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Circular Economy: Life Cycle Cost Analysis of Management Alternatives for Sewage Sludge in Malaysia

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Abstract
Purpose: In this paper, the life cycle cost of two sludge waste management scenarios were studied. This paper also aims to compare the current practices and potential of treating sewage sludge to bio-waste for energy recovery. Sewage sludge generation from the wastewater treatment is the largest waste material and expected to increase in tandem with the increase of population and urbanization growth. This study also reviewed the economic system of the sludge treatment within the framework of a circular economy.
Design/methodology/approach: A case-based approach using life cycle cost analysis and cost estimation as well as the time factor of discount rate for expected expenses of the acquisition of the application with net present value determination are used in this paper.
Findings: Considering the case of the biogas application from sewage sludge could perform best in terms of economic feasibility. While converting sewage sludge into biofuel has great potential for energy production.
Research limitations/implications: The research cover on sludge management in the wastewater sector in Malaysia in term of economic viability. Despite this early investigation, there is a need to acquire understanding in the context of consumer and stakeholders demand to inspire radical changes in producing bio-waste from sludge for economic sustainability. It is also recommended the treatment cost nevertheless needs to be investigated further.
Practical implications: The results of this analysis will be an outstanding contribution to the relevant parties and policymakers. The alternative scenarios of sludge management would be used to test the robustness of current plants against a variety of alternatives. It could also help in identifying potential risk and mitigation plan upon making decision process.
Originality/value: The framework of the alternative scenarios and economic assessment on sludge treatment in the wastewater sector in Malaysia.

Keywords: Circular Economy, Life Cycle Cost, Sewage Sludge, Renewable Energy, Waste Management

Introduction

Sludge is a by-product of treatment of wastewater process and may usually contain many toxic substances, for example, heavy metals, pathogenic organisms and low-concentration poorly biodegradable organic compounds which can increase environmental pollution (Buonocore, Mellino, De Angelis, Liu, & Ulgiati, 2018; Inglezakis et al., 2016). However, the number of nutrients such as nitrogen, phosphorus, potassium, sulphur, other micronutrients and organic matter is high in sewage sludge and it is widely used as fertilizer and soil conditioner on the land (Inglezakis et al., 2016). Sewage sludge and industrial sludge are the two common types of sludge in which the sewage sludge is a combination of organic and also inorganic materials discharged from the municipal plants (Kacan, 2016).

In a developing country such as China, large quantities of sludge have been produced due to the rapid urbanization and industrialization and also because of the increment of wastewater treatment ratio (Dong, Liu, Dai, & Dai, 2013; C. Yang, Meng, Chen, & Xia, 2011; G. Yang, Zhang, & Wang, 2015). Therefore, the management of sewage sludge is vital and due to lack of clear legislation, lack of a framework for selecting the correct sludge management system and high investment and operational costs for rehabilitating old wastewater treatment facilities, especially in developing countries, the problem remains (Buonocore et al., 2018). Besides, (G. Yang et al., 2015) stated that the process of thickening, cooling, dewatering, stabilizing and drying, using different physical, chemical and biological technologies are the typical sludge treatment. There have already been other forms of treatment of sludge, such as sanitary waste, incineration, land usage and building materials.

As the sewage sludge may contain highly concentrated levels of contaminants but due to its nutrient value, a stabilized sludge which also known as biosolids is usually deemed ideal for land application. However, this application remains controversial (Yoshida, Christensen, & Scheutz, 2013). Physical (heat, desiccation, friction, irradiation and ultrasound), biological (anaerobic digestion and composting), and chemical processes (pH-, oxidants, biochemical by-products) are used in stabilization techniques to remove pathogens, disruptive odours and enhancing aesthetics and transportability (Yoshida et al., 2013). Some stabilisation measures, such as anaerobic digestion and pyrolysis, often offer an incentive for energy recovery. Due to its relatively low capital and operating cost, anaerobic digestion has attracted considerable interest in recent years among different approaches to convert organic matter in sludge to energy (Li, Jin, Zhang, O'Hara, & Mundree, 2017). The production of biogas and digestate from anaerobic digestion can be used as substitutes for traditional energy sources and fertilizers (Cartes, Neumann, Hospido, & Vidal, 2018).

