Biogas Systems in Lesotho: an effective way to generate energy while sanitizing wastewater

TED
Technologies for Economic Development

In Maseru, Lesotho, the Non-Governmental Organization TED constructs biogas systems for decentralized wastewater treatment (BiogasDEWATS) since 2003 in households, schools, orphanages and military camps, improving food security through the re-use of plant nutrients in the treated water by irrigation.

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Abstract

This article describes Biogas as a decentralized wastewater treatment system implemented in Lesotho, where in 2002 a group of technicians, with strong interest in the link between environmental protection and human well-being, started to implement household biogas digesters for sanitation purposes in peri-urban settlements of the capital Maseru. The demand for the technology is created by problems with overflowing or leaking septic tanks and high-priced drinking water commonly used for irrigation. No subsidy is provided, thus owners pay the real cost for the systems. Although the investment cost for BiogasDEWATS is a little higher than for a conventional septic tank, the operation costs are significantly lower, plus it pays for itself in only three years. Biogas generated in these systems substitutes at least 15% of the daily required cooking fuel.

Introduction

The Kingdom of Lesotho (Figure 1):

- country with the highest lowest point above sea level in the world
- 30‘000 km^2 – all above 1‘400m above sea level; 80 % above 1‘800 m
- 28° - 31°S latitude and 27° - 30°E longitude
- completely surrounded by South Africa
- about 2 million people, the Basotho
- majority of households subsist on farming or migrant labor
- annual urbanization rate of 5.2 % (Maseru City Council, April 2011) due to droughts and floods – generally related to global climate change – that impact on agricultural yields and livestock herding
- level of urbanization: 23 % (2002 Survey, National Bureau of Statistics)
- exports diamonds, mohair, jeans, footwear
- water sold to South Africa through the multi-billion-dollar Lesotho Highlands Water Project (LHWP), which commenced in 1986
- is identified as one of the most vulnerable countries to climate change worldwide (Lesotho-Africa Adaptation Programme 2009).

Key Facts:

- Since 2003, TED designs systems according to the number of residents, mostly from 4 to 30 people (although sometimes even up to 300).
- Sizes of Biogas Digesters built so far range between 5 and 50m^3.
- Systems are constructed on site in brickwork (not pre-fabricated).
- Masons and craftsmen are trained by TED in skills and responsibilities for quality labor.
- System components include (1) fixed dome Biogas Digester (BD), (2) Anaerobic Baffled Reactor (ABR), (3) often combined with integrated Anaerobic Filter (AF), and (4) Planted Gravel Filter (PGF).
- Treated water is used for irrigation in the owners’ gardens, according to their preferences.
- Owners are trained by TED to understand and correctly maintain their systems.

Sanitation challenges and the MDGs:

- Improved sanitation coverage in 2008: 25 % in rural and 40 % in urban areas (WHO/UNICEF Joint Monitoring Report (JMP) 2010)
- If shared facilities were assumed to provide safe, convenient access to sanitation, then a further 35 % of the urban population would be covered, and Lesotho would be close to achieving the MDG sanitation target of 81 % in urban areas.
- Most of the sanitation facilities used are simple pit or unsealed VIP structures – even in middle-income households, as people do not know about other alternatives

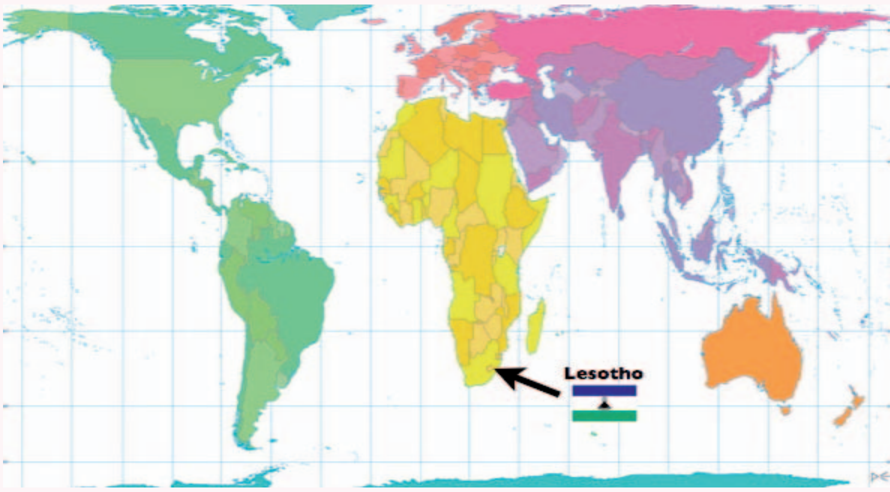

Figure 1: Location of Lesotho

Why Biogas Sanitation in Lesotho?

