BIO-SOLID AS A PRIMARY ENERGY SOURCE FOR WASTE WATER TREATMENT PLANT: A UK PERSPECTIVE

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ABSTRACT

Current research aims to explore how WWTPs can potentially become energy-neutral in the UK through deployment of bio-solid energy and optimisation of biogas generation process. The findings confirm that process optimisation has a positive effect on energy-independence of WWTPs while other renewable energies (excluding biogas) do not significantly contribute a notable share in WWTPs. Furthermore, it is concluded that the idea of an energy-neutral WWTP is technically viable but various hindrances still exist on the way. Finally, a model is proposed for an energy-neutral WWTP in the UK which can be rolled out to suit almost every other geographical location in the world, subject to minor modifications.

INTRODUCTION

In the wake of global warming, international energy crises, new environmental mandates and regulations, and continuous pressure on operational costs on one hand, and public health and safety, national security, and natural disasters, and risks management concerns on the other hand, an investigation into using renewable energies and optimising energy efficiency for Wastewater Treatment Plants (WWTPs) is vital.

Wastewater treatment is a mixture of physical, chemical and biological processes that are used to purify industrial and domestic wastewater (Degremont, 2007). According to POST (2007), wastewater treatment in the UK has significantly improved over the past 20 years and as a result approximately 75% of Rivers in the UK have now acceptable biological and chemical qualities. The energy requirement for treating sewage to this level is high and this has made water industry the fourth most energy consuming sector in the UK.

The UK Government has made a commitment to work towards a 'zero waste' economy and maximising the amount of energy that is produced through the AD process (DTI, 2006). Furthermore, based on the information in the Action Plan that is reported by Defra (2010), the average amount of energy produced in the form of electricity and heat in the UK can reach 3-5 TWh by 2020. The amount of renewable energy produced on WWTPs in 2006 was almost 490 GWh, equal to 6.4% of the total energy consumed by these plants (POST, 2007), hence, much more can be done to increase the share. According to Defra (2007), most of the sewage sludge production in the UK is applied to agricultural land as soil conditioner. Nevertheless in some parts of the country, sludge may also be incinerated with the aim of heat production. Production of sludge is on the rise but constantly receiving less agricultural demand, as farmlands are decreasing in the UK. However, this surplus sludge can be treated in WWTPs using Anaerobic Digestion (AD) process to produce biogas. The biogas that is formed through AD process is one of the most reliable sources of green energies for WWTPs. Defra's Waste Review (2011) asserts that sludge treatment AD offers the most efficient process in terms of environmental benefits. The biogas that is produced can be used for generating energy in form of heat and electricity or can be purified and used as vehicle fuel. Environmental Protection UK (EPU) report (2006) suggests that biogas is a reliable source for producing vehicle fuel. For instance, in Linköping in Sweden biogas is being used as fuel for trains, buses, taxis and some private cars. Although, in the UK the use of biogas for vehicle fuel is not common yet, generating electricity from biogas carried out from sewage sludge treatment is currently a well-established method (POST, 2011).

LITERATURE REVIEW AND PRECEDENTS

In large WWTPs, digester gas can be used for heating purposes, generating electricity, and co-generation or just be wasted. Hammer (2012), cited that biogas in some WWTPs may be used as fuel for boiler and internal-combustion engines which can be used for pumping waste-water, operating blowers and generating electricity. According to the litrature reviewed, other usage could be considered for biogas. Biogas can be purified and injected into the gas grid or can be used as fuel for vehicles. Regardless of that, in the UK, the focus is more on electricity generating. Thus, three applications can be considered for biogas in WWTPs; as source of heat, as a source for electricity generation and finally in a co-generation system.

Traditionally, biogas has been combusted to provide heat for the digestion process or buildings nearby, and often surplus biogas is burned and wasted (Descoins et al, 2012). According to POST (2011), some of WWTPs in the UK burn their biogas to generate electricity due to technical and regulatory barriers and more importantly because of insufficient financial support. To generate electricity from biogas practically there are different technologies which are currently implemented worldwide. According to a report prepared by

Oregon Association of Clean Water Agencies (2008) some of those practical methods are Fuel Cell, Internal Combustion (IC) engines and Micro-turbines. All these methods have by-products as heat when biogas is burnt to generate electricity. In addition, the US Environment Protection Agency (EPA) in 2008 has mentioned the gas-combustion engine, Stirling engine and steam turbine as other feasible technologies for generating electricity from the biogas. Table 1 summarises their features.