In Malaysia, fossil fuel dominates the majority of electricity generation. In 2017, almost 82.3% of electricity is generated by using fossil fuel such as coal, natural gas and oil while the remaining of 17.7% was generated by renewable energy, including hydropower. The generation of electricity in Malaysia climbs almost 154% in 14 years from 1995 to 2009 (Shafie, Mahlia, Masjuki, & Andriyana, 2011) and electrification rate increased from 66% in 2009 to 94% in 2015. It is expected the generation of electricity to further hikes to satisfy the rises of electricity demand at 1.8% per annum in the next 11 years starting 2020, with coal shows an increasing percentage from 9.7% in 1995 to 44.3% in 2017 (Energy Commission Malaysia, 2020). The growing energy demand has resulted in becoming increasingly dependent on fossil fuels such as coal and gas. Fossil fuel depletion and environmental issues have encouraged the government and researchers to explore renewable energy as an alternative to energy sustainability. Lately, bioenergy sources from animal waste, agriculture waste,

municipal waste and wastewater effluents have attracted attention as an alternative resource in meeting the growing energy demand of global energy.
The study aims to examine the economic potential of treating sewage sludge waste for energy recovery based on a circular economy concept. The study compares the life cycle cost of treating sewage sludge to bio-waste using anaerobic digestion for energy production. The purpose is to provide insights into the potential consequences or benefits related to economic and environmental impacts associated with sludge waste treatment for energy recovery which serves as a starting point for further research of sludge waste utilisation in Malaysia.

Overview of Sewage Sludge Production in Malaysia
Sewage sludge is the residue produced by a wastewater treatment process and has the largest volume amongst all the components removed during the process. In global terms, the amount of sludge is expected to increase in the expense of an increase in the percentage of households connected to central wastewater treatment plants (Appels et al., 2011; Werther & Ogada, 1999). Malaysia has been expected to generate approximately three million m^3 of sewage sludge annually and is projected to raise seven million m^3 of sewage sludge a year by 2020 due to unregulated development, urbanization and population growth reported by Indah Water Konsortium (IWK) (Aziera & Majid, 2015; Hanum et al., 2019). By 2035, the sewage sludge production in Malaysia is estimated to reach 10 million m^3 per year (Lau, Teo, & Mannan, 2017). (Aziera & Majid, 2015) mentioned that without a proper treatment of large sewage sludge production may lead to severe environmental problems and the gross expense of sewage sludge treatment is currently about RM 1.07 billion per annum.
According to the Indah Water Konsortium (IWK) 2018, sewage treatment in today's modern sewage treatment plants is developed to create a high-quality effluent that can be safely drained into the environment or reused (Amran & Abdul Latif, 2018). Also, they stated that the effectiveness and performance of sewage treatment facilities have been improved to meet the requirements and reduced the land used by treatment works through increasing up natural treatment levels under regulated conditions. Nearly half of Malaysia's drainage schemes utilize mechanized plants while some still use septic tanks and oxidation ponds (Hanum et al., 2019). In Malaysia, the treated sewage sludge has been disposed of through landfill. One of the approaches to solve the sludge disposal issues as well as providing useful energy for society is by converting this waste into the usable energy (Zakaria, Hassan, & Faizairi, 2015). Depletion of fossil fuels and environmental issues have led to a comprehensive research and development programs to investigate alternative energy such as biogas production from anaerobic digestion (Kumaran, Hephzibah, Sivasankari, Saifuddin, & Shamsuddin, 2016). (Amran & Abdul Latif, 2018) has emphasized that sewage sludge can also be used to produce renewable energy, therefore reduces the effects on climate change (Amran & Abdul Latif, 2018).
In moving towards energy sustainability, the circular economy concept can replace the current linear economy that will allow productive use of energy by reducing, reuse and recycle (3R) in which the circular economy activities will optimize the usage of resources which converting waste to energy, and reduce the amount of waste produced (Abas & Zainal, 2018). The circular economy defined as in which the products, materials and resources should be maintained in the economy for as long as possible, and waste should be treated as secondary raw materials that can be recovered for recycling and re-use (Neczaj & Grosser, 2018; Ponsá et al., 2017). In the case of sewage sludge, (Tsybina & Wuensch, 2018) stated the characteristics of a circular economy, for example, are the exclusion of waste management in landfills, exclusion of pollutant emissions into the environment, reuse or recycling or energy recovery, reduction of primary natural resources production, fossil fuels and power consumption relative to the current system model and exclusion of accumulation of environmentally hazardous substances and

