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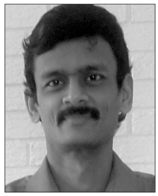
WASTEWATER TREATMENT PLANTS AS ENERGY-PRODUCERS: COMPARISON OF THE STATUS IN INDIA AND SWEDEN

Avloppsreningsverk som energiproducenter: Jämförelse av status i Indien och Sverige

*by EMMA JOHANSSON[1], G. VENKATESH[1]**
1 Department of Chemical and Engineering Sciences, Karlstad University, Karlstad, Sweden
** Corresponding author: Venkatesh.govindarajan@kau.se*



Abstract

As the population of the world rises and economies grow, both energy and water will be needed in ever-increasing quantities. There is a delicate balance between these two resources called the *energy-water (or the water-energy) nexus*. One way to reduce the energy consumption associated with wastewater treatment is to use the sludge produced during the process to generate biogas. In most countries in the developed world, the coverage, standards and reliability of wastewater treatment are high. But as the countries in the developing world are striving towards the living standards of those in the developed world, even as they combat population pressure, it is imperative that they learn from the experiences (the mistakes which occurred during the 'learning-by-doing' process) of the developed world. In this paper, Sweden has been used as a proxy for the developed world with a well-functioning sanitation infrastructure and reliable power supply; and India (the home country of one of the coauthors) is a proxy for the developing world which lacks the same. A very important starting point for development would be to educate people about the long-term socio-economic and environmental benefits of wastewater treatment.

Key words – Wastewater treatment, sludge digestion, biogas, energy, water-energy nexus

Sammanfattning

När världens befolkning stiger och ekonomier växer, kommer både energi och vatten att behövas i allt större kvantiteter. Det finns en delikat balans mellan dessa två resurser som kallas 'energi-vatten (eller vatten-energi) nexus'. Ett sätt att minska energiförbrukningen i samband med avloppsrening är att använda slammet som produceras under processen för att generera biogas. I de flesta länder i den utvecklade världen är täckning, standarder och tillförlitlighet för avloppsrening höga. Men eftersom länderna i utvecklingsländerna strävar efter levnadsstandarden hos dem i den utvecklade världen, även om de bekämpar befolkningstrycket, är det absolut nödvändigt att de lär sig av erfarenheterna (de misstag som inträffade under »att lära genom att göra» processen) i den utvecklade världen. I den här artikeln, har Sverige använts som en representant för den utvecklade världen med en välfungerande sanitetsinfrastruktur och tillförlitlig strömförsörjning. och Indien är en proxy för utvecklingsvärlden som saknar detsamma. En mycket viktig utgångspunkt för utvecklingen är att utbilda människor om de långsiktiga socioekonomiska och miljömässiga fördelarna med avloppsrening.

1 Introduction

The demand for energy will keep increasing in the years to come, as the population grows and economies expand. Most of today's energy is produced by the combustion of fossil fuels, such as oil, coal and natural gas. When these are combusted, carbon long stored in the earth, is released into the atmosphere as carbon dioxide (CO_2), disturbing the balance in the mixture of gases. The concentration of CO_2 in the atmosphere has increased from approximately 280 ppm before the industrial era, to 379 ppm in 2005, mostly due to anthropogenic causes (Solomon et al. 2007). In March 2015, it crossed 400 ppm for the first time (Imster, 2015). The combustion of fossil fuels results in not only greenhouse gas (GHG) emissions but also particulate matter which sullies the atmosphere, creating smog and increasing the incidences of asthma and allergies as well as more serious conditions such as lung cancer and heart diseases (Appels et al. 2011). To curtail the emissions of GHGs and abate pollution but still satisfy the demand for energy it is necessary to explore new renewable energy sources.

Access to clean water is also a growing concern. The importance of a secure supply of clean water cannot be overstated – it is necessary for human health as well. Polluted water can cause various diseases, decrease the fish population and the diversity of fauna in and close to bodies of water. Because of the paucity of wastewater treatment facilities, copious amounts of human waste are released into rivers and other water bodies which then are contaminated by pathogens, heavy metals and excess nutrients such as phosphorus and nitrogen. While the pathogens and heavy metals cause illness and poisoning in humans and animals that come in contact with the water directly or through contaminated crops, the nutrients create a deficiency of oxygen that makes for an unfavourable living environment for most marine organisms and might also cause hypoxia in human beings (Naturvårdsverket, 2014; Frérot, 2011).