There are advanced and practical technologies for producing energy and fuels from sewage treatment. Researche has been done to identify practical methods to take advantage of sewage as a green energy resource. For instance research carried out by Oregon's domestic WWTPs facilities in 2008 explains the methods they employ to make their facilities energy-independent by optimising the plant energy consumption and using available renewable energies. The research is based on an evaluation of energy facilities in their two WWTPs in Gresham and Corvallis. Other extensive research conducted by the EPA in 2008 examines different technologies using biogas as a fuel to produce both heat and electricity through a cogeneration system. Additionally, broad research regarding energy generated from biogas was completed in 2003 by Thomas E. Vik and P.E. Dee. They have undertaken a State-wide assessment survey about "Anaerobic Digester Methane to Energy". Their work indicates that, with suitable treatment, the biogas can be used in an IC engine to drive a generator to produce electricity for an internal plant or to be fed back into the national grid. In addition, it is possible to increase the quantity and quality of biogas in the digestion process by using other organic materials such as food or abattoir wastes.

In a very recent study, Oregon State University has claimed that the activated sludge and AD process can be replaced by fuel cells and their findings shows that microbial fuel cell can generate electricity directly from waste-water (OSU, 2012). Based on their report, WWTPs can eventually produce enough electricity to cover the power needed for the plant and even sell excess electricity.

RESEARCH DESIGN AND METHODOLOGY

Applied research methodology in this study has been established in accordance to the research scope and is based on the suitability of each methodology and corresponding methods to the objectives of the research. A mixed methodology is employed, to ensure that both breadth, across the industry, and depth, into specific points, opinions and views, are sufficiently taken account of.

The research adopted threefold data gathering, consisting of desk study, quantitative and qualitative data. Quantitative and qualitative data is gathered through an online questionnaire that serves as a comprehensive analysis basis for the research, followed by a qualitative method that involved interviews and provided more detailed exploration. The questionnaire was limited to ten questions to cut back on survey time spent by participant and encourage a larger sample to partake. With reference to the official website of Ofwat and Water UK, there are 11 major companies which are operating most of the WWTPs across the UK. The questionnaire was sent out to multiple recipients with different roles in all 11 major operators throughout the UK.

RESULTS

According to the literature review most of WWTPs in the UK do not deploy any technique to generate electricity from biogas; however the answers collected to question one indicate that only 20% of WWTPs have not implemented such methods. As the total number of received responses to the questionnaire was limited compared to the total number of WWTPs across the UK and due to the fact that they are run locally with very limited centralised data repository in their corresponding operator companies, it can be assumed that the collected data has been picked from best-operated WWTPs with reference to the focus of this study. On the other hand it can also be observed that the results of the questionnaire are mostly focused on the WWTPs that use biogas for electricity generation. Consequently, in order to capture a more realistic picture, it was decided to carry out interviews with two key managers at a water company, a Carbon Policy Manager and a Carbon Reduction Project Manager. Based on the data provided by the interviewees, one company in charge of South of England operates almost 280 WWTPs of which 26 have AD plants and only 13 plants include CHP units which generate energy from biogas. Further analysis of expert interviews triangulated with survey results and findings from literature helped the discussion further develop more in-depth into following areas:

DISCUSSION OF FINDINGS

Barriers and solutions using biogas as a source of energy in WWTPs

Barriers to use biogas as a renewable energy have been identified in literature and question two. In order to provide a precise analysis, these barriers are grouped into two categories (see Table 2).

The first category includes barriers that are relevant to stakeholders who deal with WWTPs directly, such as contractors, consultants and investors. The second category covers more generic barriers and those more relevant to the government at policy levels. The main focus of this research has been on the first category.