living organisms. Figure 1 presents a conceptual framework of relationship between environment, waste to energy and circular economy systems for facing existing environmental problems and resource scarcity. The circular economy concept was chosen as a basis of analysis in this study, since it is one of the important concepts of economic development underscores by many developed countries in the field of energy sustainability. In the case of the sewage sludge, the study should be focused on the key areas of waste management and secondary raw materials.

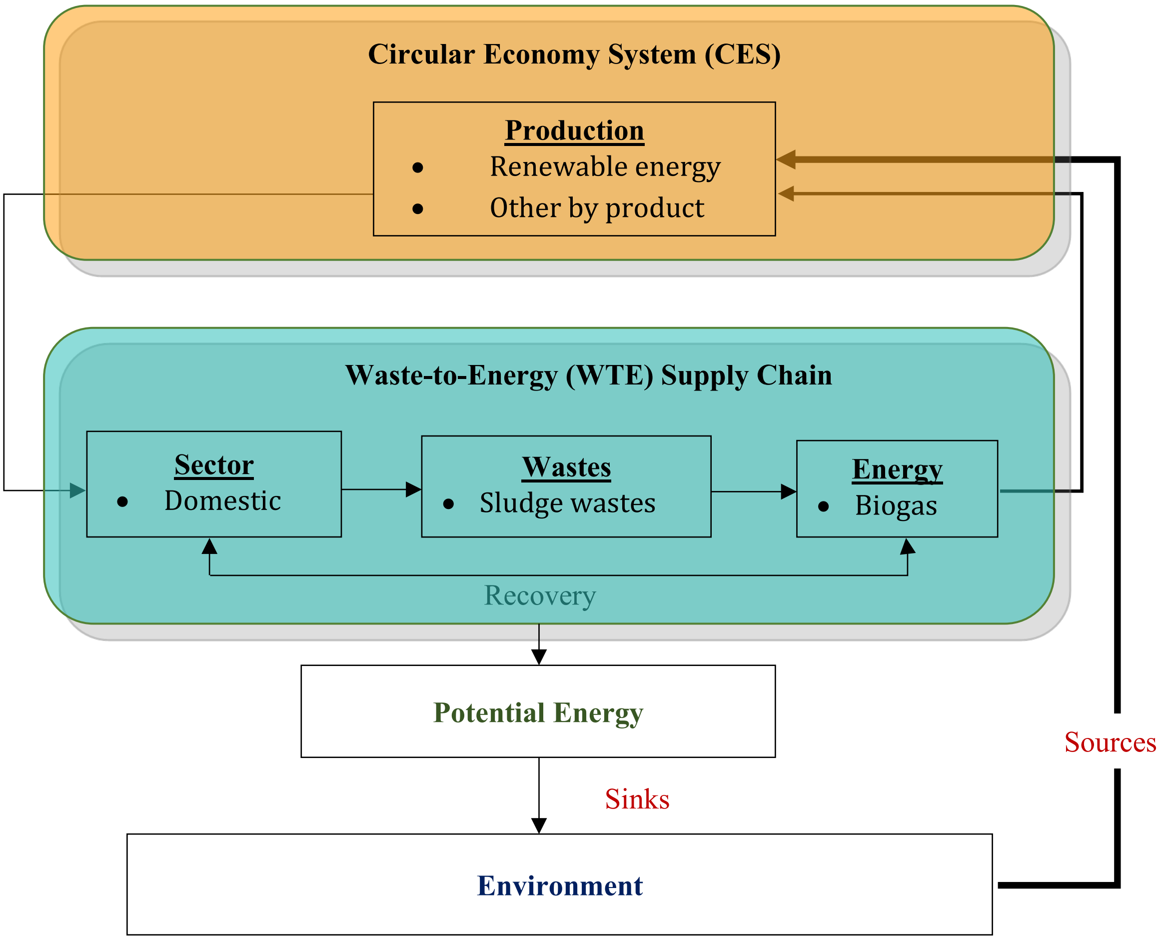

Figure 1: Conceptual framework of the relationship between environment, waste-to-energy (WTE) and circular economy system (CES)