There is a complex, and thereby interesting, relationship between water and energy. This is called the *water – energy nexus* and the interdependence is important to consider when designing an urban society to reduce GHG emissions and combat water shortage (Nair et al. 2014; Venkatesh et al. 2014).

1.1 Waste to energy

When wastewater is treated in a wastewater treatment plant (WWTP) the suspended solids are separated out as sludge. This sludge contains a high amount of organic matter as well as different nutrients and pathogens, which can create a problem if released, untreated to the environment. One way of tackling this problem is to digest the sludge (Aiyuk et al. 2006). Digestion in an anaerobic environment reduces the sludge volume, as the microorganisms consume the organic material and pathogens are destroyed. Biogas is generated as a by-product during the process. It is composed of methane (CH_4) and CO_2 (along with smaller amounts of ammonia, hydrogen sulphide etc.). This means that all WWTPs have the potential to be power producers. The power produced can be used within the plant and thus the need for energy from the power grid can be reduced, or the biogas can be up-graded to vehicle fuel. This would also bring down the operating expenses of a WWTP, making the investment economically-attractive. Additionally, water pollution can be curbed and GHG emissions abated significantly.

1.2 Developed world vs developing world

To tackle the imminent climate issues, it is imperative that countries in the developing world do not make the same mistakes, those in the developed world made in the past. If the developing world aspires to the same living standards of the western world, that would entail a rapid rise in the consumption of resources (water, energy and materials), and the planet may not be able to sustain life in the way we know it, in the longer run. In order to avoid this, measures must be taken to help these countries develop in a more sustainable manner by helping them bypass the unsustainable methods of energy production through the burning of fossil fuels and head straight to extensive use of renewable energy. While the western world is working on altering its energy production methods by investing in new wind turbines and solar panels and converting existing power plants to be able to utilize renewable fuels, the developing world does not yet have a full-fledged infrastructure for energy production and distribution. This actually presents the developing world with a good opportunity of developing sustainably from here onwards.

However, before embarking on this journey of sustainable development, understanding the reasons for the status quo which prevails in the developed and developing worlds will be necessary. The motivations behind this paper are as under:

1. To present a strong case for capacity development for wastewater treatment and biogas production in the developing world.
2. To study the challenges and obstacles, as well as the opportunities and possibilities in this context.
3. As an overarching goal, to contribute to nurturing a problem-solving attitude and a will to progress towards a cleaner, greener, securer and more sustainable future.

By using Sweden as a proxy of the developed world with reliable power supply, clean environment and no scarcity of food and comparing it with India (which has an energy shortage of 8 %, with frequent power outages, polluted rivers and poverty, compounded with a yawning gap between the rich and the poor, according to Government of India (2009)), as a proxy for the developing world, the paper discusses if a sustainable water supply, wastewater treatment and energy supply infrastructure, like the one which prevails in Sweden, can be developed in India and made compatible with the socio-economic clime which one finds in the country. The paper can also be looked upon as a modest attempt to inspire future collaboration between India and Sweden (and more generally between the developing world and the developed world) in the field of wastewater treatment and biogas utilisation for energy production within WWTPs. It takes the form of a review which studies the differences between the developed and the developing world as regards to the utilization of biogas from sludge in WWTPs. It adopts a holistic approach by factoring in a multitude of factors and aspects, political, legal, economic, environmental and social, for the expansion and development in this field.

2 Methodology

2.1 Literature review

This paper is based on a review of selected articles on wastewater treatment and biogas generation from sewage sludge, found by searching for the terms *sludge treatment, biogas and wastewater* among the keywords of relevant scientific journals, accessed through the university library. Some policy documents were also reviewed to understand the governance aspect in India and Sweden, which were chosen as proxies for the developing and developing worlds respectively. Even though these two countries were chosen as proxies, publications focusing on other countries in the world have also been reviewed and referred to. Five articles each from the developing and developed world were accessed and read.

