Technology selection and siting of a biogas plant for OFMSW via multi-criteria decision analysis

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Abstract

Multi-criteria decision analysis (MCDA) techniques were applied to choose a biogas digester technology and a site from a list of potential alternatives for an anaerobic digestion (AD) system utilising the organic fraction of municipal solid waste (OFMSW) based on a case study at the University of Johannesburg's Doornfontein campus in South Africa. The simple multi-attribute rating technique (SMART) and analytic hierarchy process (AHP) techniques of MCDA were used to select a suitable biodigester model and site respectively. From a list of 14 biodigester technologies to be established at 1 of 3 potential sites in the study area, the most preferred model was the Puxin digester to be sited near the Aurum ladies' residence within the school campus to supply biogas for heating purposes.

1. Introduction

There have been sustained concerns about the increased municipal waste generation rates in urban centres worldwide and the constantly reducing space due to rapid population growths coupled with infrastructure development. In most cases, the municipal solid waste (MSW) generated is usually sorted for recycling and the non-recyclables which are usually the larger portion are taken to landfills. However, the space for landfilling is quickly dwindling and the landfilled waste is leading to uncontrolled continuous emissions of landfill gas containing mostly methane which is a potential greenhouse gas (GHG) with a global warming potential (GWP) of 21(Kigozi et al., 2014). The possibility of bioenergy production from the organic fraction of municipal solid waste (OFMSW) as an integrated solid waste management strategy represents a scenario where an alternative source of clean energy is obtained, GHG emissions

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are reduced and at the same time minimising the nuisance of solid waste (Kumar, 2012; Weiland, 2010).

Energy from OFMSW can be recovered through incineration, pyrolysis/gasification and anaerobic digestion (AD). In addition to energy recovery, anaerobic digestion conserves the original water content of the waste and produces a nutrient rich organic agricultural fertilizer in the form of a digestate unlike the rest of the methods which burn off the water and produce toxic carbon and heavy metal rich by-products making AD the most environmentally friendly waste to energy technology of all (Klinghoffer & Castaldi, 2013; Murphy & McKeogh, 2004).

As opposed to other biodegradable wastes such as farm manure and municipal sewerage, OFMSW as an AD substrate has a typically high biogas yield per unit volume and it is readily available in abundance. However, there are some draw-backs on the use of OFMSW as a substrate for production of biogas such as its heterogeneous nature and relatively larger particle sizes, all of which lead to higher feedstock pre-treatment costs (Kigozi et al., 2014; Mata-Alvarez et al., 2000). Any technological intervention for anaerobic digestion of OFMSW should therefore be able to address quite a number of factors such as cost effectiveness, reliability, feedstock adaptability, availability and ease of construction as well as ease of operation and maintenance. Ideally, the most preferred choice of AD technology should be one that is obtainable at the least possible initial and maintenance costs while at the same time achieving optimum biogas production rates at the set conditions of feedstock quantity and quality (Igoni et al., 2008). The choice of site for locating a biogas digester on the other hand also depends on a similarly complex set of variables such as proximity to substrate source, availability of space, proximity to point of application, current and projected land use patterns, ground conditions, presence of utility lines, accessibility, proximity to point of digestate disposal, climate and property rights on the proposed site (Ma et al., 2005).

As part of a larger waste-to-energy project, the University of Johannesburg (UJ) in South Africa is planning a pilot scale biogas plant at its Doornfontein Campus (DFC) based on OFMSW generated within the campus as feedstock. To support unbiased and rational decisions on technology and site selection for the project, system analysis techniques commonly referred to as Decision Support (DS) tools were adopted.

Organisations apply DS tools for a wide variety of activities and problems such as; acquisition of assets, recruitment of staff, technology selection, site selection and risk analysis among others. Decision making tasks are most often probabilistic and multi-dimensional in nature, therefore the decision making process calls for DS tools that can capture these complexities. To make unbiased choices, the decision making process typically entails;

identification of the problem, choice of possible options or alternatives to solving the problem, and use of weighted selection criteria (Kirby & Mavris, 2000).

