al., 2006) and are consumed in larger amounts than P- and K-fertilisers (Gellings and Parmenter, 2004), it is sufficient to focus on nitrogen fertilisers only when considering energy demand and climate-relevant effects from fertilisers. Since 87% of the excreted nitrogen is contained in urine, from a climate protection point of view concentrating on the recovery and reuse of the nitrogen contained in urine (Figure 3) represents the most efficient means of emission reduction through nutrient recovery.

On the basis of a life cycle analysis, a study comparing the energy demands for nutrient removal and mineral fertiliser production versus nutrient recovery identified a considerable energy saving potential with urine diversion nutrient recovery (Maurer et al., 2003).

The emission reduction potential through energy recovery (biogas) and nutrient recovery (urine) was analyzed for a case study in India (Olt, 2008). For nutrient recovery it was calculated to 23 kg CO_2e/(cap · a) resulting mainly from avoided energy consumption for the production and transportation of mineral fertiliser, avoided field emissions during fertilisation and avoided disposal of nitrogenous wastewater into aquatic systems. From an emission reduction point of view, this case study however faced unfavourable conditions in view of nutrient recovery. Therefore, the above indicated value of emission reduction through nutrient recovery can be regarded as a lower value which by the way was found to be comparable with the one of energy recovery.

Source separation of urine and subsequent use of urine as fertiliser reduced the climate impact by 33 kg CO_2e/(cap · a) in a scenario study evaluated with life cycle assessment methodology, where wheat production in Sweden with urine as fertilizer was compared to conventional mineral fertilizer use and wastewater treatment (Tidåker et al., 2007). The benefits originated mainly from an avoided need for the production of mineral fertilisers and from avoided field emissions.

Therefore, artificial mineral fertilisers should be replaced by natural fertilisers (urine, sludge, dried faeces) as far as possible.

Figure 3: Urine application in agriculture, Burkina Faso, 2008 (source: GTZ ecosan)

2.5 Adaptation measures

2.5.1 Adaptation to water scarcity

In order to adapt to water scarcity, the following measures should be taken into account (list is not exhaustive):

- Wastewater (esp. greywater), treated to the appropriate degree for the intended use ("reclaimed water"), or rainwater can be reused for the irrigation of food crops or lawns (Figure 4), energy crops (Figure 5), parks and other public spaces, for groundwater recharge or as service water. In cases where potable water is used for irrigation, the use of treated wastewater substitutes the extraction, processing and distribution of potable water and thus may lead to energy savings. The main benefit however would lie in a reduced primary water resources demand. The nutrient content of the wastewater also reduces the need for mineral fertiliser input as mentioned in section 2.3.2. Further information on wastewater reuse in agriculture can be found in (WHO, 2006).
- Reduce physical water losses through both the repair of leaking pipes and the introduction of a water pressure management of water pipe networks.
- Minimize virtual water losses by reducing the exportation of highly water consuming products (e.g. animal meat, cotton, rice) and increase the import of highly water consuming products (e.g. cereals).
- Use dry toilet systems (especially in water scarce areas) for substituting waterborne sanitation systems. Toilets which don't require water for flushing, but can nevertheless be indoors (e.g. UDDTs, composting toilets), may save about 40 L/(cap · d) compared to conventional flush toilets.
- Install water collection and storage units (cisterns and underground reservoirs) providing water for drought

periods (in regions with an intermittent water supply).

- Increase the cultivation of drought resistant crops.
- The irrigation methods used should minimise water losses through evaporation and infiltration. Therefore, subsurface drip irrigation is preferable although possible nozzle clogging should be considered.
- Seawater desalination plants might be installed if operated by renewable energies (e.g. Saharan solar power plants).

Figure 4: Garden irrigated with treated blackwater, Peru, 2008 (source: Heike Hoffmann)

Figure 5: Energy plants cultivated in a short-rotation-plantation (source: TTZ)

2.5.2 Adaptation to flooding

In order to adapt to flooding, one effective measure consists of building sanitation system components in a way that they are either not affected by flooding (UDDTs built high enough above ground) or that water can evacuate quickly (elevated sludge drying beds, constructed wetlands).