In case studies from the developed world (Japan, the USA, Slovakia, Denmark etc.) focus was placed on biogas production in connection with WWTPs, how this was utilized and techniques to improve the methane production. In the studies from the developing world (Ghana, Nigeria, Indonesia, China etc.), owing to the fact that well-functioning WWTPs are not so common, more emphasis was placed on the cases that discussed sanitation issues and the application of biogas on a household level to satisfy some of the heat energy needs. This is to create a foundation to work from and find indications of where problems might occur when projects are initiated to introduce biogas production in WWTPs.

The two proxy countries were examined through a large collection of articles concerning wastewater treatment and energy production. This created a comprehensive view of the state of wastewater treatment in both nations and the environmental concerns regarding this as well as the major differences which place the two countries in 'different camps', so to say.

2.2 Other sources of information

To gather further information, foremost regarding the stance of the local population of India and query about the biogas potential and wastewater treatment from an expert's point of view, several email exchanges were conducted with skilled professionals in the fields of sanitation, water supply security and energy – from government and academia.

3 Results – Status in the developing and developed worlds

3.1 Developed world

In the USA, as per Shen et al (2015), barriers such as an absence of monetary incentives and inadequate biogas volumes can surely be overcome to make energy recovery from wastewater a more lucrative proposition. In the Slovak Republic, Bodik et al. (2011) researched 49 WWTPs and concluded that there was scope for an increase of biogas production. In Japan, according to Komatsu et al. (2007), the co-digestion of rice straw with sewage sludge was recommended, as a method to improve dewaterability of the sludge, decrease the ammonia-nitrogen concentration and increase the CH_4-yield (66–82 % more CH_4 for the mesophilic digestion and 37–63 % for the thermophilic). In the EU, a lot of effort is being (and will be) put into making the sludge an energy source, through a number of different methods (Fytili & Zabaniotou 2008); however, the Danish government also has a goal that the country's sludge should be of such high quality that at least 50 % can be used for agriculture (Jensen & Jepsen, 2004).

3.2 Developing world

Adeoti et al. (2000) has investigated the economic benefits of installing 6-m^3 family-sized biogas digesters in Nigeria. Since Nigeria is an oil-exporting country with easy access to fossil fuels, it is important for any alternative fuel to be economically-attractive if it is to be a realistic alternative. Rupf et al. (2015) have explored the obstacles to widespread installation of household biogas digesters in the sub-Saharan areas since it has the potential to improve energy supply, sanitation and food security. Bensha et al (2010) have discussed the prospect of connecting public toilets to biogas digesters to improve sanitation. Kerstens et al. (2016) has developed a planning framework for wastewater and solid waste services in Indonesia as a tool to apply the government's policies in the development of these services nationwide in a comprehensive way. In China, the energy consumption of water and wastewater treatment (the country has a total of 3508 functioning WWTPs) accounts for close to 1% of the total energy consumed in the country, vis-à-vis a share of 3 % for the USA (Zhang et al. 2016).

3.3 The cases of Sweden and India

There are many differences in the way wastewater and sludge are handled in Sweden and India. All the wastewater generated in Sweden goes through an extensive cleaning process before it is released into natural water bodies, while in India no more than 31% of the wastewater is processed; and even when it is, the degree of treatment is not adequate. When seen from the perspective of the population of India, it at once becomes clear that the quantities of wastes released with the sewage have an adverse impact on the environment, and also imply that a useful renewable energy source is wasted (Khursheed et al. 2016). In Sweden, it is fairly common to digest the sludge created during the wastewater treatment and thereby produce biogas. Not only does this lessen the sludge volume and eliminate pathogens, but it also creates an additional source of income by way of generation of renewable energy (for use as heat, electricity or transportation fuel) (Naturvårdsverket, 2014).

3.3.1 Status of wastewater treatment and biogas production in Sweden

3.3.1.1 Wastewater treatment

Today all wastewater in Sweden is treated before release to the sinks. About 95 % is treated by biological, chemical and mechanical processes while the remaining 5 % is treated mechanically and biologically on a smaller scale, in holiday homes etc. The BOD_7 concentration of the effluent wastewater from the WWTPs has to be reduced to 15 mg O_2/l (Naturvårdsverket, 1994).

In 1940, there were only 15 facilities in Sweden. In the 1960s, when the Swedish Environmental Protection Agency (Naturvårdsverket) was established, grants worth 5 billion SEK (in today's value), were committed to the building of more WWTPs.