DS tools for technology selection problems include;

- Multi-criteria Decision Analysis (MCDA) techniques which are employed to choose from a set alternatives based on how they score against a pre-defined set of criteria. A choice of the most preferred alternative is then made of the one with the highest score (Chai et al., 2013). There are several approaches in the application of MCDA techniques. These include; The Analytic Hierarchy Process (AHP) which aims at organising and analysing complex decisions basing on the relative importance of alternatives and criteria independent of each other using pair-wise comparisons (Pohekar & Ramachandran, 2004; Saaty, 2004) and the Simple Multi-Attribute Rating Technique (SMART) in which ranking of alternatives is based on ratings that are assigned directly from the natural scales of the alternatives (Barron & Barrett, 1996). In situations where the units of measurement for the weights of the criteria for given alternatives are not of a common scale, the decision maker has to create a unifying function referred to as a "value function". In AHP this is taken care of by the relative nature of the rating technique (Belton, 1986).

- The scenario method by use of grey statistics. This is primarily applied for technology selection problems with large future variability and inadequate historical data for reference by suggesting strategic proposals. The proposals are obtained through involvement of the stakeholders whose opinions are sought to give grey statistics that are later fed into modelled scenarios to simulate solutions (Kirby & Mavris, 2000).

- Technology Identification, Evaluation, and Selection (TIES) method uses the probability of success of a technology to make a choice based on benefit, time and budget (Kirby & Mavris, 2000; Wei & Chung, 2003).

- Marginal Analysis Guided Technology Evaluation and Selection method which is an Early Stage Technology (EST) evaluation method used specifically for selection of technologies whose future is uncertain and not yet well studied relying on the information and knowledge from previous experiences to support future project evaluation and selection (Tan et al., 2011).

On the other hand, site selection for plant set up can be guided by other DS models which include;

- The Weighted Factor Rating (WFR) Method which is an MCDA technique using important location factors such as available space, environmental impact and distances among others to make analyses that yield the most preferred choice of site based on a

scoring system of alternatives against the chosen factors after which a choice of site is made of the one with the highest score (Kumar & Suresh, 2008; Mahadevan, 2010).

- The Centre of gravity method which is primarily based on the concept of distance and transport cost considerations taking into account the alternative sites and their distribution points eventually making a choice of the most preferred site as one with the least weighted distance between the plant and its distribution points (Hiregoudar & Reddy, 2007).

- The Break even analysis method employs location economics aiming to obtain the site that will give the shortest project breakeven period via break even analyses (Kumar & Suresh, 2008).

In this study, both site and technology selections for the proposed biogas digesters were carried out using MCDA techniques owing to their robustness and simplicity as well as the fact that the selection criteria were obtainable and measurable at the same time. There are a number of previous applications of MCDA as DS tools for both site and technology selection in AD systems' design such as; Kuria and Maringa (2008) who applied a scale of 1-10 to score three (3) anaerobic biodigester models to make the most preferred choice of alternative based on a list of selection criteria for small scale biogas units (Kuria & Maringa, 2008). The study compared the fixed dome, floating drum and flexible bag digesters, and the floating drum model scored highest. However, the study did not consider the relative importance of each selection criteria; it assumed that all criteria were equally important. In addition, the three models considered in the study were rather generic compared to the models currently on the market worldwide that possess design specifics (Kuria & Maringa, 2008). Ma et al. (2005) employed the AHP technique of MCDA to ascertain the relative importance of site selection criteria in an effort to develop a geographical information system (GIS) based model for siting farm-based centralised AD systems in Tompkins County, New York, U.S.A. The study employed MCDA in combination with GIS based approaches (Ma et al., 2005). Karagiannidis and Perkoulidis (2009) used MCDA as a DS tool via the Electre III technique to choose the most preferred biogas digester technology from five (5) models for the anaerobic digestion of OFMSW. The study showed that MCDA techniques are practical and feasible for the integrated assessment and ranking of AD technologies (Karagiannidis & Perkoulidis, 2009). Despite the several examples of MCDA applications for AD systems, there has been no such previous area specific study applied for the South African environment which has up to now faced challenges in the implementation of AD systems. This paper presents the results of applying MCDA techniques for supporting decisions on the selection of the most suitable biogas technology for the waste-

to-energy UJ-SANEDI project, and the choice of the most preferred site on the UJ DFC campus for installing the proposed biogas digester.

2. Materials and Methods

2.1 Digester Model Selection

The SMART technique of MCDA was used to analyse the various biodigester models owing to the fact that all their attributes were directly measurable and non-subjective. In addition, the SMART technique supports the evaluation of an elastic set of alternatives, which makes it better suited for constantly changing sets of variables such as supplier lists, unlike other MCDA techniques such as AHP and ANP.

