sustainable
sanitation
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SuSanA factsheet

Links between sanitation, climate change and renewable energies

April 2012

1 Summary

Sustainable sanitation projects can contribute to both climate change mitigation (through energy or nutrient recovery) and to climate change adaptation (through innovative sanitation systems and wastewater management).

Measures of renewable energy production consist basically of either biogas production from waste water or biomass production through the use of waste water to grow short rotation plantations for firewood. Biogas can also be used for heat generation while heat exchangers can recover heat energy from wastewater in sewers. Measures of nutrient recovery are primarily based on nitrogen reuse. Adaptation measures in the area of sanitation aim at coping with increasing water scarcity or flooding.

By using 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 cases where these measures for reduction of greenhouse gases are achieved in developing countries, the emission allowances can be sold on the international emissions trading market and thus can contribute additional financial benefits. In order to be financially viable, there is a minimum project scale due to fixed transaction costs, with project bundling the minimum scale can be achieved.

This factsheet emphasises the need for climate change mitigation and adaptation measures in the area of sanitation. In addition, it provides an overview of the possibilities of using sanitation systems for renewable energy production, nutrient recovery and it explains the financial benefits that emission trading can bring.

2 Introduction

2.1 Overview

UNFCCC[1] defines ‘Climate change’ as a “change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods”. Some of the major climate change effects that have been predicted are the significant rise in temperature due to greenhouse gases, rising sea level and shifts in precipitation and evapotranspiration patterns (IPCC, 2007a). By 2050, the number of countries facing water stress or scarcity could rise from 48 to 54, with a combined population of four billion people i.e. about 40% of the projected global population of 9.4 billion[2].

Increasing water scarcity combined with increased food demand and water use for irrigation as a result of less precipitation are likely to be a driving force leading to water reuse. Areas with low sanitation coverage might be found to be practising more uncontrolled water reuse i.e. reuse performed using polluted water or even wastewater (Bates et al. 2008).

Sustainable sanitation has a strong link to climate change and renewable energy production. For example, sanitation systems can be designed in a way to produce renewable energy sources (biogas or biomass) 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.

Figure 1: Urine Diversion Dehydration Toilets (UDDT) withstood the flood waters that resulted from a cyclone that struck southern Bangladesh in 2009 (source: A. Delepiere). More photos from this project: www.flickr.com/photos/gtzecosan/sets/72157626407064863/

Another example is dry toilets such as Urine Diversion Dehydrating Toilets (UDDT) with a raised platform and safe containment of excreta and which use no water for flushing (suitable for areas with increasing water scarcity) or which

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[1] UNFCCC – United Nations Framework Convention on Climate Change, www.unfccc.int

[2] See: www.maps.grida.no/go/graphic/increased-global-water-stress

can still function during flooding events. UDDTs are potentially resilient to all expected negative climate change impacts while water born systems (flush toilets and sewers) are more vulnerable to different climate change scenarios (WHO and DFID 2009)[3].

2.2 Greenhouse effect and contributing gases

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

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

2.3 Relevant greenhouse gases

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

- *Methane* (CH_4) is a potent greenhouse gas with a global warming potential 25 times higher than that of carbon dioxide (CO_2) in a 100 year perspective (IPCC/TEAP, 2005*)*. 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 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.
  While combustion of biogas produces CO_2, a greenhouse gas (see below), the carbon in biogas comes from solid or liquid biomass that has fixed carbon from atmospheric CO_2. Thus, biogas usage is carbon-neutral and does not add to greenhouse gas emissions.
- *Carbon dioxide* (CO_2) is produced as a result of combustion of any fossil or biomass fuel. However, CO_2 from biomass combustion does not contribute to global warming as it originates from the atmosphere; it is a step in the organic carbon cycle. In sanitation, CO_2 emissions occur whenever fossil energy is used, as fossil fuel-based electricity. The treatment of wastewater for removal of organic matter 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.
- *Nitrous oxide* (N_2O) is a strong greenhouse gas with a global warming potential 298 times higher than that of CO_2 in a 100 year perspective (IPCC/TEAP, 2005*)*. 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 in excreta or wastewater can be recovered and reused as a fertiliser to save energy.