3.3.1.2 Biogas production

Biogas was first produced in Sweden in the mid-20th century to reduce sludge volume and odour in relation to WWTPs with the added benefit of eliminating infectious matter (Olsson & Fallde, 2015). The total biogas potential from WWTPs and the animal husbandry sector is estimated to be 10.6 TWh/year; with the addition of forestry-sector waste products into the mix, likely to increase the potential by 59 TWh/year (Avfall Sverige, 2008). Of Sweden's approximately 2000 WWTPs, only 135 are equipped with sludge digesters, as most of the others are very small to warrant the setting-up of a digester. If distances between WWTPs are not too great, the sludge from a smaller one is sometimes transported to a bigger one equipped with a digester for biogas generation (Naturvårdsverket, 2014). What all the WWTPs in Sweden have in common is access to a steady and abundant supply of organic waste matter.

In 2014, 1.8 TWh of energy were produced from biogas in Sweden, of which 57 % was upgraded to vehicle fuel, 24 % used for heating, 3 % for electricity generation, 4 % used for industrial purposes, while the remaining 11% was flared off (Energimyndigheten & Energigas Sverige, 2014) The use of upgraded biogas as a vehicle fuel in Sweden is a tool to reach the EU's objective of having 10 % renewable energy in the transport sector by 2020 and to lessen the dependency on imported oil in the geopolitical scenario that prevails at the time of writing.

3.3.1.3 Raison d'etre

Swedish culture, policy and education facilitate constructive thinking and a progressive approach to environmental issues and climate change. The welfare state model inculcates the significance of a clean environment and its influence on health, the economy and the future in general. Sweden, being a member of the European Union, abides by the EU's targets, two of which are the decrease in GHG emissions in 2020 vis-à-vis 1990 and the promotion of biofuels to account for at least 10 % of the vehicle fuel consumed in the country, by 2020.

3.3.1.4 Development

In Sweden, methods for increasing methane yield, nutrient capture and energy efficiency in WWTPs are being developed to tackle environmental challenges. In an endeavour to use wastewater treatment as a possible tool to decrease GHG emissions, Levlin (2010) explored the opportunity of increasing the biogas production related to WWTPs. But, if a maximum amount of organic matter is used for biogas production there will be a carbon deficiency for the biological nutrient removal. To solve this problem, new methods for nutrient removal without a carbon source need to be developed. It is suggested that struvite precipitation and anammox might be suitable methods to solve this problem.

Source control systems used to separate urban food waste and domestic wastewater, which contains black water (faeces and urine) and grey water (not originated in toilets), have the ability to increase energy and nutrient recovery in waste and wastewater systems. In a study carried out by Kjerstadius et al. (2015), it was discovered that source control systems have the potential of increasing biogas production by more than 70 %, by using an initial hydrolysis step; and also yielding more phosphorus and nitrogen as bio-fertilizer (Svenskt Gastekniskt Center, 2010).

3.3.2 Status of wastewater treatment and biogas production in India

3.3.2.1 Wastewater treatment

No more than 31% of the wastewater generated in the country is treated before discharge. In the late 1970s, water pollution gained some attention and most of the WWTPs existing today were developed under various river action plans for the major rivers since then. Amongst others there have been projects such as the Ganga Action Plan (GAP), and Yamuna Action Plan (YAP), both having as their end-goals the construction of more WWTPs to increase the treatment capacity. Activated sludge treatment was favoured in the GAP, and up-flow anaerobic sludge blanket process in the YAP. In cities with more than 100 000 inhabitants, activated sludge is the commonly-used technology with 59.5 % of the installed capacity, with up-flow anaerobic sludge treatment accounting for 26 % (Kaur et al. 2012, Khursheed et al. 2016).

However, these projects have had limited success. Owing to economic infeasibility, there is little interest in investing in wastewater treatment despite the advantages of a cleaner environment and a more reliable water supply, both of which become manifest in the medium-to-longer run. Old, leaking sewage pipes release wastewater to the surroundings, and compounded by the heavy rainfall in the monsoon, the biota gets negatively impacted. Some WWTPs which have already been constructed are not functioning, for financial reasons, and those that are, happen to be in an unsound state, running much below or above their designed capacities. The prescribed BOD_7-limit of 30 mg O_2/l after treatment (Central Pollution Control Board, 2015), vis-à-vis 15 mg O_2/l in Sweden, is often not reached. Water that does not meet the required discharge standards is however utilised in some places for irrigation; the nutrients in the effluent wastewater reducing the need for artificial fertilizers by up to 25 % (Khursheed et al. 2016).