The Table 2 shows that some of these barriers are found in both categories. With reference the answers to question three, due to these barriers, some of the WWTPs in the UK burn and waste their biogas or just use it for producing heat which both are unsustainable and would increase their carbon *footprints. For instance the energy that was annually wasted in case study ten is 3850 kWh, and 4350 kWh for case study six. Hence, one of the big challenges for this industry is to prevent small plants wasting their biogas.*

One of the most important obstacles for WWTPs employing technologies for generating electricity is their small size which can be assumed to be the root cause of other barriers. In other words due to small size of WWTPs, the amount of produced biogas is not considerable, therefore it is not technically and financially viable to utilise advanced technologies for electricity generation using bio solids. In addition the low amount of produced biogas in WWTPs will influence the financial issues such as payback time and investment risks. On the other hand by considering results of question five, only IC engines were deployed by WWTPs in the UK and none of the other technologies identified in the literature review were indicated by the participants. Among the technologies available for generating electricity from bio solids, some of them are advisable for small plants in terms of capacity and capital cost. Fuel cells, micro turbines and Stirling engines can be assumed as an alternative technology to IC Engine and Gas Combustions Turbines in small WWTPs. Although, fuel cells and Stirling engines are not commercially available and cannot be considered as a reliable method, their advantages should not be overlooked.

One of the interviewees believes that one of the most significant barriers to wider use of biogas is the problem of "economies of scale" and usually significant masses of bio solids are needed to make the process financially viable. Hence, as a solution they transport sludge from smaller plants to the nearest AD plant to produce biogas. Another interviewee stated that the sludge is dewatered through fire driers or drum driers prior to transportation. By this process the transportation becomes more cost effective. Participants also supported the idea that the IC engines in a cogeneration system are the most common method for generating energy from biogas produced from sludge in the UK. They mentioned health and safety, economic viability and proven technology as key reasons to choose IC engines. In addition, another participant also explained that in one of their projects they preferred to use IC engines to Micro-turbines, because the gas preparation system in IC engines is simpler. However, with reference to the literature review the IC engine is not always the most feasible and most efficient technology for generating energy from biogas. Furthermore, there are other technologies that are being used worldwide but they were not common in the UK because they have not yet been tested and proven to work in this country. Moreover, most of the water companies in the UK are private and face difficulties in investing their shareholders money in new technologies to get proof of concept. This causes uncertainty and risk in investment process necessitating risk value management and risk mitigation techniques.

Techniques for improving biogas production

The findings of questionnaire survey were surprising. Six of the case studies did not carry out any method for enhancing the AD process. Case studies number six and ten which have not implemented any techniques to generate electricity from their biogas were also among them. Therefore, it can be assumed that lack of any additional techniques for improving AD process prevents small plants from generating electricity from biogas. It can also be supposed that one of the practical solutions for small plants is implementing a method for enhancing the digestion process and increasing the biogas production. Thus, utilising one of the technologies for generating electricity from biogas in small WWTPs would be more viable in terms of technical and financial aspects.

Additionally, the issue of AD process improvement was discussed in interviews. The interviewees believe that biogas optimisation is essential for WWTPs to become more sustainable. One of the interviewees highlighted that applying techniques for enhancing the AD process would not only result in more biogas production but it also influences the quality of sludge and bacteria degradation, making it more suitable for agricultural applications. Despite all these benefits, the financial issues and payback period should also be considered. However, there should be a balance between all the results to create an optimum condition. The second participant mentioned that they are using a Real-time Control System (RCS) on the aeration process on one of their WWTPs. The quality of their sludge was improved as a result while the power consumption was reduced. Subsequently, this resulted in a 12% energy reduction in the aeration process and a 20% increase in biogas production. The second interviewee also stated that applying any additional techniques in digestion process would need constant attention and this requires vast investment which requires thorough and careful consideration. It can then be concluded that employing these techniques for small WWTPs would increase their biogas production therefore they will be able to use one of the technologies to produce energy from biogas instead of transporting it or wasting it. This could rationalise these investments, to different extents depending on the type, size and location of the WWTP and the amount of generated bio solids.