3 Climate change mitigation and adaption potential of sanitation

3.1 Mitigation measures

3.1.1 Energy recovery

Sanitation systems can be designed and operated to produce renewable energy in the forms of either biogas or biomass and thus reduce primary energy consumption (see Section 4 for details). Small scale biogas systems can generate enough biogas to cook main family meals and thus replace part of the traditional used cooking fuels. It should, however, be kept in mind that particularly in small systems the organic load from human excreta alone is in most cases not high enough for the economical usage of biogas for cooking, lighting or heating but still beneficial. Much more biogas is produced if animal excreta, organic solid waste (e.g. from kitchens and/or markets), or agricultural waste is co-digested as well.

Figure 2: Biogas stove at Cachoire Girls High school, Kiambu, Kagwe District, Kenya (source: S. Blume, 2009). More photos about this project: www.flickr.com/photos/gtzecosan/collections/72157616752316076

Biogas can also be used for combined heat and electricity generation by means of a combined heat and power (CHP) plant. This can substitute the use of fossil or non-renewable energy sources.

Another possible energy recovery method is the recovery of heat from wastewater especially in cold countries where the wastewater temperature is higher than the ambient temperature. Warm greywater from showers, wash basins and sinks (with temperatures of up to 35℃) usually flows directly into the sewage system. The energy contained in the greywater can however be effectively recovered by means of heat exchangers installed inside or close to the house. Conversely, most of the thermal energy in the wastewater is lost in the sewer. Depending on climate,

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[3] WSSCC working group on WASH and climate change www.wsscc.org/topics/hot-topics/climate-change-and-wash

region and season wastewater temperature can go down below 12℃ making it much more difficult and insufficient for energy recovering. Similarly, a large amount of warm wastewater is also produced in industries, hospitals, swimming pools etc., which could also be harvested and used efficiently for preheating cold water.

3.1.2 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. Hence, a substitution to the manufactured mineral fertilisers with their associated energy intensive production and transport over long distances. Further information on the safe use of excreta in agriculture can be found in WHO (2006) and Gensch et al. (2012).

Figure 3: Urine application in agriculture, in Ouagadougou, Burkina Faso (source: S. Tapsoba, 2009). For more information on this project see the SuSanA case study: www.susana.org/lang-en/case-studies?view=ccbktypeitem&type=2&id=84

Nitrogen fertilisers require more energy (Remy and Ruhland, 2006) and are consumed in larger amounts than P- and K-fertilisers (Gellings and Parmenter, 2004). Since 87% of the excreted nitrogen is contained in urine, concentrating on the recovery and reuse of the nitrogen contained in urine represents a possible means of emission reduction through nutrient recovery.

A life cycle analysis 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). Compared to a conventional wastewater treatment system, the use of reuse-oriented sanitation systems can lead to energy savings (e.g. due to smaller sewer networks and treatment plants). However, when reuse-oriented sanitation systems are dependent on road-based transportation of excreta or sludge, they are also associated with energy consumption. Thus, while comparing reuse-oriented with conventional sanitation systems, a careful analysis of the different systems from an energy perspective is necessary.

The emission reduction potential through energy recovery (biogas) and nutrient recovery (urine) was analysed for a case study in India (Olt, 2008). For nutrient recovery it was calculated as 23 kg CO_2/person/year resulting mainly from savings in energy consumption for the production and transportation of mineral fertiliser, savings in 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 as pumps were used to pump flush water to overhead storage tanks from the wells. Therefore, the above indicated value of emission reduction through nutrient recovery can be regarded as a lower value.

Source separation of urine and subsequent use of urine as fertiliser reduced the climate impact by 33 kg CO_2/person/year in a scenario study evaluated with life cycle assessment methodology, where wheat production in Sweden with urine as fertiliser was compared to conventional mineral fertiliser 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 safe application of excreta-based fertilisers (urine, faecal or wastewater sludge, dried faeces) as far as possible.