3.3.2.2 Biogas production

Most biogas is generated in India in small-size digesters (in individual homes for instance) in rural India, and used for cooking and lighting, and are fuelled by cow dung, night soil and food waste (Surendra et al. 2014). Very few WWTPs however, are equipped with biogas digesters, and even if a WWTP has one, it does not automatically follow that it is always utilised. Biogas is often flared and exergy destruction happens in the process, while the conversion of methane to biogenic CO_2 is the only saving grace (Khursheed et al. 2016). If biogas was produced on a larger scale and partly used to generate electricity, and partly upgraded to vehicle fuel, it would help to reduce CO_2 emissions not only during the production of electricity but also on the upstream of the mine-to-power-plant life-cycle of the fuel. Fossil fuels are often transported a long way from distant oil fields and coal mines while biogas is a locally-produced energy source. This improves the self-sufficiency of the region and lessens the vulnerability in case of conflict or damage to infrastructure crucial to energy transfer.

3.3.2.3 Raison d'etre

India is a country with a high percentage of people living below the poverty line. The rate of urbanisation has been increasing over time, and a good proportion of urban inhabitants are slum-dwellers who lack free access to a well-functioning toilet. This results in environmental degradation, as the surroundings get sullied. The common belief, more often than not, is that individuals cannot make a difference by setting examples and acting differently and that it is the elected government's duty to improve sanitation conditions for all (World Bank Group, 2015). Poverty often implies illiteracy. Education, if imparted to poorer people, will enable them to understand better how the systems in the world work, and how things are interconnected. For most people, the topmost priorities are procurement of food/nutrition and good health, but without education and awareness generation, it is difficult to make them understand the strong nexus that exists between water quality and health. Measures to improve water quality entail large investments and it is easier for the local governments to lobby for actions that give immediate profit – such as large food supplies, generation of employment opportunities and healthcare facilities. As people start understanding the importance of a clean water supply, they can put some positive pressure on the government to prioritize the construction and proper care of WWTPs (Government of India, 2009b; NIPFP, 2009; World Bank, 2006).

3.3.2.4 Case studies investigating the critical components to success

There are a number of projects in the fields of environment, sanitation and energy in India that have been performed with varying degrees of success. Chatterjee et al. (2016) has explored the differences in efficiencies of different technologies currently used in WWTPs, in five decentralized and one centralized WWTP in Kolkata in eastern India. A centralized WWTP might not be a sustainable solution for a developing country, where power supply is unreliable and operation cannot be ensured with only one treatment facility for an entire town. Small-scale, adaptable treatment units, on the other hand, may be better options. It has been suggested that regular performance monitoring, education of staff and proper operation of the facility is indispensable for effective wastewater treatment.

Problems related to water-borne diseases, unhygienic living conditions, flooding and overflowing drains in the cities of Puri (Orissa, eastern India), Surat (Gujarat, western India), Chennai and Namakkal (Tamil Nadu, southern India) and Indore (Madhya Pradesh, central India), have been discussed by Surjan & Shaw (2008). These authors have further stated that cooperation among all stakeholders – government, civil society and the private sector – facilitated the alleviation of these problems by way of cleaning, renovations and infrastructural changes. Sirsi, (Karnataka, southern India) is a success story regarding biogas utilization. Close to 43 % of the rural households had dung resources to operate a biogas plant in 2001. Of these, about 65 % already had one built and all of them were working satisfactorily at the time this analysis was done. Bhat et al. (2001) have explained how this experience can be used for further development.

Water resources are a vital asset in the world, but they are limited in nature. This makes a bouquet of strategies – reuse of treated wastewater (water recycling), drought and flood management, rainwater harvesting etc. – indispensable for the country (Kumar et al. 2005).

The major cities of India generate about 38,354 million litres of wastewater daily, of which approximately 11,786 million litres are channelled to WWTPs.