In applying SMART to select the most preferred biogas digester model, the steps below were followed;

- Identification of the goals/objectives; the objective of the analysis was to make a decision on what the most preferred biogas plant was for the project under consideration,
- Listing of potential alternatives; a list was made of the 14 biogas digesters herein also referred to as the alternatives from which a choice would be made. These are as shown in Table 1,
- A list of selection criteria was built basing on factors that are considered for selection of a biogas plant. Such factors include temperature regulation abilities, local availability, ease of construction and study specific factors such as the plant's suitability to treat OFMSW. Details are as shown in Table 3.
- Creation of a unified weighting scale for the set criteria basing on their level of importance. The criteria were then assigned weights ranging between 0 to1. Unifying the weights implies that the sum of all weights is equal to 1. That is;

$$\sum_{i=1}^{n} W_i = 1 \qquad (1)$$

Where;

W_i is the unified weight of criteria i.

Weights of corresponding criteria are also listed in Table 3 alongside justifications for their corresponding values.

- Assignment of scores to individual alternatives depending on how they score on the set criteria ranging from 0 to 1.
- Computation of the weighted ranks (R) of individual alternatives as a sum of the product of scores and factor weights. That is;

$$\sum_{i=1}^{n} W_i S_1 = R_1 \qquad (2)$$

Where;

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R_1 is the rank of alternative 1,

And S_1 is the score of alternative 1 with regards to criteria i.

- Then finally, a decision was made on the most preferred digester basing on one with the highest rank. Details of the ranking according to corresponding aggregate scores of alternatives as shown in Table 5.

2.2   Site Selection

For site selection, the AHP technique of MCDA was adopted owing to its ability to include pair-wise comparisons of the alternatives as well as the criteria to emphasize relative importance and independence of the alternatives. This gives a more accurate result for comparison of spatial data. The procedure followed was as below;

- Identification of the goal/objective; the objective of the analysis was to make a decision on what the most preferred site was for siting a biogas plant around the UJ Doornfontein Campus,

- Choice of alternatives; preliminary surveys guided by stakeholder meetings were conducted around the school campus in search for potential alternatives. This yielded a total of three (3) locations on which detailed studies and analyses were undertaken to make the choice of the most preferred site. That is; the site near the existing waste transfer station (WTS), near the students' centre (SC) and finally next to Aurum ladies residence (AR). A list of these and their attributes is presented in Table 2. And figure 1 shows a google maps' satellite image of the relative locations of the 3 sites at the UJ DFC campus.

- Choice of selection criteria; a list of factors herein referred to as the criteria was made against which the sites would be scored. These included among others the available area at the site and distance from feedstock source. Details of these are given in Table 4.

Using the 1-9 AHP fundamental scale of scores (Saaty, 2004), pairwise comparisons of the alternatives were made with regards to each criterion using a Microsoft excel programmed sheet. These would finally yield priorities of the alternatives with respect to a particular criterion. The obtained priority values are as presented in Table 4**.** Using the same scale, pairwise comparisons were made for the various criteria against each other as well basing on how well they satisfy the set objective and their relative priorities obtained. The obtained priority values are as presented in Table 6.

- Total aggregate priorities were obtained as sums of the products of the individual priorities of alternatives and criteria. For alternative A whose priorities according to criteria 1, 2, 3 and n are P_{a1}, P_{a2}, P_{a3} and P_{an}, its aggregate score S_a is given by the equation 3;

$$S_a = [p_I(P_{a1}) + p_{II}(P_{a2}) + p_{III}(P_{a3}) + p_n(P_{an})] \quad (3)$$

Where p_I, p_{II}, p_{III} and p_n are the relative priorities of the criteria 1, 2, 3 and n. The results from the scoring are as shown in Table 6.

- Then finally, the decision on the most preferred site basing on one with the highest score was made.