"Lesotho has water as its most important natural resource, second to her people. The ownership of all water within Lesotho is vested in the Basotho Nation. The Government of Lesotho has the duty to ensure that this resource is used in a sustainable manner and to the benefit of all users, and the responsibility to provide security of access to water sources and improved sanitation." (Lesotho Water and Sanitation Policy, Ministry of Natural Resources, 2007). Statistics may show an encouraging trend with regards to water coverage, but sanitation coverage is still far below the target. Based on the most recent data, from 2008, Lesotho has seven years to raise sanitation coverage from 40% to 81% in urban areas and from 25% to 66% in rural areas.

In 2007, diarrhoea and gastroenteritis were responsible for 14% of deaths of children under 13 years of age. They also accounted for 3% and 5% of deaths of men and women, respectively, in the same year (Ministry of Health and Social Welfare, Annual Joint Review Report, 2009).

Experience shows that it is hard to keep water and sanitation infrastructure functional, as it often fails before its planned lifetime, thus being a massive waste of investment. Water supply projects in rural and peri-urban areas are usually implemented in isolation, ignoring important links with sanitation, health and education. Children's education is directly influenced by the quality of water and sanitation facilities in schools, since low quality water supply and dark, dirty facilities do not promote a healthy learning environment.

In addition, people moving to one of the 11 urban centers in the country rarely find complete infrastructure provided by the city administration. While piped water supply is often available, centralized sewer systems do not, and will not, reach the new settlement areas within the next decades. The mountainous topography of the country, with steep slopes and rocky soils, impedes "business as usual" in wastewater collection and treatment. In Maseru, the connection rate to sewer lines is only about 4% (Water and Sewerage Company (WASCO), April 2011). A decentralized, privately financed and maintained wastewater handling system seems necessary.

TED's decentralized biogas sanitation system

Technologies for Economic Development - TED

TED is a Lesotho-based, non-profit, non-governmental organization, founded and registered in 2004 (Registration No. 2004/90). It began as the Biogas Technicians' Self-Help Group, which was established in 2003 by Basotho technicians who wanted to make sure that the environment, especially the trees and the ground water, are protected. They identified biogas digesters as a reliable technology for decentralized wastewater treatment and cooking gas production to tackle many of the most pressing problems faced by the people of Lesotho, like health, food, water, energy, environment and employment.

Since 2003, the primary focus has always been the engineering and fine-tuning of appropriate technologies (such as biogas systems, UDDTs, efficient wood stoves) to foster their long-term adoption by the Basotho. The NGO contributes to international knowledge sharing through consultancy work and lectures at national and international Universities since 2005, and in 2006 TED started cooperation with BORDA (Bremen Overseas Research and Development Organization), a German NGO specialized in community-based Decentralized Wastewater Treatment Systems (DEWATS).