2.6 Emission trading as an additional financial benefit

The Kyoto Protocol – the internationally binding contract on climate protection measures valid until the end of 2012 – assigns each participant country which has emission reduction commitments an allowed amount of greenhouse gas emissions. In order to reach this emission target at the least macroeconomic costs, the Kyoto Protocol offers three market-based flexible mechanisms. One of them, the Clean Development Mechanism (CDM), is designed for trading emission reductions which have been achieved in developing countries.

The CDM can be used for emission reductions achieved through sustainable sanitation systems. It can contribute to an additional financial benefit but also generates CDM-related costs which are mostly fixed and which compensate achieved credits to some extent.

Hence, for sustainable sanitation systems, a minimum project scale is required to make CDM economically attractive. This is very much dependent on both the baseline and the project scenario, the energy demand of the fertiliser production plants, the energy mix of the country considered, the transaction costs and the price of the carbon credits.

Assuming average transaction costs and a long-term price of 20 €/CER, the minimum project scale was found in (Olt, 2008) to be around 25,000 PE[1] (for energy recovery) and 37,000 PE (for nutrient recovery).

The minimum project scale for an economic use of CDM for energy recovery (biogas use) and nutrient recovery (urine use) was analyzed for a case study in India (Olt, 2008). From an emission reduction point of view, this project faced favourable conditions in view of energy recovery and unfavourable conditions in view of nutrient recovery. Therefore the above indicated project scale for energy recovery represents an absolute minimum value, while the value for nutrient recovery can also be lower.

In order to reach this number, similar CDM projects may be bundled to a "Programme of Activities" (PoA). A manual for biogas plants at household level is given in (GFA, 2009). Further information on PoA is available at (UNFCCC, 2009).

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[1] PE = population equivalent. It is the organic biodegradable load having a five-day biochemical oxygen demand (BOD_5) of 60 g O_2/d (equalling approximately the organic biodegradable load of one person).

3 Renewable energy production from sanitation

3.1 Biogas production

3.1.1 Overview

Biogas is a renewable energy that can be used for cooking, lighting, heating purposes, and for generating electrical power. It is produced by bacteria that decompose organic matter under anaerobic conditions (i.e. in the absence of oxygen). The technology of anaerobic digestion (AD) has been applied to human and animal excreta for over 150 years. The anaerobic bacteria grow slowly and higher temperatures result in faster decomposition rates. For biogas generation various substrates can be used (often in combination of each other):

- blackwater, i.e. mixture of excreta and flushing water (best from low-flush or vacuum toilets)
- organic waste from households or agricultural farms
- animal manure
- sewage sludge originating from domestic wastewater
- human excreta from dry toilets

In many Asian countries, e.g. China, human excreta or so-called "night soil" is being treated in this way together with animal manure and other organic waste. As a result of a Chinese national programme in the 1970s ("Biogas for every household"), the increasing energy demand and continuing efforts to combat wood cutting, there is an on-going interest in biogas which is supported by the Ministry of Agriculture. Today, there are 5 million family-sized plants of 6, 8 and 10 m^3 in operation, mainly built as fixed dome plants as shown in Figure 6 (Balasubramaniyam et al., 2008).

3.1.2 Goals of anaerobic digestion

Due to the two benefits of energy production and nutrient recovery, anaerobic digestion (AD) is receiving new interest as an option in sustainable sanitation concepts. Anaerobic digestion may have two different goals:

1. To maximize biogas production by adding animal manure or other biomass and optimising the retention time with regards to energy output and reactor volumes.
2. To maximize hygienisation (pathogen kill) of the digestate by providing long retention times.

In sanitation, maximizing the hygienisation of the incoming wastewater is more important than maximizing the biogas production. The pathogens contained in the raw blackwater are reduced during treatment but not totally removed. The pathogen reduction during AD is higher the longer the hydraulic retention time (HRT) is. For example, the reduction of *E.coli* bacteria during mesophilic digestion (temperature of 35°C) at a HRT of 20 days is 2.4 log. Another reduction of 2.0 log can be achieved by post storage at ambient temperature of 20°C for 40 days (Wendland, 2009).