3. Results and Discussion

3.1 Potential Alternatives

The developed lists of biogas digesters and potential sites alongside a summary of their attributes are presented in Tables 1 and 2 respectively. In addition, Figure 1 shows the relative locations of the proposed sites at the school campus as viewed from a google maps' satellite image.
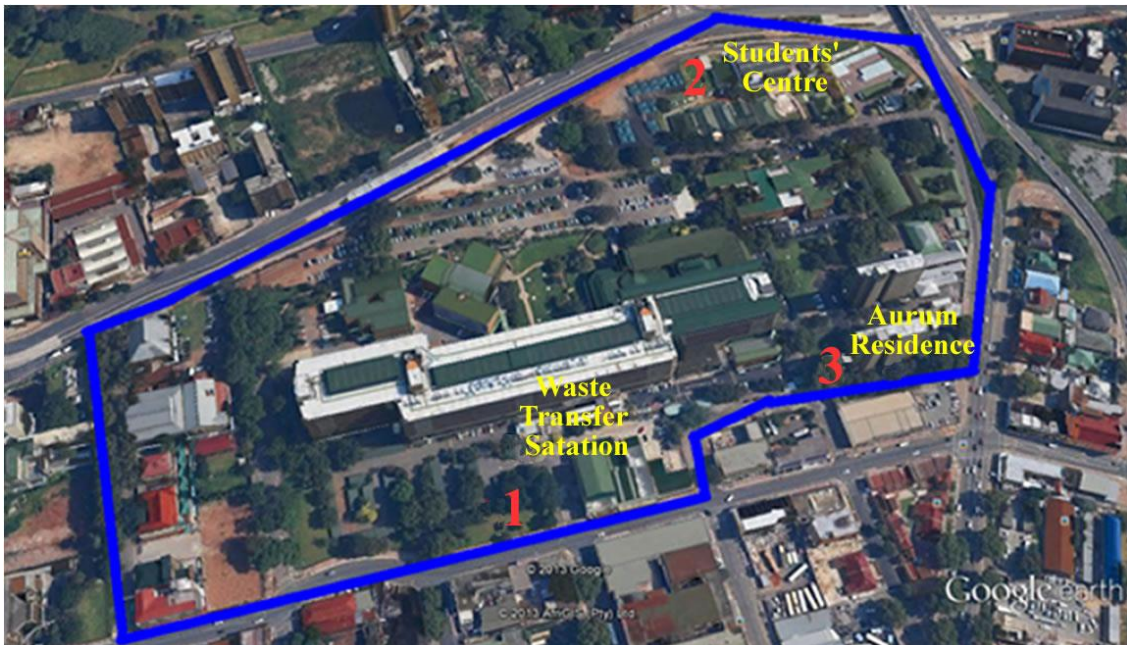

Figure 1: A google maps' satellite image of the UJ DFC showing the proposed sites

Table 1

A list of potential technologies of biogas digesters and their specifications

A	B	C	D	E	F	G	H	I
Agama Pro 6	BiogasPro S.A	6 max	Yes	45	Buried Underground	Polyfibre Tank	South Africa	Manual
Puxin	BiogasSA	10 max	Yes	60	Buried Underground	In-situ Concrete	China/ South Africa	Hydraulic
Bio4gas	IBERT	From 200	Yes	600	Incorporated CHP generator	In-situ Concrete	Germany/ South Africa	Incorporated
GREENBOX	AEPS	From 100	Yes	1,200	Insulated	On-site steel	Germany/ South Africa	Incorporated
Geo membrane	Biotech	35	Yes	180	None	Polyfibre tank	India	Manual
WELTEC	Weltec	2,500	Yes	25,000	Incorporated	Stainless Steel	Germany	Incorporated

PVC Portable digester	Chongqing Biogas New Energy Co.	10	NO	10	Buried underground	Concrete	Chongqing, China	None
ÖKOBIT	ÖKOBIT	2,500	Yes	20,000	Incorporated	Stainless Steel	Germany	Incorporated
BioConstruct	BioConstruct	2,400	Yes	21,000	Incorporated	In-situ concrete	Germany	Incorporated
BITECO	BITECO	600	Yes	4,980	Incorporated	In-situ concrete	Italy	Incorporated
STANDARD	BIODIGESTER	30	NO	210	Insulated	Polyfibre tank	England	External Hydraulic System
Food Waste Biodigester SR100	Sunrise-econergyCo. Shenzhen	100	Yes	1,000	Incorporated	enamel sheeting	Guangdong, China	Incorporated
Floating Digester	Sunrise-econergyCo. Shenzhen	60	NO	35	Buried underground	Concrete structure	Schenzen, China	None
Helios® system	UTS Biogastechnik GmbH	From 2000	Yes	15,000	Incorporated	Cast In-situ concrete	Germany	Incorporated