The concept of an energy-neutral WWTP: An expert view

For this purpose, the amount of biogas produced in each case study is converted to energy. This gives a better and more comprehensive view of the results. The methane gas at standard temperature and pressure (20°C and 1 atm) has a lower value of 960 Btu/ft^3 (35,800 kJ/m^3), and given that the *percentage of methane in biogas in WWTPs that participated in this study ranged between 60% and 64%, the heat of combustion for one cubic feet biogas varies from 575 Btu/ft^3 to 615 Btu/ft^3. By considering this data, the energy generated from each case study was recalculated and the results are presented in Figure 1. In addition this figure demonstrates the actual energy generation and consumption for each of the case studies.*

Case study one was excluded due to quality check on data collection process.In some of the case studies e.g. case studies number seven and eight, it was not possible to draw any logical conclusion between the collected data. Considering the amount of energy that was generated in these WWTPs is more than their capability and this is impossible, it can be concluded that their data was not completed correctly or some other factors were involved which may well fall out of the scope of this research.

On the other hand, focusing on data for case studies number two, four, five and nine resulted in an interesting finding. In these cases the amount of energy that could potentially be produced from biogas is significantly higher than what is currently produced. In addition, in case studies two, four and five, this amount is even higher than the actual WWTPs energy demand. Thus, it can be concluded that, had appropriate CHP systems with high efficiency been utilised in these plants, it would have been possible to operate them fully independently from the grid. However, in terms of security issues it is not reasonable to operate any facilities in water and wastewater industry energy-independently with no backups. Moreover, some of those case studies are even capable of feeding in their surplus electricity back into national grid. Hence, this emphasises the importance of using CHP systems in WWTPs for generating energy to best utilise the biogas generated as a result of the produced bio solids.

The issue of an energy-neutral WWTP vs. energy-independent WWTP was discussed in interviews. The first interviewee largely agreed with the idea of an energy-neutral WWTP. In their opinion in an optimum condition it is possible to have an energy-self-sufficient WWTP and even export the surplus electricity to the grid. They believe one of the key issues with this approach is the "economies of scale" and it should be planned as a cost-effective framework. The second interviewee stated that having an energy-independent WWTP in terms of security issues is not reliable. They asserted that it was not possible to run such critical facilities independently from the grid and there should always be a steady source of electricity available in an emergency situation, although that is theoretically possible. For instance, a constant flow of biogas is needed to ensure a certain amount of energy generation to run a WWTP, in reality this is impossible due to seasonal or occasional variations in sewage flow. Moreover, WWTPs depend on their process types and they will have different energy consumption. For example if a WWTP has an UV system in its tertiary treatment, this will significantly increase the WWTP's energy requirements. In addition the geographical location, pumping system, site limitation and used equipment efficiency are other variables that will affect this issue. Nonetheless, employing other renewable energies such as solar-, wind- and hydro-power is advisable in order to cover all the energy needed for a WWTP, but requires vast investment. Therefore, it can be concluded that the idea of energy-neutral WWTP is technically achievable. However, it needs to be considered rather carefully from a financial point of view. An energy-neutral WWTP is expected to become more and more viable in the future with new and more efficient technologies being made available at more competitive prices.

PROPOSING A MODEL FOR ENERGY-NEUTRAL WWTPS

Finally building upon the literature, the data gathered from case studies, questionnaire surveys, and expert interviews, and in light of all the discussions made, a model was developed for operating WWTPs energy neutrally (see Figure 2). At first step, the model will ask whether or not WWTP involved an AD process. If the answer is "No" then it will suggest transferring the produced sludge to the nearest AD plant. In this case it is also recommended that full financial assessment be carried out. If the answer to the first question is "Yes" then daily average biogas production will be asked for. An earlier model developed for this study was based on the WWTP size, but due to the variation that may influence the production of biogas regardless of the plant size, this was amended to rectify any problems associated with the correlations between size of the plant and the level of its biogas production.

Considering the results of the literature review, WWTPs were grouped into four categories in this model; WWTPs with 'very low', 'low', 'medium' and 'high' biogas production output. It was determined that for 'very low' category, producing electricity with current technologies is not cost-effective. Therefore, the model suggests employing techniques for increasing biogas production. If the amount of biogas increased to a certain level a series of technologies are then recommended for generating electricity. Otherwise it is suggested that a biogas purification system is installed and the produced gas is fed back into the grid. Likewise methods are recommended for other three categories. For each category three technologies are recommended based on efficiency, size and technical issues. obviously one important factor, is the CAPEX which due to the market fluctuation was not discussed here and updated market information should be considered later by users when considering interventions.