3.1.3 Technology

Two different digester types are applied for AD:

1. Digester where the HRT is similar to the sludge retention time (usually more than 20 days).
2. Digester where the HRT is independent from and often shorter than the sludge retention time.

The advantage of the digester of Type 1 as seen in Figure 6 and Figure 7 is that they are low-tech systems requiring fewer skills for their operation and maintenance.

The digester or high-rate reactor of Type 2 can be much smaller than the digester of Type 1 but it requires professional skills for its design, operation and maintenance. Several types were developed during the last decades, best known are the upflow anaerobic sludge blanket (UASB) reactor and the anaerobic baffled reactor (ABR). They are applied for blackwater (Zeeman et al., 2007), domestic wastewater and municipal wastewater (van Haandel and Lettinga, 1994; Singh et al., 2009). In a UASB reactor for domestic wastewater, the HRT is around 1 day at ambient temperature of 20°C (Elmitwalli, 2000). The UASB and ABR for municipal wastewater treatment have so far been implemented mainly in Latin America and Asia as the tropical climate throughout the whole year is favourable for AD.

Highly concentrated wastewater (i.e. blackwater with a low flush water volume) is particularly suited to AD and vacuum toilets with low flush volumes can be applied. The standard vacuum toilet needs 0.7 L/flush, and so-called micro flush vacuum toilets are available that use only 0.2 L/flush.

3.1.4 Biogas production

Biogas from anaerobic blackwater treatment contains 60-70% methane. The biogas and therefore methane production depends on the amount of COD[2] removed by anaerobic treatment.

In theory methane production is 350 L CH_4/kg $COD_{removed}$ resulting in 14 L/(cap · d) at optimum conditions of anaerobic digestion of blackwater in Germany (Wendland, 2009). However, in practice the process conditions are not ideal and thus methane production is often around only 200 L CH_4/kg $COD_{removed}$ (TBW, 1998) and according to Balasubramaniyam et al. (2008), as an indicative value, excreta from either 50-90 humans, 2-3 cows or 7-8 pigs over a 24 hour-period are needed to produce approx. 1 m^3/d of biogas which is enough to cook three meals for a family of 5-6 members.

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[2] COD = chemical oxygen demand, a measure of organic matter content in wastewater

There is no human health risk caused by pathogenic contamination in biogas itself (Vinnerås et al., 2006).

A simple, low-tech and relatively low-cost reactor for the digestion of animal and human manure can be seen in Figure 6 and Figure 7.

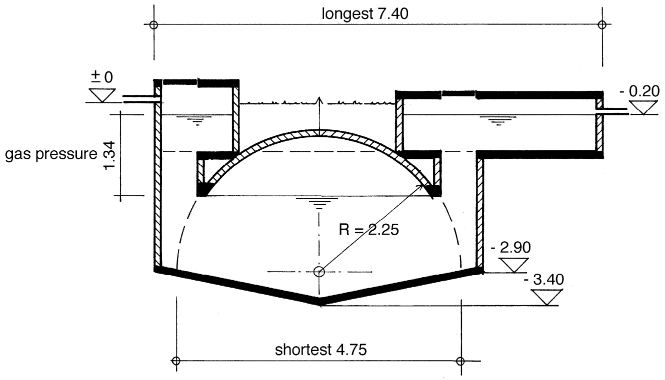

Figure 6: Exemplary cross section of a fully mixed biogas digester (Sasse, 1998)

Figure 7: Fixed dome digester in construction, Lesotho, 2006 (source: Mantopi Lebofa)

For further information on AD and biogas production, please refer to SuSanA's recommended reading section at http://www.susana.org/lang-en/working-groups/wg03/recommended-reading03.

3.1.5 Use of the biogas

Biogas can either directly be burnt in a normal gas stove (Figure 1) or used within a combined heat and power unit (CHP) for electricity generation (Figure 2). In case of the use in a CHP, the biogas must be scrubbed of aggressive sulphur compounds (S). The CHP is equipped with a gas engine for producing electricity and heat. The efficiency is 30% for electricity generation and 60% for heat production which may sum up to a total energy efficiency of 90% in case the excess heat is used on-site. This high efficiency represents the main advantage of a CHP compared to a biogas plant.