As indicated in Figure 2, waste management and the recovery of secondary raw materials play a central role in a circular economy. As illustrated, to deliver the best environmental outcome, biological materials are to be returned to the natural metabolic cycles after the necessary pre-treatment, such as digestion or composting (Point B). The waste that cannot be prevented or recycled is to be used for the recovery of its energy potential, which is considered preferable to landfilling (Point A). The introduction of secondary raw materials or by-products into the economy is considered a positive factor that extends the security of supply (Point C). Transformation of waste into secondary raw materials ensures reorganization of linear material flows of a conventional economy into circular flows, where waste generation is excluded.

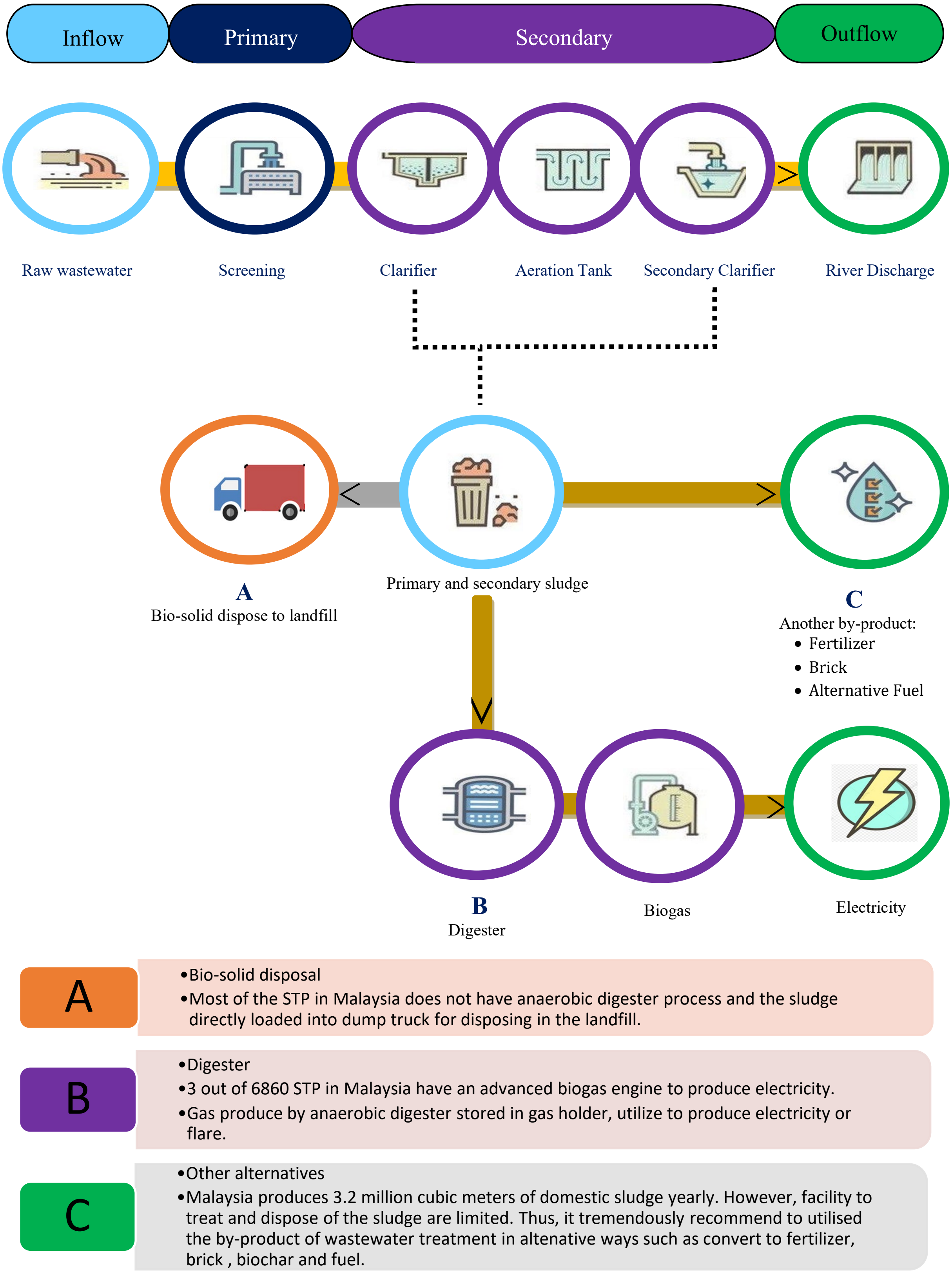

Figure 2: Circular Economy Concept in Sewage Sludge Treatment

Methodology

The work aims to assess the economic cost of waste management and recovery of secondary raw materials focusing on the comparison between advanced waste management and common practices in Malaysia. To enable decision-makers to draw a sustainable wastewater services and sludge disposal policy, clear evidence about the management preferences is in need to portray the huge potential available in the system. The life cycle cost (LCC) approach is one of the most important methodologies when planning and specifying an alternative (Bhoye, Saner, & Aher, 2016). There are several approaches for LCC calculation as being proposed by (Heralova, 2014). However, this study embarks a deterministic approach which is based on the expert assessment of input in discrete values (Diependaele, 2018). The economic feasibility analysis is conducted by examining the Net Present Value (NPV), Internal Rate of Return (IRR), and cost benefits methods and sensitivity analyses is provided to examine the influences of energy recovery scenarios as depicted in Figure 3.