3.2 Adaptation measures in the area of sanitation

Adaptation to climate change ensures that sanitation systems can in the future - with a potentially different climate - still deliver services and maintain safe hygiene practices to prevent the spread of diseases.

Adaptation measures include the planning for preparedness, prevention, protection, and response (relief and rehabilitation). Risk management and adaptation planning aims to develop different strategies based on the different scenarios, by choosing technologies that are resilient to the expected scenarios, by adapting operation and management of existing services, and by taking into consideration socio-economic factors. Furthermore, it is also advisable to separate the preparedness for extreme events and adaptation measurements from expected perpetual challenges.

Figure 4: Tanker supplying water to low-income areas in Lima, Peru (source: H. Hoffmann, 2010). Climate change will aggravate the existing water scarcity problems in Lima due to melting and

disappearing of glaciers in the Andes – which is currently the source of water supply for Lima. More photos showing water scarcity in Lima: www.flickr.com/photos/gtzecosan/sets/72157629511631340/

Climate change proofing measures involve households, communities, service providers and governments alike, and some examples are given below.

3.2.1 Adaptation to increased occurrence of droughts and increasing water scarcity

In order to adapt sanitation systems to water scarcity, the measures that can be taken include for example:

- Wastewater especially greywater, treated to the appropriate degree for the intended use can be reused for the irrigation of food crops, energy crops, parks, lawns 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 would substitute the extraction, processing and distribution of potable water and thus may lead to energy savings. The nutrient content of the wastewater also reduces the need for mineral fertiliser input. Further information on wastewater reuse in agriculture can be found in WHO (2006).
- Dry toilet systems can be an alternative, especially in water scarce areas, to water-flushed toilets. Toilets which do not require water for flushing, but can nevertheless be indoors (such as urine diversion dehydration toilets (UDDTs) or composting toilets), save about 40L/person/day in comparison to conventional flush toilets.
- Water or wastewater irrigation methods should minimise water losses through evaporation. Therefore, subsurface drip irrigation is generally preferable although possible nozzle clogging should be considered (Palada et al, 2011).

3.2.2 Adaptation to increasing amounts and periods of rainfall and flooding

In order to adapt sanitation systems to flooding, one effective measure is building sanitation structures in a way that they are above ground and either not affected by flooding such as UDDTs built high enough above ground, or to use mobile toilet systems (Johannessen et al., 2012)[4]. Another measure is building sanitation systems where flood water can drain quickly, such as elevated sludge drying beds, or constructed wetlands.

3.3 Emission trading as an additional financial benefit

The first phase of the Kyoto Protocol – the internationally binding contract on climate protection measures valid until the end of 2012 – assigns each participating 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 negate achieved credits to some extent.

Hence, for sustainable sanitation systems a minimum project scale is required to make CDM economically attractive. This is dependent on the baseline and the project scenario, the energy demand of the fertiliser production plants, the different available sources of energy of the country being considered, the transaction costs and the price of carbon credits which fluctuates.

The minimum project scale for an economic use of CDM for energy recovery (biogas use) and nutrient recovery (urine use) was analysed for a case study in India (Olt, 2008). Assuming average transaction costs and a long-term price of 20 EUR/CER[5], the minimum viable project scale was found to be around 25,000 PE[6] for energy recovery, and 37,000 PE for nutrient recovery.

From an emission reduction point of view, this project had favourable conditions regarding energy recovery but unfavourable conditions regarding 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 project size, similar CDM projects may be bundled together 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 the website of UNFCCC[7].

4 Renewable energy production from sanitation

4.1 Biogas production

4.1.1 Overview

Biogas is a renewable energy that can be used for cooking, lighting, heating 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 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[8].

For biogas generation various substrates can be used (also in combination with each other):

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[4] See publications of SuSanA library dealing with the issue of flooding: www.susana.org/lang-en/library?search=flood

[5] 1 CER (Certified Emissions Reduction) is considered equivalent to one metric ton of CO_2 emissions

[6] PE = population equivalent, equalling approximately the organic biodegradable load of one person.