A: Model, B: Supplier, C: Capacity (m^3), D: Suitability for OFMSW, E: Cost of plant (ZAR *1000), F: Temperature regulation modification, G: Materials, H: Origin, I: Agitation method

Table 2
A list of alternative sites for siting the biogas digester

		Area (m^2)	Distance from WTS (m)	Distance from Closest Point of Use (m)	Land Use Pattern	Other Site Physical Features	Presence of Utility lines
1	Transfer Station (WTS)	720	50	80	Near parking area and main road	An open green site on natural ground with slight slope	None Visible
2	Student Centre (SC)	300	700	30	Near eatery	An open green site on natural ground on flat terrain	None Visible
3	Aurum Residence (AR)	450	250	10	Near residence	A paved flat site covered by trees	None Visible

3.2 Criteria

Table 3 presents a list of set criteria for the selection of the various biogas digester alternatives. The same table gives the unified weights of each individual criterion followed by a detailed justification for the choice of unified weight.

The project was fixed at small scale level with OFMSW as a preselected type of feedstock. Therefore the scalability of the plants and their suitability to handle OFMSW were found to be the ruling factors for digester selection each having individual weighted factors of 0.2. Next in importance were the relative cost prices of the individual plants and their availabilities locally because both factors had a direct implication on the overall project cost. They weighed 0.17 and 0.18 respectively. Temperature regulation and ease of construction, operation and maintenance both weighed relatively lower at 0.1 because the technologies in consideration were relatively simple, easy to set up and therefore temperature as an operating factor can easily be regulated.

The least important factor was the presence of agitation accessories weighing 0.005 since at small scale, biogas digesters can be agitated manually with relative ease.

On the other hand, Table 4 lists the various criteria considered for site selection alongside their priority values obtained from the pairwise comparisons of the criteria against each other using Saaty's scale of 1-9 (Saaty, 2004). The current and future expected land use at the proposed site was found to be the ruling factor in making the decision of a suitable site with a priority score of 0.164 followed closely by the available area at 0.154 and the existence of utility lines as well as energy saving impact of the site at 0.134 and 0.117 respectively. The climatic pattern of the sites was the least important factor because the sites are located within the same area and therefore experiencing similar climates.

Table 3
Selected criteria with corresponding unified weights for selection of a biogas digester

Attribute	Unified Weights (Wi)	Justification
Cost	0.17	The cost price of any technology to be procured is a very vital factor in the selection process since it dictates the economic viability of the project. An economical choice of technology is the one that will serve the intended objective of the project at the least possible cost. The price of the plant therefore is a strong attribute in the selection process having a weight of 0.17 just 0.01 below local availability at 0.18. The cost of the plant is not a limiting factor unlike others such as the scalability of the technology that are fixed hence not the strongest criterion (Amigun & von Blottnitz, 2010; Cheng et al., 2013; Karagiannidis & Perkoulidis, 2009; Walekhwa et al., 2014).
Local availability	0.18	Locally available technologies reduce the project costs considerably since there are no extra costs incurred in mobilisation of labour and materials as well as reduced taxes. In addition to lowering project costs, locally available technologies are already understood within the area of application therefore easy to set up and promote the development of local products as well as the economy at large. Therefore local availability is a strong factor and hence carries a strong weight at 0.18 (Austin & Morris, 2012; Walekhwa et al., 2014).
Capacity scalability	0.2	This is the measure of the ease with which the presented technology can be scaled to the envisaged capacity of the project. This is a very important factor because some plants are only available in particular scales. This is a project limiting factor because in the event that a particular model cannot be sized within the required project scale, it is automatically disqualified therefore having a very strong weight of 0.2 (Austin & Morris, 2012).
OFMSW suitability	0.2	The nature of substrate is one of the most important factors in the selection of a given biogas plant. In this case the substrate to be treated was fixed as OFMSW and therefore the suitability of the given technology to treat this substrate was a project limiting factor hence carries a very strong weight of 0.2 at the same level of importance as the scalability of the plant(Kumar, 2012; Weiland, 2010).
Temperature regulation ability	0.1	Anaerobic digestion of biomass by microbes for biogas production occurs optimally at temperature ranges of 30°-40°C. Therefore a techno-efficient biogas plant system should have the ability to regulate its working temperatures within the optimal range otherwise the system can underperform or even fail. However, most systems have laboured to incorporate temperature regulation design modifications making the factor a rather fairly strong one as