Data Collection

The research was conducted for two sewerage treatment plant (STP) area in Peninsular Malaysia as described in Figure 3.First, STP A with 360,000 population equivalent (PE) and their business as the usual daily operation is without anaerobic digestion process and the sludge waste is dumped into the landfill. Secondly, STP B with 377,000 PE was selected. The daily operation is with anaerobic digestion process with electricity recovery from biogas production and the remaining sludge waste is dumped into the landfill. The anaerobic digestion process is added to reduce the mass sludge for disposal and producing rich biogas (methane) for energy recovery.

Appropriate variables including the capital cost, operation and maintenance cost, electricity cost, and revenue as well as benefits were collected and generalised from the wastewater treatment plants and this data were complemented with benchmarking and literature data when required. Inputs during the operational stage (i.e., polymer, security, labour) were included. Detail information on the generalised parameters used to calculate the LCC is provided in Table 1 below.

Table 1: Summary of Parameter Inventory Data

Parameter	**Unit**	**Parameter**	**Unit**
Population Equivalent	PE	Capital Cost	RM Million
Flow Rate Capacity	kg	Maintenance Cost	
Total Sludge Production and Disposal	m^3/Year	Operational Cost	
Total Biogas Production (Output)	m^3/Year	Energy	
Electricity Consumption (Input) Electricity Generation (Output)	kWh/Year	Polymer	
Life Cycle	25 Years	Administration	
Discount Rate	8.0 %	Labour	
Growth Rate	3.0 %	Security	
Revenue	RM Million	Waste Disposal	
Tariff and Other Services Revenue		Sludge Disposal	
Benefits		Water consumption	
Bio-fuel Cost	RM324/tonne	Biochemical Oxygen Demand (BOD)	kg/Year
Electricity Cost	RM0.37/kWh		