[7] http://cdm.unfccc.int/ProgrammeOfActivities/index.html

[8] For further information on anaerobic digestion and biogas production, please see the SuSanA library and filter for biogas systems. Also photos of biogas systems are available in the Sustainable Sanitation photo collection: www.flickr.com/photos/gtzecosan/collections/72157 626218224122/

- organic waste from households or agricultural farms
- animal manure
- sewage sludge originating from domestic wastewater treatment
- blackwater, i.e. mixture of excreta and flushing water (best from low-flush or vacuum toilets)
- fresh faecal sludge from public toilets and septic tanks and pit latrines

Figure 5**:** Construction of a fixed dome biogas plant, Lesotho (source: M. Lebofa, 2006).

In many Asian countries, e.g. in China, India and Nepal, human excreta are 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"), addressing increasing energy demand and wood cutting, there is an on-going interest in China in biogas which is supported by the Ministry of Agriculture. For example, there are now approx. 5 million family-sized biogas plants of 6, 8 and 10 m^3 in operation, mainly built as fixed dome plants (Balasubramaniyam et al., 2008).

Due to the two benefits of energy production and fertiliser production, anaerobic digestion (AD) is receiving interest as an option in sustainable sanitation concepts.

For a sanitation system, maximising the stabilisation and hygienisation of the wastewater is more important than maximising the biogas production. The pathogens contained in the raw wastewater are reduced somewhat during anaerobic treatment but not to a high degree. In general the pathogen reduction during anaerobic digestion is higher the longer the retention time.

Biogas from anaerobic wastewater treatment contains 60-70% methane. The biogas production depends on the amount of organic matter removed by anaerobic treatment. 1 m^3/d of biogas is enough to cook three meals for a family of 5-6 members. According to Balasubramaniyam et al. (2008), as an indicative value, this can be produced from excreta of either, 50 - 90 humans, 2 - 3 cows or 7 - 8 pigs over a 24 hour-period. This means that the excreta from approximately 10 people is needed to produce biogas for the cooking needs of one person. Hence, the available energy potential in human excreta should not be overestimated. An advantage is that, there is no human health risk at all caused by pathogenic contamination in biogas itself (Vinnerås et al., 2006).

If the biogas cannot be used, then it should at least be flared (this converts methane to carbon dioxide which has a 25 times lower GHG potential than methane, see Section 3.2). However, as described in Hoffmann et al. (2011), when biogas needs to be burnt, there are additional costs for equipment. The flare for a household plant has nearly the same costs as a flare for a large plant of 20,000 inhabitants – thus the specific costs per person are relatively high for flares implemented in small systems.

If neither biogas use nor flare can be realised, uncontrolled biogas production should be avoided. There are various possibilities to reduce unintended biogas leakage:

- Replace existing anaerobic ponds and septic tanks by a controlled anaerobic treatment system such as biogas plant, UASB reactor or anaerobic baffled reactor.
- Design and build any new anaerobic treatment systems as a closed gastight construction with biogas capture.
- Make existing open UASB reactors as well as leaky biogas plants gastight and avoid biogas emissions by installing or restoring the flares.

Where septic tanks are too small for a controlled anaerobic treatment (i.e. generally or household level), consider replacing septic tanks by appropriate, low-energy, composting toilets or aerobic treatment methods such as dry toilets, or constructed wetland systems.

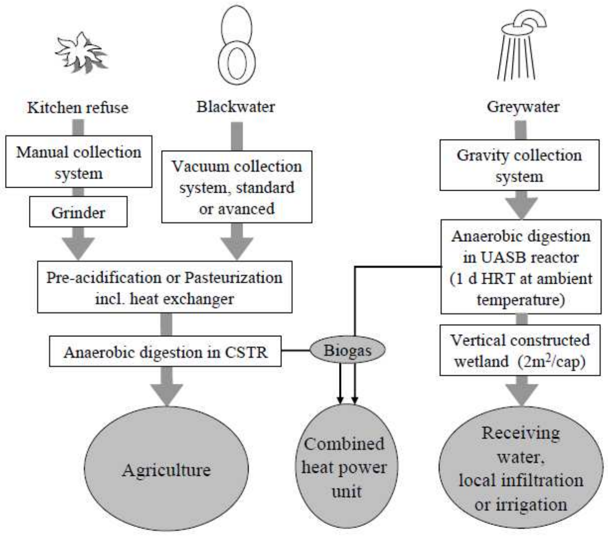

Figure 6**:** Schematic of the proposed AD system for household wastewater which includes a Decentralised Wastewater Treatment System (DEWATS) for greywater (source: C. Wendland, 2009).