At next stage, the model compares the amount of energy produced by biogas with the amount of energy needed to run the WWTP. If the energy produced form biogas is enough to cover all the energy needed then it would be the end of the process. If the energy produced is not enough, applying techniques for improving biogas and using other auxiliary renewable energy would be recommended. Different techniques are available for increasing the amount and quality of biogas in WWTPs. Implementing any of these techniques needs careful consideration of the design criteria, investment and risks management. Nonetheless, after applying any of these methods the amount of produced biogas would change. This is a reiterative process. Therefore, the users can (or will, depending on how the model is devise) be redirected to the start point in the model. Inputting new values they can then reassess their WWTP with updated data to choose a proper technology. Additionally, due to the seasonal variation in the amount of daily biogas production in WWTPs, it is vital that decision-makers consider it prior to finalising their plan and this needs exact asset management skills.

CONCLUSION

As a result of this research, a novel model for energy-neutral WWTP was developed, for the first time, based on the data gathered from literature review as well as extensive primary data analysis. The required data was collected using questionnaire, interviews and through selected case studies of WWTPs in the UK. In addition to the developed model, main findings of this study with their implications for wastewater industry in general and WWTPs in particular are as follows:

- *Energy-neutrality of a WWTP highly depends on energy efficiency of treatment stages and equipment. Implementing highly efficient technologies would reduce energy requirements and facilitate operating WWTP's energy-neutrally.*
- *Additionally, the WWTP's energy-neutrality is strongly dependant on the type of WWTP and treatment trains which have significant influence on actual energy demands of the plant.*
- *It was also concluded that the concept of an energy-neutral WWTP is more viable than an energy-independent WWTP because of security issues. In fact, in water and wastewater industries it is always essential to have an alternative reliable source of energy such as electricity from national grid for emergency situations.*
- *Although the idea of energy-neutral WWTP is technically possible, some considerations need to be taken into account to make this happen. For instance, it needs a high CAPEX and usually third party investment is required for these facilities.*
- *One of the main difficulties for utilising renewable energies facilities in WWTPs in later stages is the retrofitting high cost. Hence, early design considerations in the project lifecycle can make it more cost effective.*
- *A model was developed for an energy-neutral WWTP (see Figure 2). This model would be helpful for project managers, policy makers and construction and consultant companies likewise subject to minor modifications in planning a WWTP in feasibility through to operating phase of a project's lifecycle. It is also strongly recommended that this model should be adopted as early in the project lifecycle as possible to avoid extra costs for retrofit and adapted to the context-specifics of the project/plant in question.*
- *The practical barriers associated with the use of biogas for generating energy were identified. One of the most significant obstacles for generating energy from biogas is small amount of biogas generated in WWTPs. Certainly, the amount of biogas production is more important in smaller plants. In these plants due to lack of "economies of scale" generating electricity form biogas is not usually considered as cost-efficient as it is in bigger plants. Moreover, the small amount of biogas itself may stimulate other constraints such as technical and financial barriers.*
- *The data gathered in the literature review and through surveys, suggest that the small amount of biogas production is also an impediment to energy-neutrality of WWTPs. Implementation of one or two techniques for increasing biogas production may financially and technically justify the energy production in smaller plants. Hence, this would offer remarkable amount of savings on energy which would be considered wasted otherwise. Moreover, it is a step forward to operate them in an energy-neutral manner. Nonetheless, it is essential to have a right value management and feasibility study before investing on those technologies.*
- *As part of this study the share of the other renewable sources (excluding biogas), in providing energy for WWTPs were investigated. The results of the questionnaire and interviews indicated that currently these green energies (Solar-, Wind- and Hydro-power) in the UK do not cover considerable portion of WWTPs' energy requirements (less than 5%).*
- *Implementing renewable energies in WWTPs is expected to increase in the future. In addition, it was found in the study that the initial difficulty in this way is the lack of investment by the corresponding stakeholders.*