If 0.07 % of this is digestible organic solids (Templeton & Butler, 2011) presumably with the same density as water and there is a biogas potential of 195 Nm^3 CH_4/tonne total solids (Avfall Sverige, 2008) and 9.67 kWh of energy can be produced per Nm^3 CH_4 (Biogasportalen, 2015), there would be a biogas potential from the wastewater passing through a WWTP of 1.56 MWh per day. If all the wastewater from all major Indian cities is collected and treated, and the sludge subjected to anaerobic digestion, the biogas potential will rise to 5 MWh/day. Since coal dominates the electricity mix in India, assuming a GHG-emission-coefficient of 900 g CO_2-eq/kWh for coal-sourced electricity (Mölndalenergi, 2015), replacing it with the biogas-sourced electricity would reduce GHG emissions by 1663 tons of CO_2 per year or 4557 kg CO_2-eq per day. In addition, the transport costs and emissions related to the movement of undigested sludge to landfills can be drastically reduced (or totally avoided, in the best case possible).

4 Discussion

With a rapidly growing population and urban sprawl, the requirement for improved sanitation is vital for India. Water supply is a primary concern, especially during the summer months when water sources dry up, but sanitation issues are given short shrift (Mohapatra, P. 2016). Respect for nature is an essential part of the Indian mindset with nature worship (pagan influence, one can say) being quite common. However a proper understanding of the mutually-sustaining or mutually-damaging relationship between humans and the environment is lacking. With the population growing steadily, defecating out in the open is no longer sustainable, from both social and environmental points of view. (The World Bank, 2006; Kansal, A. 2016).

Situations in different towns, villages and cities are different from each other and hence one cannot have a single 'one-size-fits-all approach' to sanitation challenges. The participation of people, their cooperation and support are essential for the success of sanitation projects regardless of their magnitudes (in terms of scope, time period, investments etc.) (Mohapatra, P. 2016).

4.1 Problems

Despite the advancements in wastewater treatment technology, introduction of new technologies, methods and approaches in the Indian sanitation sector is difficult owing to fear of failure and criticism on the part of the authorities. Because of tradition and social structure, people do not feel that they would benefit by adopting the developed world's solutions when it comes to wastewater treatment and sanitation in general. There also seems to be a mindset that makes people think that they cannot make a difference and that it is up to the government and technological advancements to solve environmental and climate issues.

When investments are made and WWTPs are constructed, it is not unusual that the treated wastewater does not reach the prescribed effluent-standards. Inter alia, when the projects are implemented, the people concerned are not consulted adequately. Also, at times, the design does not factor in all the relevant factors necessary for attaining the desired set of outcomes. There is a lack of skilled personnel, which results in improper operation of the WWTPs as well as poor design of the facilities which thereby do not work to their full potentials. Problems such as leaking pipes can cause a huge difference in the amount of sewage reaching the WWTPs.

Investing in a WWTP in India today is not a lucrative affair since the cost associated with the treatment is much greater than what can be earned from the consumers over the lifetime of the plant; necessitating the government to 'subsidise' and plug the deficit. The ageing and inadequate sewage-pipeline network that needs to be rehabilitated and also expanded, is a critical one. There are also open channels of polluted water which need to be attended to, as these are used as dumping sites for all kinds of wastes – hazardous ones as well.

4.2 Possible solutions

Foreign enterprises have the possibility of helping to get projects started at a grassroots level, demonstrate the benefits of new technologies that have been tried, tested and trusted in other countries, and thus generate the 'inspiration' needed to progress towards a cleaner future.

The most powerful asset of a country is its population. If the population of India could be convinced of the benefits of a well-functioning sanitation network, many battles can be won and great improvements can be made. To achieve this, education is the primary tool. People need to be made aware of what they can and must do to prevent the spread of water-borne diseases and apprised of the overall socio-economic benefits of a well-developed sanitation infrastructure. Repositioning and projecting WWTPs as employment-generators for the local population – all through the life-cycle – will be a much-needed image-building exercise.

No matter how many WWTPs are constructed, it may all come to nothing, if they don't function properly. It is crucial that the effluent is tested on a regular basis to make sure that the standards of pollution are reached and if not, something must be urgently done about it. With the technology available today, it is possible to create smart solutions to operate pumping stations and WWTPs to optimize the process, as well as a proper asset inventory and customer database, to make the wastewater (and sludge) treatment processes as efficient as possible. Well-functioning WWTPs and their personnel should be rewarded to encourage others to reach the same level of efficiency.