		a selection criterion with a weight of 0.1 (Kumar, 2012; Ward et al., 2008).
Presence of agitation accessory	0.05	Constant agitation of the substrate in the digester needs to be done to ensure intimate contact between the microorganisms and substrate which ultimately results in improved digestion process. Most systems have however laboured to incorporate modifications to facilitate substrate agitation making the factor also rather fairly strong as a selection criterion with a weight of 0.05 (Ward et al., 2008).
Ease of construction, operation and maintenance	0.1	The plant should be easy to construct, operate and maintain to reduce the need for expatriate labour which usually increases the project's overall costs. Most available biogas technology has been simplified for easy set up thereby making the criterion also a rather fairly strong one with a weight of 0.1 (Bhat et al., 2001; Kuria & Maringa, 2008).

Table 4:
Selected criteria for evaluation of the alternative sites

Criteria	Priority	Justification
Current and future expected land use	0.157	The current land use pattern dictates the suitability of a particular site for establishment of a biogas plant. For example a proposed site located in an industrial area would be a better option than a gazetted residential area. In addition, if the proposed site is expected to be used in a way that cannot co-exist with the project in plan it makes it a project limiting factor and the project cannot go on hence given high level of importance (Epp et al., 2008; Ma et al., 2005; Sultana & Kumar, 2012).
Available area	0.147	The proposed site should have adequate space to accommodate the envisaged size of plant. The available area should also give enough working space and leave room for future expansion. Available area is a limiting factor to the project because without adequate space the project cannot proceed therefore area is given high priority (Sultana & Kumar, 2012).
Existing utility lines	0.134	Just like any other plant, the proposed site for the new establishment should be free of existing underground service lines such as water lines, and underground sewers among others. Presence of these would increase the project cost in relocation of the services or sometimes the project is blocked especially if the construction involves deep excavations like in the case of biogas plant installations. Therefore the high level importance (Sener et al., 2011).
Biogas application and energy saving impact	0.117	The supply of the gas produced by the plant should have a remarkable impact on the intended point of use so as to achieve the project's objectives. This impact is a function of the current energy demand and intended use at the point of application. Energy recovery from biogas for cooking and heating gives a higher benefit than if used for electricity. On the other hand, the place with the higher energy demand needs the extra supply more therefore the better target. Since this factor has direct bearing on the project returns, it is given high priority to ensure economic viability of the successful choice (Thompson et al., 2013).
Proximity to substrate source	0.106	The intended substrate or feedstock intended for use in the digester should be generated as close as possible to the site to minimise the cost of feedstock transportation. Ideally, the biogas plant should be set up in the same vicinity as the feedstock source such as a landfill in case of municipal solid waste or a cattle farm for manure. A long distance increases project costs and therefore a direct negative impact on the economic feasibility hence should be given high priority(Amigun & von Blottnitz, 2010; Kumar, 2013).
Property rights	0.086	A proposed site for a biogas plant should have a clear ownership history void of ownership conflicts. Therefore prior to project implementation, all legal checks and ownership paperwork should be made to ensure a streamlined process of project implementation. Ownership can sometimes create major hurdles for project progress and hence given relatively middle level priority(Epp et al., 2008).
Proximity to digestate disposal point	0.065	The digestate from the anaerobic digestion of biomass is a potent source of organic agricultural fertilizer. This should therefore be discarded in an environmentally friendly manner or applied for use within acceptable distances to reduce transportation costs. The ideal and most economical sites should be located near farm land where the fertilizer can be applied or better if it's an area with ready market for the fertilizer. In an urban setting, the effluent can be redirected into a nearby sewer line. The site closest to a sewer line is the most preferred choice. This has some bearing on project cost and environmental impact hence gets a middle level importance(Amigun & von Blottnitz, 2010; Sivanagaraju et al., 2010).
Ground conditions	0.053	Preliminary geotechnical investigations can guide the designer on the nature of the subsoil. If bedrock occurs frequently, the design must avoid deep excavation work because this would increase the construction costs tremendously. Therefore sites with evidently soft grounds are preferred to ones with paved surfaces or hard rock. However, this can be solved by advanced excavation equipment at a raised cost hence not a limiting factor and therefore given middle level importance (Sener et al., 2011).
Accessibility of site	0.043	The proposed site should be accessible to allow for easy access for delivery of feedstock and evacuation of the digestate as well as construction equipment. This can be solved by creating access roads hence given lower level importance (Sener et al., 2011).
Proximity to point	0.037	Combustible gases burn better at high pressures. Biogas just like any other fluid moving over a considerable distance tends to have pressure drops. The longer the distance, the higher the pressure drop.