3.1.6 Use of the digestate

After the generation of biogas, the residue of anaerobic digestion (called "digestate") still contains all the nutrients and some organic matter. It is therefore suitable for application in agriculture as a fertiliser and soil conditioner. The macronutrients (N, P and K) contained in the substrates remain in the digestate and are mineralized, making them easily available to plants. Carbon compounds are reduced by the digestion process but are still available in the digestate, contributing to raising the soil organic matter content. The digestate has reduced odour emissions, pathogens and weed seeds compared to undigested manure. The use of the digestate as a fertiliser reduces the need for expensive mineral fertilisers.

3.2 Biomass production

3.2.1 Overview

Biomass is a non-fossil energy source which is neither always harmful nor always neutral to the climate. According to the UNFCCC definition (UNFCCC, 2006), renewable biomass is understood as:

- wood (provided that wood harvest does not exceed its growth)
- other wooden biomass (provided that the cultivated area remains constant)
- animal or human manure
- solid organic waste (domestic or industrial)

Both food and biomass production are essential for people's livelihoods, and often compete with each other for available land, water and nutrient resources. Food and biomass production might be seen as equally important in economically rich countries with a safe food supply. But in many developing countries food production takes priority, whilst at the same time most people are dependent on biomass (particularly wood) for their energy supply, primarily to cook their food. One way to establish whether priorities should tend towards either food or biomass production is to carry out a national food balance taking into account food production and food consumption (OECD-FAO, 2008). This can then be used as a basis for making decisions regarding the cultivation of more food or more energy crops. The use of sanitation-derived fertilisers in agriculture may increase the productivity of the land and thus decrease the conflict between food and biomass production at the local level.

If the decision has been made in favour of the cultivation of energy crops, the reuse of domestic wastewater or sewage sludge to irrigate and fertilize energy crops in so-called Short-

Rotation-Plantations (SRP) is a new approach which aims at using the nutrients contained in waste residues for an enhanced biomass growth (Figure 8).

Figure 8: Short-rotation-plantation (SRP), Spain (source: TTZ)

Their name (SRP) is given after plant species which are harvested after short periods (usually between 2-8 years, but also annually in the case of herbaceous plants or grasses). Their cultivation intensity, their high nutrient uptake and the frequent harvests require irrigation and fertilization. By irrigating with wastewater rich in plant-available nutrients, fertiliser costs are zero, plant growth is enhanced, and waste products are subjected to a more sustainable treatment. Further information is available in (TTZ, 2009).

While constructed wetlands (CW) focus mainly on wastewater treatment only and are sealed at their base for groundwater protection, the advantage of SRPs over constructed wetlands lies in the combined wastewater treatment and the production of wooden biomass (as an additional income for farmers). An SRP represents an open-bottom fixed-bed reactor of a construction height of between 1.0 and 1.5 m resulting in an effective reduction of pathogens. In order to avoid nutrient overload, wastewater application has to follow a dosing recommendation depending on the site and plant species and – if built within the European Union – which complies with the EU Nitrates Directive. In addition, the nitrate content has to be measured by soil samples or by sampling from drainage channels.

The following substrates can be applied on SRPs:

- domestic wastewater (which contains nutrients in ratios that are close to the nutrient needs of SRP plants,
- sewage sludge originating from domestic wastewater,
- industrial wastewater from food processing or beverage industries, and
- diverted human urine.

Wastewater is usually applied on SRPs by means of surface irrigation in order to avoid aerosol formation and spread of pathogens by air.

Besides the above-mentioned benefits there are also a number of critical points to consider:

- Groundwater pollution needs to be prevented (from nitrate, pathogens and toxic substances especially if industrial wastewater is applied).
- The increase in soil salinity resulting from the irrigation with wastewater (containing salts like e.g. sodium chloride and hydrocarbonates) might be a problem.

3.2.2 Treatment performance of SRP

With a 10 ha SRP, the wastewater of approx. 6,500 people with a daily discharge of 100 L/person may be biologically treated (corresponding to an area of 15 m^2/pers). The actual treatment takes place in the root system of the trees where bacteria are active. However when the soil freezes, biological activity slows down considerably and there is a need for storage ponds to retain the wastewater during cold periods.