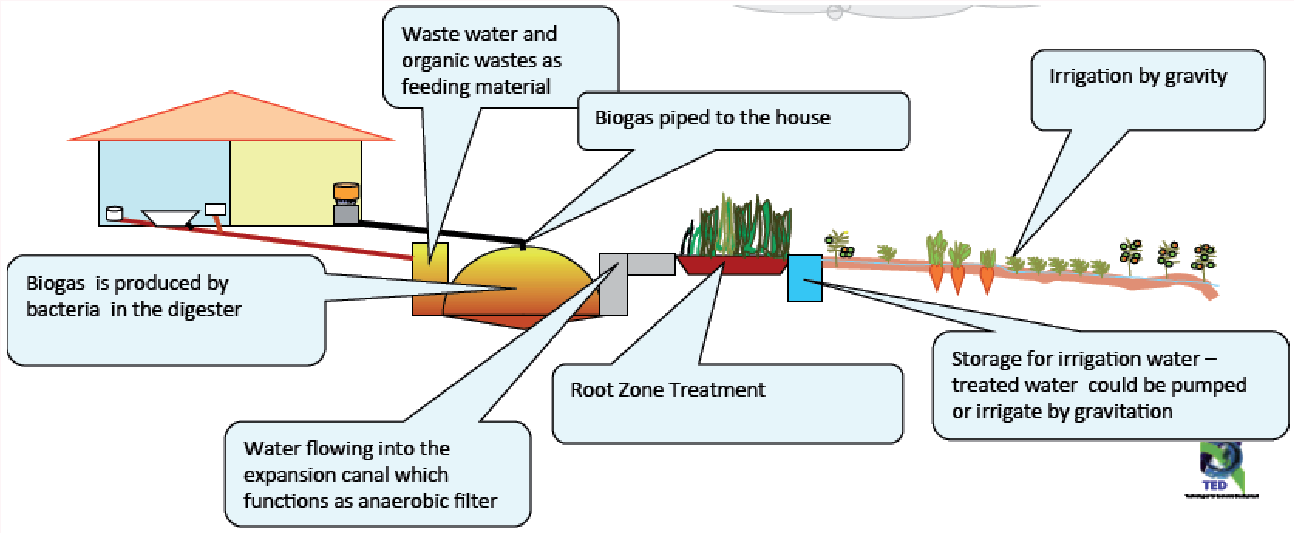

Figure 2: Original TED design for biogas sanitation

In 2007, TED started working under a seven-year agreement brokered by the Programme for Basic Energy and Conservation (ProBEC) and Climate Care Trust Ltd to roll out, in alliance with the World Food Programme, an efficient wood stove project, financed on the international carbon trading market. The initiative aims to minimize wood fuel gas emissions; Pioneer Carbon Ltd (PCL), a UK registered company, handles the carbon verification process and ensures the procedures for obtaining carbon credits.

Aiming at long-term sustainability of sanitation systems, TED applied for and was appointed, in 2010, the Country Coordinator of the WASH United Campaign that uses sports (mainly football, rugby and other ball sports) and celebrities to promote Hand Washing with Soap, and water and sanitation as a human right.

Technology details

The original TED Biogas Digester design is displayed in Figure 2, which is also used to explain the system to clients.

Solids settle at the bottom of the digester where bacteria feed on them, and convert any organic matter into gas and liquid. Thus, over time any organic solids are decomposed. Therefore education of system users not to throw plastic, sand, gravel into the digester is crucial. The same applies for water consumption: system owners are trained to control their water consumption in flush toilets and bathrooms, as highly diluted wastewater does not enhance biogas production.

TED has constructed over 150 systems since 2004. However, about 300 Biogas systems are known in Lesotho, due to the fact that several trainees and laborers left TED, after some weeks of experience, and set up their own similar business. In a large number of cases, their systems are not performing properly, due to problems in the quality of craftsmanship, lack of understanding of the biological processes taking place in the system, or simply having based the faulty construction on copied plans without knowing the engineering details. If the owners show up in TED's office asking for help TED offers support; however, to repair these systems – once constructed with wrong levels of inlet, outlet and overflow - is not possible in most of the cases. Nevertheless, TED intervenes to pamper the negative effects for the owners, and thus avoid a bad reputation for this technology.

The TED Biogas Digester is an underground, dome-shaped structure with an inlet and an outlet, which was adapted, and further developed, from Chinese, Tanzanian and Ethiopian models. At the inlet – without any additional stirring device, organic wastes from humans, animals or plants enter the digester, where solids settle and are converted into biogas. The air-tight, waxed dome made of bricks captures and pressurizes the biogas, and stable biogas production may be expected three to five months after wastewater starts flowing into the system, depending on its organic content.