	To ensure optimum gas pressure over a long distance, hydraulic pumps have to be installed along the delivery pipe to step up the pressure. This in turn increases the overall cost of the project. Hence the most preferred choice of site should be as close to the point of use as possible to avoid such unnecessary additional costs. It is not a limiting factor to the project hence a lower level of importance (Amigun & von Blottnitz, 2010).
Commun ity attitudes 0.029	For an industrial processing plant to become a success, it has to be set up in locations where the inhabitants will support its establishment. Or else, its establishment is hampered. However the attitude problem can be solved by community sensitisation via liaison channels. However, for this case study, the university owns all the potential sites outright. Hence the factor carries a low level of importance at 0.29 (Mwirigi et al., 2014).
Prevailin g climatic patterns 0.027	The site choice should respond to the prevailing climatic conditions of the location. Bearing in mind that biogas plants operate optimally at temperature ranges between 30°C to 40°C, in areas with generally low temperatures, insulation and heating devices may be an important part of the design which can increase project costs. But for this particular case study, the sites are affected equally by climate because they are within the same confine hence a low level of importance (Kigozi et al., 2014).

3.3 Scores and Ranking

Table 5 represents the summary of the results from the scoring and ranking of the various biogas digesters against the weighted selection criteria.

Table 5
Scores against criteria and overall ranks for the alternative biogas digester models

Criteria	A		B		C		D		E		F		G		
Weight	0.17		0.18		0.2		0.2		0.1		0.05		0.1		
Model	S	WS	S	WS	S	WS	S	WS	S	WS	S	WS	S	WS	RANK
Puxin	0.65	0.11	0.85	0.15	0.85	0.17	0.70	0.14	0.50	0.05	0.10	0.01	0.80	0.08	0.709
Agama Pro 6	0.60	0.10	1.00	0.18	0.65	0.13	0.70	0.14	0.10	0.01	0.10	0.01	1.00	0.10	0.667
Geo membrane	0.80	0.14	0.00	0.00	1.00	0.20	0.90	0.18	0.30	0.03	0.30	0.02	0.70	0.07	0.631
Bio4gas	0.75	0.13	0.70	0.13	0.00	0.00	0.80	0.16	1.00	0.10	1.00	0.05	0.50	0.05	0.614
GREENBOX	0.20	0.03	0.35	0.06	0.40	0.08	0.80	0.16	0.70	0.07	0.90	0.05	0.50	0.05	0.502
Helios® system	0.60	0.10	0.40	0.07	0.00	0.00	0.70	0.14	0.85	0.09	0.90	0.05	0.50	0.05	0.494
SR100	0.30	0.05	0.00	0.00	0.20	0.04	1.00	0.20	0.85	0.09	0.80	0.04	0.70	0.07	0.486
PVC Portable	1.00	0.17	0.00	0.00	0.80	0.16	0.00	0.00	0.50	0.05	0.10	0.01	0.80	0.08	0.465
Standard	0.65	0.11	0.00	0.00	0.90	0.18	0.00	0.00	0.65	0.07	0.60	0.03	0.75	0.08	0.461
Biteco	0.60	0.10	0.00	0.00	0.10	0.02	0.70	0.14	0.80	0.08	1.00	0.05	0.40	0.04	0.432
Bioconstruct	0.60	0.10	0.00	0.00	0.00	0.00	0.70	0.14	0.85	0.09	1.00	0.05	0.40	0.04	0.417
Weltec	0.30	0.05	0.20	0.04	0.00	0.00	0.70	0.14	0.90	0.09	0.90	0.05	0.40	0.04	0.402
Ökobit	0.55	0.09	0.00	0.00	0.00	0.00	0.65	0.13	0.85	0.09	0.90	0.05	0.40	0.04	0.394
Floating digester	0.80	0.14	0.00	0.00	0.50	0.10	0.00	0.00	0.50	0.05	0.10	0.01	0.70	0.07	0.361

A: Cost, B: Local Availability, C: Scalability, D: OFMSW Suitability, E: Temperature Regulation Ability, F: Presence of Agitation Accessory, G: Ease of Construction, Operation and maintenance, S: Score, WS: Weighted score

The Geo Membrane digester from India's Biotech comes at the lowest cost compared to the rest in the top three technologies hence the high score. It also turns out to be the most flexible to size especially at small scale and the most preferred plant for treatment of OFMSW as well. However, its downside was the fact the technology is not available locally and hence scoring 0.00 in that particular selection criterion dropping its overall total score considerably.