3.2.3 Use of the biomass

The SRP-produced biomass is most commonly used in European countries as wood chips for direct combustion in district heating plants or processed further into wood pellets or briquettes to be used in private households, smaller enterprises or hotels. However, SRP-produced biomass can also be used for a variety of biomass conversion products and processes (i.e. combustion, gasification, hydrolysis, and fermentation) which can produce heat, electrical power, combined heat and power, ethanol or syngas (mixture of carbon monoxide and hydrogen).

4 Conclusions

It has been shown that sustainable sanitation projects can contribute to both mitigate climate change (through energy or nutrient recovery) and to adapt to climate change (through an intelligent water and wastewater management).

Measures of energy recovery (or: renewable energy production) consist basically of either biogas or biomass production while measures of nutrient recovery are primarily based on nitrogen reuse. Water and wastewater management measures aim at coping with either water scarcity or flooding.

Most of these measures lead to GHG emission reductions. In case they were achieved in developing countries, they can be sold on international emission allowances markets and thus contribute to an additional financial benefit. In order to be financially viable, the minimum project scale must not be lower than 25,000 PE which however can be achieved by project bundling.

References

- Balasubramaniyam U., Meriggi N., Zisengwe L., Buysman E. (2008) Biogas production in climates with long cold winters. Feasibility study, Wageningen University. http://wecf.eu/download/2008/Biogascoldclimates_WEB-WECF0608.pdf.
- Elmitwalli T.A. (2000) Anaerobic treatment of domestic sewage at low temperature. PhD thesis at Wageningen University.
- Elmitwalli T.A., Shalabi M., Wendland C., Otterpohl R. (2007) Greywater treatment in UASB reactor at ambient temperature. Water Science and Technology, 55 (7), pp. 173-180.
- Gellings C.W., Parmenter K.E. (2004) Energy efficiency in fertiliser production and use. In: Efficient Use and Conservation of Energy, Chap. 3 and Fig. 1. Encyclopedia of Life Support Systems. EOLSS Publishers, Oxford, UK. http://www.eolss.net/ebooks/Sample%20Chapters/C08/E3-18-04-03.pdf.
- GFA (2009) PoA CDM Manual "Mini Biogas Plants for Households". http://www.cd4cdm.org/Publications/PoAManualBiogasHouseholds.pdf
- IPCC (2007a) Climate Change 2007 – The Physical Science Basis. Intergovernmental Panel on Climate Change, Contribution of Working Group I to the IPCC Fourth Assessment Report, Summary for Policymakers. Geneva, Switzerland. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf.
- IPCC (2007b) Climate Change 2007 – Impacts, Adaptation and Vulnerability. Intergovernmental Panel on Climate Change, Contribution of Working Group II to the IPCC Fourth Assessment Report, Summary for Policymakers. Geneva, Switzerland. http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-spm.pdf.
- IPCC (2007c) Climate Change 2007 – Mitigation of Climate Change. Intergovernmental Panel on Climate Change, Contribution of Working Group III to the IPCC Fourth Assessment Report, Summary for Policymakers. Geneva, Switzerland. http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-spm.pdf.
- Mang H.P., Jurga I. (2005) Biogas sanitation systems. Presentation on the International Conference on ecosan, Bangalore, India. http://www.susana.org/images/documents/05-working-groups/wg03/recommended-reading/mang-jurga-biogas-sanitation-systems.pdf
- Maurer M., Schwegler P., Larsen T.A. (2003) Nutrients in urine: Energetic aspects of removal and recovery. Water Science and Technology, 48 (1), p. 37-46. Abstract: http://www2.gtz.de/Dokumente/oe44/ecosan/en-ABSTRACT-ONLY-nutrients-in-urine-energetic-aspects-of-removal-and-2003.pdf.