Figure 3: Approaching the final stage of construction: biogas digester and anaerobic baffled reactor before being covered with soil and installation of planted gravel filter will start

From its first design, the TED biogas sanitation system was always connected to an Anaerobic Filter as a second treatment step and a constructed wetland for a third treatment, before using the effluent for irrigation in order to recycle the contained plant nutrients.

Since 2006, entering in cooperation with the DEWATS specialized German NGO BORDA (Bremen Overseas Research and Development Association), TED included an Anaerobic Baffled Reactor (ABR) as the second treatment step: an ABR is a biological treatment system where the almost solid-free effluent from the biogas digester passes through a series of chambers, leading to the formation of stabilized bio-sludge sediments at the bottom of mainly the first chambers. The size of the chambers depends on the sewage flow rate, such that the up-flow velocity of the water is less than the settling velocity of the solids. Figure 4 provides a sketch of an ABR displaying how the wastewater flows through this treatment step. In this sketch, the first chamber functions as settler and is equipped with a gas outlet. In the most common TED Design, the biogas digester replaces this first chamber.

In TED's design, the also mostly underground constructed ABR integrates an Anaerobic Filter (AF), shown in Figure 5. Like in the Baffled Reactor the water passes the filter vertically from the bottom to the top. The chambers are filled with filter material like stones, gravel or recycled and cut plastic bottles; these surfaces are proven to offer living space for bacteria dedicated to absorb organic particles.

The Planted Gravel Filter (PGF) is filled with gravel or with recycled pumice stones from Maseru-based jeans factories, and planted with aquatic plants. The PGF performs the final treatment to the effluent before its reuse in irrigation: biological conversion, physical filtration and chemical adsorption by gravel or pumice stones and absorption by plant roots take place in the PGF. The water is purified as is flows horizontally and slowly through the filter material. The plants provide a nice appearance to the whole system.

TED does the first planting in the PGF as soon as water accumulates in the third treatment step. Only locally available aquatic plants from riverbanks and wetlands are planted. As experience show that they will grow very fast in their new environment due to the offer of plant nutrients in the treated wastewater, planting starts with only few plants distributed in the PGF. Owners take over responsibility for maintaining the plant cover adding real flowers, even roses, to the wetland plants.