FURTHER RESEARCH

Based on the above elaborations, future research can be focused on solely or as a combination of the following areas:

- *During the course of investigation in this study, it became clear that there are multiple trains for treating sewage, but there is usually insufficient information about the energy used by the treatment trains. Thus a further investigation is suggested on how WWTPs can be operated more energy* *efficiently with special focus on using new techniques in this industry in order to achieve a highly efficient treatment process.*

• In this study it was illustrated that implementing methods and techniques for improving AD process and increasing biogas production will have a significant influence on energy-neutrality of WWTPs. It would be recommended as a future research, to investigate different techniques for improving AD process and to compare them in terms of their energy efficiency and economic viability.

• In conducting this study and developing the model for an energy-neutral WWTP, mostly technical issues were considered with information contributed only from eleven water companies in the UK. Thus, it would be recommended to conduct this study with consideration of financial issues such as payback period, capital costs, running costs and "economies of scale", gathering information from both water companies and the government agencies such as DEFRA, etc. Additionally, it is suggested to have an investigation of available financial incentives and obligation for WWTPs such as Feed-in Tariffs (FiTs), The Renewable Heat Incentive (RHI) and The Renewable Transport Fuels Obligation (RTFO).

• There are several novel technologies to produce energy or fuel as a by-product of sewage treatment. Hence, further research is needed to investigate their performance, reliability and cost-effectiveness. One of such novel technologies is conversion sludge to oil and gas under carefully controlled conditions. Processes include gasification, which produces syngas (similar to natural gas), and pyrolysis which produces biodiesel (EPU, 2006). These technologies however, are heavily context-dependent and need to be tested out in the context and modified accordingly. Action research is proposed in any context where such technologies are planned to be deployed to ensure the most predictable and efficient results are achieved.

• Another novel technology in this field is Microbial Fuel Cells. According to POST (2007), these devices offer the possibility of simultaneous sewage treatment and energy production, with water, CO_2 and inorganic residue as by-products. Here, bacteria use organic substances to produce electricity. To date, lab-scale microbial fuel cells have been developed that are able to power small devices, such as pocket-sized fans. Based on recent research by Oregon State University (2012), this technology enables electricity generation even more than the energy consumed in WWTP which can be a big step forward to make the plants energy-neutral. Therefore, it would be suggested to conduct research about possibility of using those novel technologies in WWTP in the UK. Similar to previous area, this need to be contextualised to the bacteria culture, climatic conditions and the construct of the bio solids where they are to be applied. This will require lab-based and subsequently action research. Furthermore, practicality of utilising those novel technologies in WWTPs should be investigated technically and financially.

REFERENCE

Defra. (2007). Study of Emerging Markets in the Environmental Industries Sector . Department for Environment, Food and Rural Affairs.

Defra. (2010). Anaerobic Digestion Strategy and Action Plan. Retrieved August 28, 2012, from http://www.biogas-info.co.uk/index.php/ad-strategy-a-action-plan.html

Defra. (2011). Government Review of Waste Policy in England . London : Crown.

Descoins, N. et al., 2012. Energy efficiency in waste water treatments plants: Optimization of activated sludge process coupled with anaerobic digestion. Energy, Volume 41, pp. 153-164.

DTI. (2006). The Energy Challenge Energy Review. Department of Trade and Industry. London : A National Statistics publication.

EPA. (2008). Catalog of CHP Technologies. Combined Heat and Power Partnership. Michigan: U.S. Environmental Protection Agency.

EPU. (2006). Biogas as a Transport Fuel . Retrieved July 25, 2012, from Environmental Protection UK: http://www.environmental-protection.org.uk/assets/library/documents/biogas_as_transport_fuel_june06.pdf

Hammer, M. J. (2012). Water and Wastewater Technology (7th ed.). London: Prentice Hall.

Oregon State University (OSU). (2012, August 14). Fuel cells: a replacement for wastewater activated sludge treatment. Retrieved August 17, 2012, from http://www.waterworld.com/articles/2012/08/fuel-cells-a-replacement-for-wastewater-activated-sludge-treatment.html?cmpid=$trackid

POST. (2007). Energy and Sewage. Houses of Parliament. London: Parliamentary Office of Science and Technology.