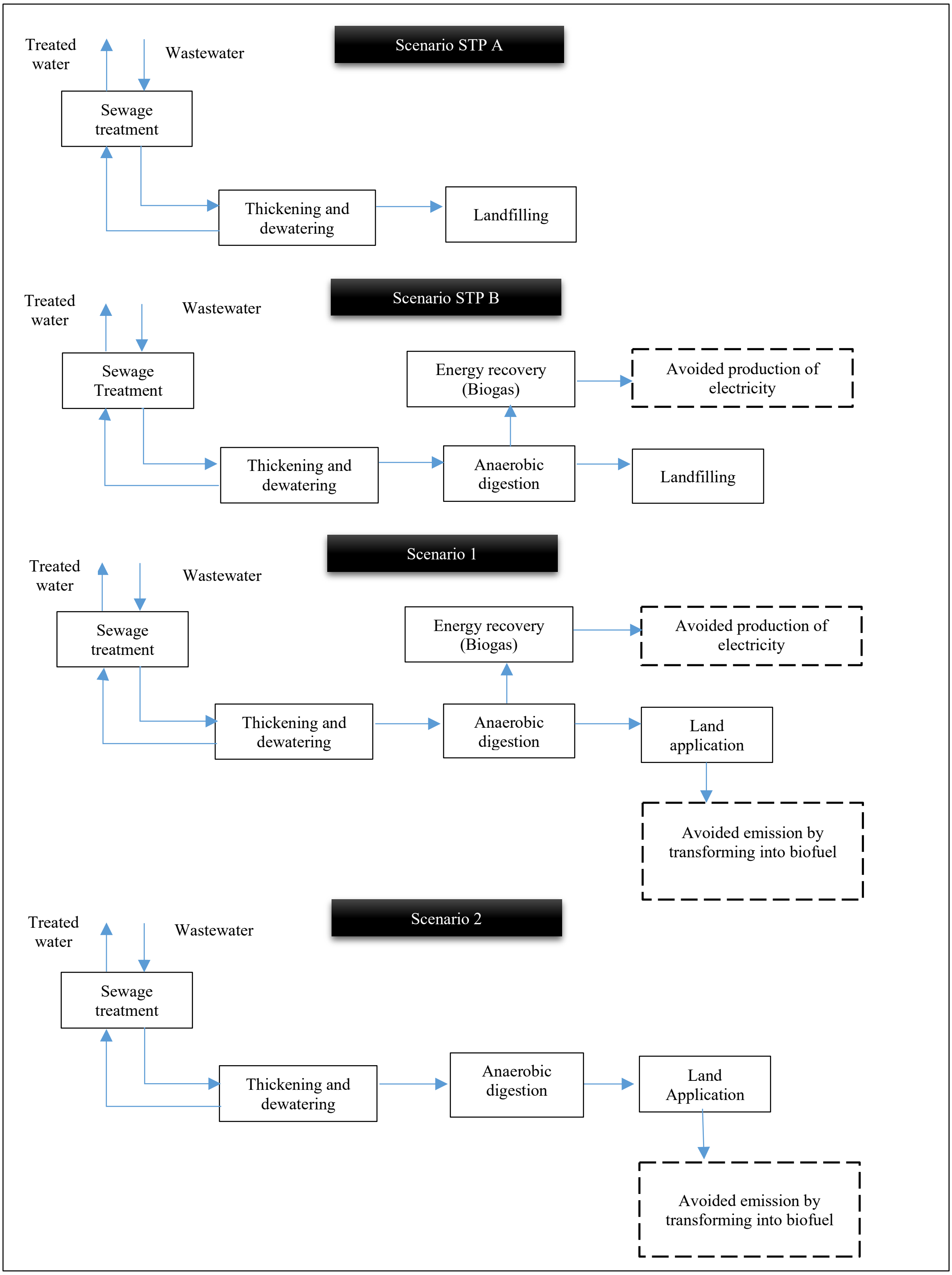

Figure 3: Scenario Framework. Dashed lines represent avoided product and emission.

Data Analysis
The economic feasibility of energy recovery and by-product transformation to biofuel from the sludge of the STPs was analysed. Both STPs were modelled into two energy recovery scenarios as per Table 2 below and Figure 3 above:

Table 2: Summary of Scenario Cases

Plant	Scenarios 1	Scenario 2
STP A	Installed anaerobic digester for biogas production for energy recovery. It assumed the electricity produced credits the system by displacing grid-produced electricity.	The remaining sludge waste dried to produce biofuel and sell to utilities.
STP B	Improve the efficiency rate of the biogas engine and anaerobic digester to produce more biogas for generating electricity and selling the remaining sludge production. It assumed the electricity produced credits the system by displacing grid-produced electricity.	The remaining sludge waste dried to produce biofuel and sell to utilities.