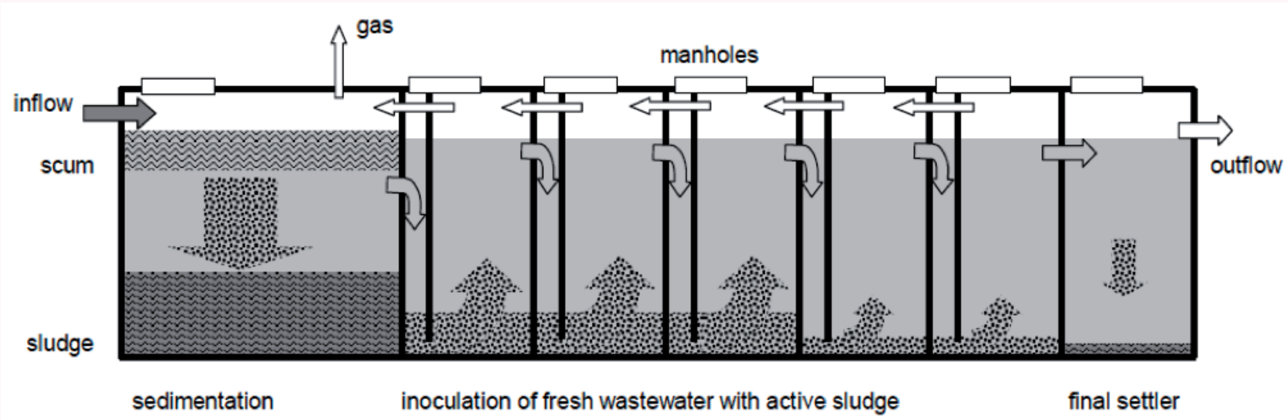

Figure 4: Wastewater flow through an ABR TED BORDA 2006

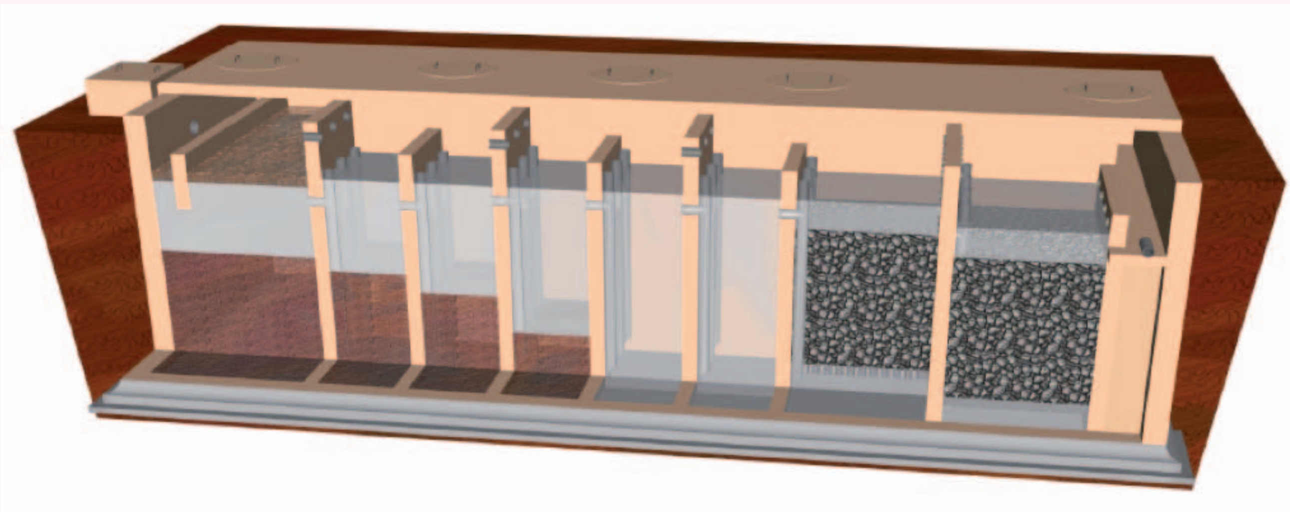

Figure 5: Example of an underground ABR with integrated Anaerobic Filter as last chambers before the treated wastewater overflows into a planted gravel filter TED BORDA 2006

The effluent water is tested ever since, often carried out as research work by international students; no harmful substances or pathogens have been detected so far. However, TED recommends to the system owners to stick strictly to soil and root irrigation.

Figure 6: Nice-looking on-site wastewater treatment: treated water at a PGF with recycled pumice stones shortly after system start (left) and PGF after 3 years of operation

Sustainability factors

Social and cultural sustainability

Hygiene awareness, health and nutrition aspects and community and family participation are key aspects for TED to achieve social and cultural sustainability of sanitation technology in general and the installed Biogas DEWATS systems in each specific case. This is enhanced by the strong involvement of the homeowners in the decision on where to place the treatment system for the household's wastewater and the choice of re-use options. Also, wherever possible, already existing septic tanks and sanitation facilities are integrated into the new design of the treatment system. Due to these close and personal relations with its clients, TED's promotion strategy relies on "word of mouth" and clients' testimonies to other interested households.

In cases where communities (such as villages, schools, orphanages) ask for upgraded sanitation systems, TED informs the communities about different options, including Urine-diverting Dry Toilets (UDDTs). Urine diversion technologies and BiogasDEWATS may also be successfully combined.

Working closely with local partners, TED spreads the message about the importance of sanitation, hygiene and water for human well-being to different groups via various educational materials. Local authorities, civil society organizations, and the media form part of this still informal sanitation network that TED is creating in Lesotho.

Economic and financial sustainability

"Social Marketing Principles" are adapted to sanitation requirements and TED's strategy is based on three pillars: (1) stimulating demand, (2) private sector involvement in supply chain, i.e. construction material is purchased only on the local market, and (3) social status.