It is possible to refine by-products from the treatment process and generate revenue from the sale of the same. The sludge per se, can be sold as fertilizer or nutrients can be extracted from the sludge and then used for fertilizing the soil. In this paper though, the focus has been on the generation of biogas from sewage sludge. The gas can then be sold as it is or can be upgraded to vehicle fuel or be used for heating and/or electricity-generation purposes. The heat can be used in plant to provide the temperature needed (30–40°C) during the anaerobic digestion and the electricity can cover at least up to 40 % of the energy requirements within the WWTP. What is done with the biogas depends on the prevalent local situation. In those parts (states or regions) of India, where the electricity mix has a significant fraction of renewable energy – hydropower or wind for instance – the biogas can be upgraded to transportation fuel. Elsewhere, electricity generated from it can replace a fraction of the electricity the WWTPs source from the grid. If a WWTP cuts down its purchases from the electricity grid, the reduction in indirect GHG emissions attributable to the functioning of the WWTP, makes it a strong candidate for carbon credit financing.

4.3 Exchange of experiences

As far as the status of the sanitation infrastructure is concerned, countries vary from one another owing to a combination of factors. In India, with its large population, it can be difficult for individuals and small societies to see how they can make a difference. Often, passing the buck is quite common, and not wanting to be the first one to initiate a change is a common human failing. In Sweden, however, this failing does not manifest itself. Being relatively sparsely populated, everybody truly has the possibility of making his/her voice heard and contribute meaningfully to bringing about much-needed changes. If this could be replicated in India on a larger scale (the ratio of Swedes to Indians on the surface of the earth is approximately 1:125) one can easily visualize the dramatic changes that would be made possible in the country. If establishments working with the sanitation issues in India could be supported by strong and influential foreign partners that have already tried relevant and implementable solutions, the necessary stimulus will be provided instantly.

In Swedish WWTPs, there are many strict regulations and routines for optimum performance and to ensure that the given standards are reached. This is regulated through a strict monitoring system with regular analysis of water quality with immediate adjustments and interventions if the results are found to be unsatisfactory. If this stricter testing process were used in India, the functioning of the WWTPs would have to improve, but it would only be possible if they were given the funds, technology and expertise necessary to invest in rectifications.

With the better economic situation in Sweden, the connection fees for households to the WWTP can be higher than those in India. Because of this, the Swedish WWTPs are largely self-sustaining. The challenges faced by WWTPs in India, in this regard, have been discussed earlier in the paper. To help surmount these challenges, the upper class with better economic means should step in and be willing to carry a bigger part of the economic burden to create the possibility to maximise the utilisation of WWTPs. This would make it possible to improve the environment quicker, and both the rich and the poor can benefit therefrom.

5 Conclusions and recommendations

Wastewater treatment is not a prioritized issue in India, when compared to Sweden. This, as discussed, is due to a complex combination of reasons – tradition, the economic situation that prevails, and lack of awareness, *inter alia*. This creates an unfavorable setting in developing countries like India, for investments in WWTPs and government officials are reluctant to invest, fearing failure and criticism. The WWTPs already constructed often perform badly due to unsuitable design, poor operation and maintenance. The economic infeasibility is a strong deterrent as well.

To surmount these challenges, one has to stress on the importance of education and awareness generation. Educating the local population about the importance and necessity of wastewater treatment, its role in restricting and eliminating eventually, the spread of waterborne diseases, and the slow but steady improvement in the economic situation that this will bring about, is something which authorities have to invest time and money in. The local population apart, it is also extremely necessary to educate the WWTP-personnel to make sure that the plants function reliably and efficiently.

Economic feasibility – a good return on investment – is crucial for the success of ventures in this sector. This can be guaranteed by considering the anaerobic digestion of sewage sludge as a 'source of energy for the plant' and thereby a contributor to the lowering of energy expenditure in the medium-term. If the environment can be factored in by means of awareness generation, as a vital third pillar of sustainable development, investments in biogas generation and the benefits of the utilisation thereof, will be easily appreciated as an environmental good.

In short, collaborative projects among research groups and universities in the countries of the developing and developed world, have the potential to transfer knowledge, and combat local problems which have global implications.

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