The net present value would be calculated by the following formula (1). The base year for the analysis was in 2018 and all the value was converted to a base year.

$$LCC = C_A + \sum_{t=0}^{LC} \frac{C_t}{(1+r)^t} \qquad (1)$$

LCC - Current Value of Total Life Cycle Cost
CA - Acquisition Cost
r - Discount Rate (time value of money)
LC - Life Cycle
CT - Sum of relevant LCC of the property after deducting the positive cash flow

Meanwhile, the formula for calculation of the current value of the total life cycle cost was determined as following formula (2):

$$LCC = C_A + \sum_{t=1}^{LC} C_t \times \frac{(1+r)^n - 1}{(1+r)^n \times r} \pm \left(\frac{1}{(1+r)^n} \times NBV\right) \qquad (2)$$

NBV - Net Book Value

It is also necessary to modify the discount rate if the cash flows are displayed in the constant price and the inflation rate is low and stable. As been suggested by (Kampf, Potkány, Krajčírová, & Marcineková, 2016), the modification of discount rate is by using the inflation rate, and could be quantified by the following formula (3):

$$discount\ rate\ (r) = \frac{\emptyset\ interet\ rate\ \times 100}{\emptyset\ inflation\ rate\ \times 100} \quad (3)$$

Furthermore, to calculate the discount rate, interest rate and inflation rate was considered for a 25-year concession.

Sensitivity Analysis

A sensitivity analysis was performed in the presence of fossil carbon in the sludge. Anaerobic digestion is a common technology to biologically stabilize wasted solids produced in wastewater treatment globally. In Malaysia, some of the modern mechanized plants have been upgraded with anaerobic digesters whereby the bio-solid are treated anaerobically to produce methane. Based on the methane production from secondary thickened sludge of population of 30.1 million people in Malaysia, the sewerage treatment plant has the potential to generate 130.3 MWh per year of biogas energy. For calculating the potential, the assumed of 0.25m^3 of wastewater generated per day per person, an anaerobic conversion factor of organic carbon to methane of 0.35 m^3 CH4 per kgCOD with the calorific value of methane being 37,750 kJ/m^3 CH4 with gas engine conversion efficiency of 40% and the gas engine is operated 330 days per year (Harikishan, 2008). By utilizing these values, Malaysia can potentially provide 94,166.7 m^3 CH4, assuming medium-strength wastewater and can efficiently deliver enough electricity for internal usage even for neighboring households of the plant. However, at present, the biogas production is at an average of 1,010 m^3 per day. This is due to the inflow's low solid content and poor degradability of volatile solids.

Nevertheless, in terms of technical aspects, improper operation of the anaerobic digestion also could lead to low biogas yield. Several elements are limiting the full utilization of methane from existing and planned wastewater treatment plants such as the cost of initial or capital investment, technological aspects, the return of investment, reliability, continuity, and awareness. Hence, this study highlights three scenarios whereby the assumptions on the engine conversion efficiency were 0%, 70% and 90% recovery toward the existing plant that has biogas facility. It's assumed to have no target reduction of methane emission for several existing plants. However, the 70% target reduction is averaged from the current practice of major STPs. The 90% target is assumed to be achievable based on the role model plants that currently on the operation.

Table 3: Estimation of Methane Emission Reduction from Sewage Sludge Treatment for Energy Recovery.

Plant	Methane Emission (without Recovery)	Methane Recovered Emissions (kg CH4)		Net Methane Emissions (kg CH4)	
		*70%	*90%	*70%	*90%
STP A	23.077	16.150	20.770	6.923	2.308
STP B	24.167	16.920	21.750	7.250	2.417
Total	**47.244**			**14.173**	**4.725**

*Efficiency Rate

Result and Finding

From the LCC analysis, it is found that the total life cycle cost for STP A based on Scenario 1 is RM232,632,770 and Scenario 2 is RM189,982,378. While STP B recorded RM242,622,199 and RM123,351,942 for Scenario 1 and Scenario 2, respectively in the 25-year concession. Overall, all the scenario cases could generate net revenue when the sludge treated by anaerobic digester technology. The summary of the LCC result as per in Table 4 below and the estimation of emission reduction as per Table 3 above:

Table 4: Summary of Life Cycle Cost Analysis

Plant	Item	Scenario 1	Scenario 2
STP A	NPV	RM232,632,770	RM189,982,378
	IRR	14%	3%
	ROI	313%	157%
	Payback Period	7	15
STP B	NPV	RM242,622,199	RM123,351,942
	IRR	-1%	-10%
	ROI	13%	-15%
	Payback Period	>25	>25