4.1.2 Use of the biogas

Biogas can either be burnt in a gas stove or used within a combined heat and power unit (CHP) for electricity generation. For use in a CHP, the biogas must be filtered to remove aggressive sulphur compounds. 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.

4.1.3 Use of the digestate

After the generation of biogas, the residue of anaerobic digestion (called "slurry or digestate") still contains all the nutrients and some organic matter. This residue is therefore suitable for application in agriculture as a fertiliser and soil conditioner. The macronutrients (N, P and K) which are contained in the substrates remain in the digestate and are easily available to plants.

Organic matter is reduced by the digestion process but is still available in the digestate, and can contribute to raising the soil organic matter content. The digestate is “stabilised” with reduced odour emissions, pathogens and weed seeds compared to undigested manure (pathogens are not removed to a significant extent). The use of the digestate as a fertiliser reduces the need for mineral fertilisers, which reduces costs as well as greenhouse gas emissions. However, safety measures in the application of digestate should be applied, especially when the substrate sources contain human and animal excreta.

4.2 Biomass production

4.2.1 Overview

Biomass is a non-fossil energy source which can substitute fossil fuels. However, it is neither always harmless 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 wood 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 or energy 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 people are dependent on biomass (particularly on wood) for their energy supply, primarily to cook their food.

Conducting a national food balance, which takes into account food production versus consumption is one way to establish whether priorities should tend towards either food or biomass production[9]. 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 to irrigate and fertilise energy crops in so-called Short-Rotation-Plantations (SRP) is a new approach which aims at using the nutrients contained in wastewater for an enhanced biomass growth.

The term SRP refers to 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 fertilisation. By irrigating with wastewater rich in plant-available nutrients, fertiliser costs are zero, plant growth is enhanced, and wastewater is subjected to a more sustainable treatment[10].

While constructed wetlands focus 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. An SRP is not lined at the base and has a filter height of between 1.0 and 1.5 m resulting in an effective reduction of pathogens. Wastewater is usually applied on SRPs by means of sub-surface irrigation in order to avoid aerosol formation and spread of pathogens by air.

Figure 7: A two year old short-rotation-plantation (SRP) in Braunschweig, Germany, (source: TTZ, 2006).

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 – comply with the EU Nitrates directive. In addition, the nitrate content has to be monitored 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.

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[9] A useful online resource by OECD for agricultural food production by country and commodity is: http://stats.oecd.org/Index.aspx.

[10] Further information is available on the website of TTZ, Germany. www.ttz-bremerhaven.de/

Besides the above-mentioned benefits there are also some drawbacks to consider:

- Groundwater pollution could occur and 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 such as sodium chloride and hydrocarbonates might be a problem.

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

4.2.2 Treatment performance of SRP

With a 10 hectare SRP, the wastewater of approximately 6,500 people with a daily discharge of 100 L/person may be treated, corresponding to an area of 15 m^2/person. The actual wastewater treatment takes place in the root system of the trees where bacteria are active. When the soil freezes, biological activity slows down considerably and there is a need for storage ponds to retain the wastewater during cold periods. Note that the area requirement per person is much higher for SRPs than for constructed wetlands. SRPs cannot be used when there is a space limitation.

4.2.3 Use of the biomass

The biomass produced in SRPs 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, the 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).

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Acknowledgements are given to the following persons for their valuable contributions:

Elisabeth von Muench (GIZ, Germany), Patrick Bracken (AHT, Germany), Mirko Haenel (TTZ, Germany), Dexter Lo (Xavier University, Philippines), Christoph Platzer (Rotaria del Perú, Peru), Rob Lichtman (e-systems, The Netherlands), Kim Andersson (SEI-International, Sweden)

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