BiogasDEWATS has several "unique selling points", as a real alternative to the conventional septic tank. Price comparison between conventional on-site waterborne sanitation systems and BiogasDEWATS results currently in lower investment costs for the conventional system, but in significantly lower operational costs for BiogasDEWATS. The example of a Bill of Quantity and quotation given in Table 1 relates to a 6 m^3 biogas digester with corresponding ABR, AF and PGF; the total cost for "construction and supervision" depends on the size of the system and the distance between the construction

Figure 7: Before and after the installation of BiogasDEWATS

Table 1: Bill of Quantity in 2011 for 6m³ BiogasDEWATS installation

Material	Unit	Quantity	Supplied by	Unit Price (Maluti)	Total Price (Maluti)
Ordinary portland cement 50kg	bags	50	Client		
Plastering sand	m^3	3	Client		
Rough sand	m^3	4	Client		
Course aggregates (19 mm)	m^3	3	Client		
Burned bricks grade 2, 220x110x70mm	Items	2000	Client		
Concrete blocks 4“	Items	400	Client		
Water proofer	bags	10	TED	40,00	400,00
Chicken mesh (15x1200x25) (60m^2)	m^2 /roll	1	Client		
Lintels (105/0,9m)	Items	2	Client		
Manhole covers 450x600mm	Items	2	Client		
Manhole covers 300x300mm	Items	1	Client		
4“ (110mm) PVC pipe	m	5	Client		
4“ (110mm) t-junctions	Items	16	TED	70,00	1.120,00
4“ (110mm) elbow joints	Items	6	TED	45,00	270,00
Pipe Cover (110mm) female	Items	20	TED	30,00	600,00
Filter material	m^3	2	TED	300,00	600,00
100l drum	No.	1	TED	180,00	180,00
Water for construction	m^3	31			
Wax and oil	Items	1	TED	150,00	150,00
Gas connection set	Items	1	TED	200,00	200,00
Galvanized pipe 4/3“	m		later/Client		
Water trap galvanized	Items	1	later/Client		
Electrical pump	Items	1	later/Client		
Biogas stove	Items		later/Client		
Subtotal Material					3.520,00
Labour					
Earthwork including landscaping (We request Client to do this, we will supervise)					1.500,00
Contruction and supervision					9.800,00
Subtotal Labour					10.400,00
Total					13.920,00

site and TED’s office. In September 2011, it equals to USD 1,850 and is paid by the clients in three quotas.

Given the specific geophysical context of Maseru and its growth rate into peri-urban mountainous areas, the connection to centralized sewer lines and wastewater treatment plants is for most of TED’s clients just not possible.

Wastewater naturally produces biogas and the treated effluent that still contains plant nutrients is reused in the garden.

- Owners save money because they do not have to call a truck to empty the septic tank. They can use daily biogas for cooking: at least 15% of the cooking fuel (electricity, LP gas or fire wood) could be substituted by biogas, some households replace up to 100% of their cooking fuel during summer time.

- They can use the water for irrigation, thus reducing the fresh water bill. The money saved within a reasonable time (some owners calculate a maximum of three years for amortization) can be used for further investments to develop the local economy.

The costs for a biogas digester and related wastewater treatment steps are divided into production costs, running costs and capital costs:

Production costs depend on the size of the BiogasDEWATS and the prices of materials and labor; they include all expenses necessary for building the system (e.g. land, excavation work, construction, piping and gas utilization system).

Running costs include: the feeding and operating of the system; supervision, maintenance and repairs; storage, re-use and/or disposal of the effluent; gas distribution; and administration. TED's BiogasDEWATS in general have very low running costs, as the feeding happens by gravity, and maintenance required is very low, due to strict quality control during construction. In some cases, where the treated water cannot flow by gravity to the gardens being irrigated, electrical pumps are used.

Capital costs consist of pay back and interest for the capital taken up to finance the installation. Many customers provide building materials to cut costs, therefore only a few have to borrow money. In calculating the depreciation, the economic life span of BiogasDEWATS can be taken as 15 years, provided maintenance and repairs are carried out regularly and as needed (Renwick et al., 2007). This life span is understood as an international average and depends on the quality of the construction, regular feeding, gas use and maintenance of gas pipes and system parts that are above ground.

TED's clients have various problems and therefore various reasons why they want to install a BiogasDEWATS in their premises. The money saved by using "waste" as energy source and ferti-irrigation needs to be calculated for each specific case.