- Olt C. (2008) Emissionshandel für kreislaufwirtschaftsorientierte Sanitärkonzepte in Entwicklungsländern. MSc thesis (in German), Bauhaus University of Weimar, Civil Engineering Dept., Germany. http://www.susana.org/index.php/lang-en/working-groups/wg03/recommended-reading03.
- OECD-FAO (2008) Agricultural Outlook 2008-2017, by variable. (Click on "Agriculture and Fisheries", "Agricultural Outlook", then "OECD-FAO Agricultural Outlook 2008-2017, by variable". Select country and commodity and compare production and consumption values.) http://stats.oecd.org/wbos/Index.aspx?usercontext=sourceoecd.
- Remy C., Ruhland A., Jekel M. (2006) Ecological assessment of alternative sanitation concepts with Life Cycle Assessment. Final report for task 5 of the EU demonstration project "Sanitation Concepts for Separate Treatment of Urine, Faeces and Greywater" (SCST). Kompetenzzentrum Wasser (ed.), Berlin. http://www.kompetenz-wasser.de/SCST-Downloads.295.0.html.
- Sasse L. (1988) DEWATS - Decentralised Wastewater Treatment in Developing Countries. BORDA, Bremen (Germany). http://www.borda-net.org/modules/wfdownloads/uploads/062%20BORDA_Dewats-Handbook.pdf.
- Singh S. Haberla R., Moogb O., Shresthac R.R., Shresthad P., Shrestha R. (2009) Performance of an anaerobic baffled reactor and hybrid constructed wetland treating high-strength wastewater in Nepal – A model for DEWATS. Ecological Engineering, 35 (5), pp. 654-660.
- SuSanA (2008) Food security and productive sanitation systems. Sustainable Sanitation Alliance, Fact sheet of working group 05. http://www.susana.org/images/documents/05-working-groups/wg05/en-wg5-factsheet-2008-05-28.pdf.
- TBW naturgerechte Technologien, Bau- und Wirtschaftsberatung GmbH (1998) Förderung der Anaerobtechnologie zur Behandlung kommunaler und industrieller Abwässer und Abfälle. Deutsche Gesellschaft für Technische Zusammenarbeit GmbH (ed.), Eschborn, Germany (in German). http://www2.gtz.de/Dokumente/oe44/ecosan/de-anaerobtechnologie-1998.pdf.
- Tidåker P., Mattsson B., Jönsson, H. (2007) Environmental impact of wheat production using human urine and mineral fertilisers - a scenario study. Journal of Cleaner Production, 15 (1), pp. 52-62.
- TTZ (2009) Website of the Technology Transfer Centre, Bremerhaven, Germany. http://www.ttz-bremerhaven.de/english/.
- UNFCCC (2006) Definition of renewable biomass. United Nations Framework Convention on Climate Change, CDM Executive Board 23 report, Annex 18. http://cdm.unfccc.int/EB/023/eb23_repan18.pdf.
- UNFCCC (2009) Website of the United Nations Framework Convention on Climate Change: http://cdm.unfccc.int/ProgrammeOfActivities.
- van Haandel A.C., Lettinga G. (1994) Anaerobic sewage treatment. Chichester: John Wiley & Sons.
- Vinnerås B., Schönning C., Nordin A. (2006) Identification of the microbiological community in biogas systems and evaluation of microbial risks from gas usage, Science of the total environment, 367 (2-3), pp. 606-615.
- Wendland C. (2009) Anaerobic digestion of blackwater and kitchen refuse. PhD thesis, Hamburg University of Technology, Institute of Wastewater Management and Water Protection, Germany. http://doku.b.tu-harburg.de/volltexte/2009/553/.
- WHO (2006) Guidelines for the safe use of wastewater, excreta and greywater. World Health Organization. http://www.who.int/water_sanitation_health/wastewater/gsuww/en/index.html.
- Zeeman G., Kujawa-Roelefeld K., Meulman B., Kwant F. (2007) Full scale demonstration of vacuum collection, transport and treatment of blackwater. Proceedings, Advanced Sanitation conference, 12 - 13 March 2007, Aachen, Germany.

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- Lo, Dexter – Xavier University, Philippines
- Olt, Christian – German Technical Cooperation (GTZ), Germany
- Platzer, Christoph – Rotaria del Perú, Peru
- Reuter, Stefan – Bremen Overseas Research and Development Agency (BORDA), Germany
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