LCC-Life Cycle Cost, IRR-Internal Rate of Return, ROI-Return on Investment

The LCC analysis showed the total life cycle cost (LCC) is higher for Scenario 1 in both STP A and STP B. In the case of STP A, the application of anaerobic digester (S1) has significantly positive IRR and NPV of RM232,632,770 million, indicating of beneficial investment for the treatment facility with a payback period of 7 years as compared to the investment required to dry the sludge waste into biofuel (S2) for utility usage. The reasons of this might due to the higher capital investment for installing a modern and efficient technology for the biogas facility which requires large assets and capital intensive (Rebitanim, Wan Ab Karim Ghani, Rebitanim, & Amran Mohd Salleh, 2013). The potential benefit of S1 attributed to displacing the burden associated with grid electricity consumption and disposal cost avoidance. While in STP B, it is estimated that within 25 years, the NPV of S1 and S2 are RM242,622,199 million and RM123,351,942 million, respectively. From the estimation, it offers the value of investing through selling all the sludge production as biofuel relatively better than the two-fold alternative which is to improve the efficiency rate of the biogas engine and anaerobic digester to produce more biogas for generating electricity. This result is consistent with the case of the UK which found the option to create biofuel was the most economical and sustainable solution (Mills et al., 2014). However, from the IRR and ROI perspective, the investment of Scenario 1 and 2 in STP B seems not worthwhile in the 25-year concession. However, with the improvement of the digester operation and selling all the sludge remaining, the investment of S1 over S2 is relatively worthwhile with a 13 per cent return on investment and an almost positive return on internal growth.

Based on Table 3 above, it estimated that if the engine conversion efficiency is running with 90% efficiency rate, the net emission could be only 2.308 kg CH_4 for STP A and 2.417 kg CH_4 for STP B with both totals of 4.725 kg CH_4. It is fewer amounts of emission rather than if the plant ran without biogas facility whereby it could contribute to 47.244 kg CH_4 emitted. Even though it is still not economically feasible for commercial implementation due to quality and quantity-wise, but the results show the move from conventional technology to implement the biogas facility in wastewater treatment plant has advantages due to its net environmental impact which support the future direction of wastewater treatment in Malaysia in reducing the greenhouse gas emission. On the other hand, instead of it could reduce fossil fuel utilization, having a biogas facility could boosting the renewable energy share in mix energy generation.

Conclusion

The sewerage treatment plant is a non-profit organization instead it has a huge responsibility in the provision of public services. However, in recent years more country witnessed the changes in a way of public services. Further privatization has experimented and development of various forms of public-private partnership is newly entering the organization arrangement. This is due to the distinguishing economic and legal feature of a non-profit where the role is limited and quality (Bennett, 2003). Besides, in term of technology, the study has found that the case in STP A for S1 where installing biogas facility to convent electricity has advantages over other choices from the cost point of view as the electricity cost largely known as the major burden cost for every STP could be reduced. The anaerobic digester able to improve the energy yield and to effectively implement the proposed scenarios at large scale across Malaysia, efforts must be made in facilitating the operator by providing grants and financial support until the tariffs could help to recover the operational expenses. Besides, the operator also should have more leniency in conversing their loans and debt while providing infrastructure, especially in rural areas. As the current tariff is too low as compared to the servicing operation cost, it is recommended that an independent party or entity perhaps SPAN should take the responsibility of reviewing and deciding the tariff until it reaches full recovery by 2030 (Akademi Sains Malaysia, 2015). On the other hand, the initiative to use alternative sources such as rainwater harvesting of efforts to recycle, reuse and reduce water consumption should be more emphasized to anticipate in the present circumstances. In term of pollution from sewerage sector, the eco-friendly services and greener technology could maximize the usage of sludge where it could lead the plant to achieve near-zero waste production and develops better management of sludge as well as reduce the emission and pollution. The standard of STP effluent needs to be improved to enable reuse practice while reducing pollution loading to the rivers too. To ensure appropriate exercise usable in managing the wastewater, it good to build up the capacity building, established centralized training centre, understand, and develop research parallel to industry problems and needs. Nevertheless, the most important preparation is educating the future generation on the importance of sewerage treatment as a public health and environmental concern to ensure the benefit for the society and the country's economic growth. Improving process and technology through the adoption of circular economy concept could provide significant benefits for further energy recovery from sludge and life cycle cost analysis support to determine the best overall option for the decision process.

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