Environmental sustainability

BiogasDEWATS installed by TED fit into a local, ecologically sustainable cycle:

- Natural processes take place in the BiogasDEWATS
- Anaerobic digestion improves the fertilizer quality of human and animal waste by converting the contained plant nutrients into liquid form and therefore more easily accessible for plants
- The system avoids pollution of sub surface and groundwater by treating wastewater to manure up to required standards
- Using biogas instead of firewood or fossil fuels reduces greenhouse gas emissions, especially since the methane of biogas would otherwise be a greenhouse gas itself.
- As the system is mostly constructed underground, the landscape is not negatively affected.

Technical sustainability

In order to assure technical sustainability and continuous updating of technical staff, TED applies the following approaches:

1. Integration into worldwide networks and cooperation with research partners, like BORDA and the University of Science & Technology Beijing – Centre for Sustainable Environmental Sanitation (USTB-CSES),

2. Collaboration with other partners to integrate the technology into a broader environmental sanitation concept and "Service Packages". This includes school sanitation, community-based sanitation, and sanitation systems for hospitals, hotels and tourism resorts, military camps, and agricultural enterprises.

3. Inclusion of applied research into implementation. Research & Development include topics like sanitation and renewable energies, sustainable environmental sanitation, and energy from agriculture and livestock. Monitoring of system performance and data evaluation by academic partners support R&D. TED offers future-oriented researchers to gain experience in reuse-oriented wastewater treatment, even though this topic is not yet included in the curriculum of the National University Lesotho or technical colleges.

Figure 8: Underground BiogasDEWATS: beautifying the compound with flowers in the PGF and treated water always available for ferti-irrigation of lawn and bushes

4. Training of home owners and operators, and the offering of after-sales services. During the first 12 months after construction, TED provides training to the owners and operators (in the case of schools or enterprises), in order to familiarize the responsible

person with all relevant details for successfully maintaining a wastewater treatment process for biogas production and irrigation water re-use. Understanding that BiogasDEWATS functions due to a well-maintained biology of micro-organisms minimizes requests for maintenance support as the owner will maintain survival of the micro-organisms.

Lessons learned for implementation

TED's experience and "success story" so far shows that there are acceptable, affordable and ecologically safe sanitation technologies already installed in peri-urban settlements in Lesotho. The fact that TED is implementing BiogasDEWATS without subsidies indicates clearly that a sanitation market is viable, as customers pay fully for the systems.
Sanitizing wastewater on-site, making it fit for irrigation, saving valuable drinking water and encouraging home gardening, especially in a country with high incidence of HIV/AIDS, where it helps to improve the living conditions of the population. Turning organic waste into biogas for cooking is an important measure for mitigating and adapting to Global Climate Disruption.

Challenges & Lessons Learned

Challenges encountered and relevant for the way forward refer to craftsmanship quality, expertise in BiogasDEWATS construction, ownership and the means of coping with the increasing demand. TED's way of dealing with these challenges is and was always developed in a very pragmatic manner, due to its characteristics as a small non-profit organization in a country with an endless number of constraints and limitations. The following overview should be read as an outline for "lessons learned" on how to up-scale implementation of "Biogas for Sanitation" purposes.

i. Craftsmanship Quality: continuous quality control of construction staff, in-house training and a quality management system.

ii. Expertise in construction: TED's national construction team carries out standardized constructions up to 50 m^3; only for very special situations international cooperation partners provide short-term engineering consultancy, paid for by TED.

iii. Ownership: BiogasDEWATS sponsored by a third party suffer increased system performance problems, due to the lack of responsibility and ownership; this is often observed at community-based systems. TED developed a user training principle that includes not only the technically responsible person but also the person who will benefit most from a well-functioning BiogasDEWATS, like the cook in a school or orphanage.

iv. Increasing demand: this may only be answered by an increasing number of skilled and responsible BiogasDEWATS constructors. Therefore TED applied for funds to train five masons, and received financial support in 2010 from Levi Strauss Foundation to this aim. Today, the trainees are integrated into the construction team.

v. International cooperation as partners is giving and receiving: partners are learning from TED's experiences, and TED is learning by being actively integrated into international networks.

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