POST. (2011). Anaerobic Digestion. Houses of Parliament. London: Parliamentary Office of Science and Technology.

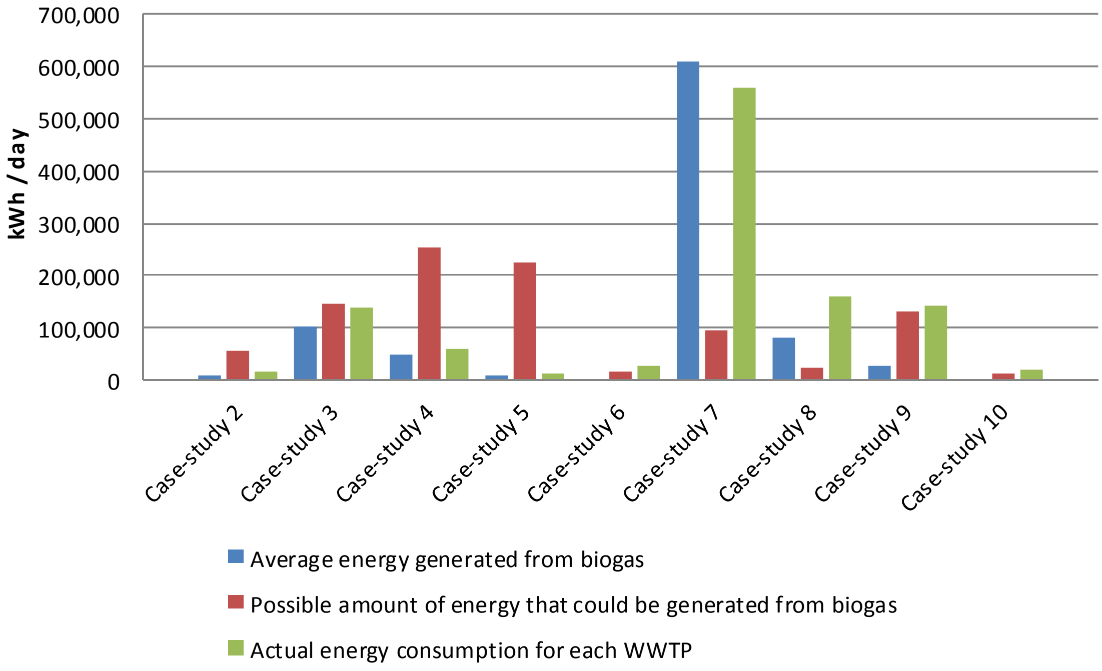

Figure 1: Case studies energy production and consumption status

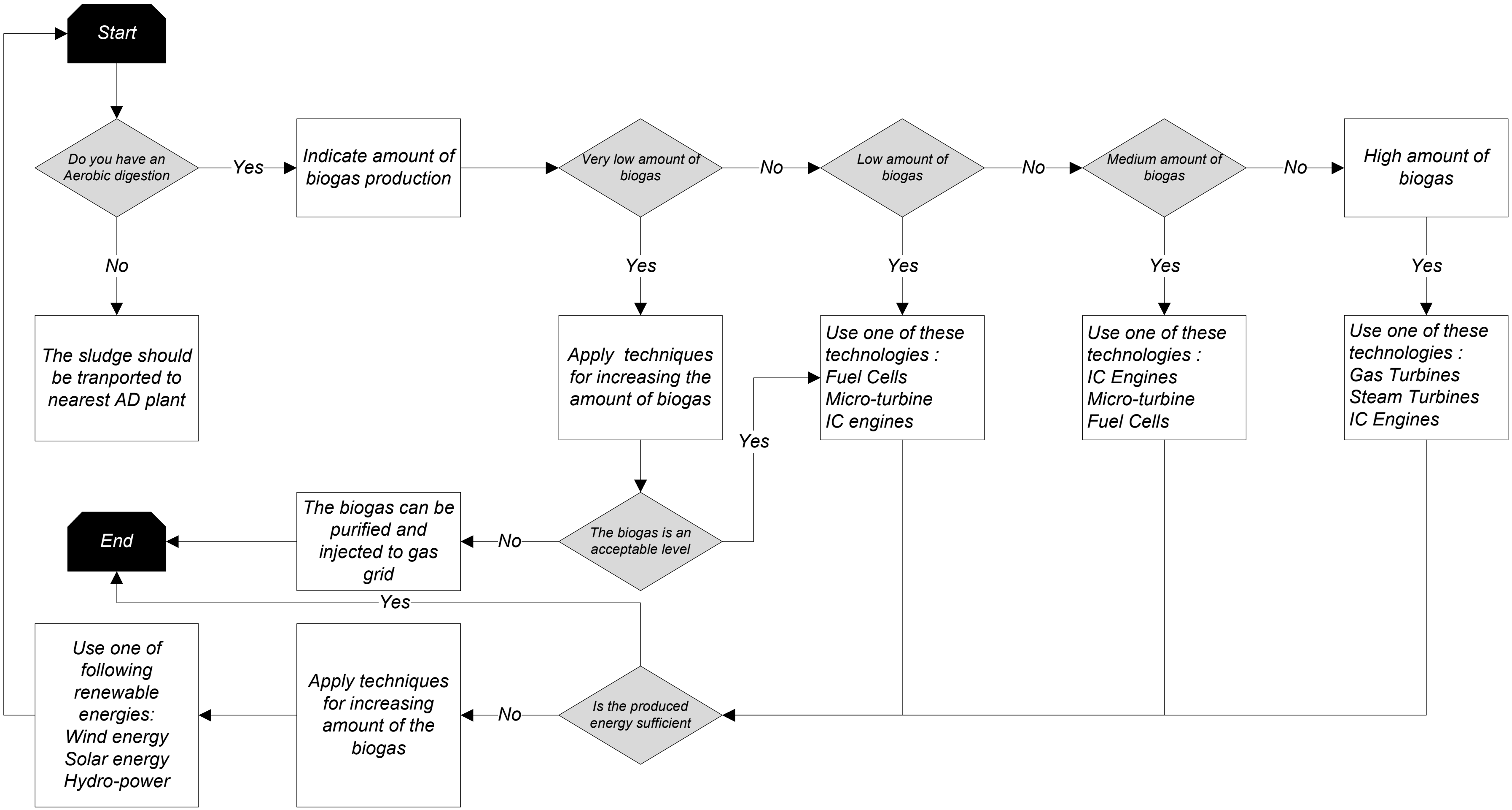

Figure 2: Proposed model for an energy-neutral WWTP

Table 1: Comparison of technologies available for generating electricity from biogas

Characteristic	**Technology Type**					
	Fuel Cells	**Internal Combustion Engine**	**Micro-turbine**	**Gas Combustion Turbine**	**Stirling Engines**	**Steam Turbines**
Capacity	< 1MW	< 5MW	30kW to 250kW	500kW to 40MW	< 200kW	50 kW to 250 MW
Fuels	Biogas	Biogas	Biogas	Biogas	Biomass, Biogas	Biomass, Biogas
Fuel Purification	High	Low	Medium	Low	None	None
Efficiency	Very High	Medium	High	Medium	Low	Medium
Operating Issues	Low durability and low noise	Fast start up, noisy, periodic maintenance needed	Fast start up, Gas compressor needed	High reliability, Noisy, regular Maintenance needed	Low noise	High reliability
Technology proven	some	Extensive	Extensive	Extensive	Limited	Extensive
Commercialisation Status	Few models available	Many models available	Few models available	Many models available	Commercially not available yet	Many models available
O&M Costs	High	Medium	Medium	Low	Low	Low
CHP Capability	Yes	Yes	Yes	Yes	Yes	No

Table 2 : Barriers Using Biogas as Renewable Energy

Category one	**Category two**
• **Investment risk and economic consideration**	• Lack of enough regulation
• **Technical barriers**	• Financial issues and long payback time
• **Financial issues and long payback time**	• High capital cost
• **High capital cost**	• Small plant size
• **Operation and maintenance difficulties**	
• **Small plant size**	