The Agama Pro digester is readily available locally for small scale applications in the form of prefabricated Polyfibre tanks making it the easiest to set up since it is already finished from the supplier. The Agama digester however comes in standard non-flexible sizes with the largest capacity of 6 m^3 making it not as easy to size as well as maintain since its interior is inaccessible just like the Geo membrane digesters. No effort whatsoever was made by the technology designer to incorporate automated substrate agitation.

The Puxin digester on the other hand has balanced attributes scoring well across all criteria despite not being the most preferred option at any hence obtaining the overall highest score and therefore the most preferred option for the envisaged project. Its attributes' scores are almost similar to the Agama digester owing to the fact it's a locally available technology and an easy one to construct too. However, the technology design has incorporated a hydraulic agitation modification as well as system temperature regulation through its mode of construction since it is a below-ground construction. The Puxin digesters are available in customisable 10 m^3 and 6 m^3 capacities therefore easily scalable for small scale applications. All these factors combined give the Puxin digester a much higher aggregate score compared to the rest of the models under consideration.

Generally, foreign manufactures mostly venture into larger scale projects especially the ones from Europe. However, China and India have potential suppliers that could fit into the needs of small scale biogas projects but the costs of mobilisation including import duty make imported technology uneconomical to source thereby favouring the locally available technologies.

The least preferred option of biogas plant is the floating digester produced by China's Sunrise Ecoenergy Company Shenzhen. The digester, although an easy one to construct and quite affordable, it is not an available product on the market locally, it is not suitable for the treatment of OFMSW, only available for small scales and lacks design modifications to cater for substrate agitation and system temperature regulation as well.

Overall, the most preferred biogas digester model for the project was the Puxin digester originally from China but locally produced by BiogasSA. The plant is constructed below ground using in-situ reinforced concrete to maintain a warm temperature within the plant for optimum performance. It also runs as a hydraulic system to automatically agitate the substrate. This was closely followed by the Agama Pro digester and the Biotech's Geo membrane digester from India in that order.

At the time of the study, 14 suppliers were the only ones that could give satisfactory required information for the study. This in a way could lead to a bias in decision making. Therefore additional studies are encouraged with larger sample sizes of suppliers from numerous locations worldwide.

Similarly, Table 6 represents the summary of the results from the scoring and ranking of the sites against the prioritised selection criteria from the earlier mentioned AHP pairwise comparisons of both the alternatives against criteria and criteria against other individual criteria.

The site near the transfer station doesn't conflict much with existing land use patterns since it is secluded surrounded by car parks and the school boundary hedge line with the main road hence making it a good potential site. On the other hand, the site near the student centre is so close to an eating place and could become a problem as biogas production from waste is most often associated with foul odours and the one near the residence is situated near a residence though quite far from the habitable sections of the building.

Table 6:
Scores and Ranks for the Alternative Sites

		SCORES			WEIGHTED SCORES		
FACTOR	Priority	WTS	SC	AR	WTS	SC	AR
Current and future land use pattern	0.157	0.168	0.094	0.738	0.03	0.01	0.12
Available area	0.147	0.480	0.168	0.352	0.07	0.02	0.05
Existing utility lines	0.134	0.516	0.344	0.140	0.07	0.05	0.02
Biogas application and impact	0.117	0.074	0.283	0.643	0.01	0.03	0.08
Proximity to substrate source	0.106	0.669	0.088	0.243	0.07	0.01	0.03
Property rights	0.086	0.333	0.333	0.333	0.03	0.03	0.03
Proximity to digestate Disposal point	0.065	0.414	0.172	0.414	0.03	0.01	0.03
Ground conditions	0.053	0.400	0.400	0.200	0.02	0.02	0.01
Accessibility of site	0.043	0.221	0.460	0.319	0.01	0.02	0.01
Proximity to point of service	0.037	0.095	0.415	0.490	0.00	0.02	0.02
Community attitudes	0.029	0.333	0.333	0.333	0.01	0.01	0.01
Prevailing climatic patterns	0.027	0.333	0.333	0.333	0.01	0.01	0.01
SUM	1.000				0.36	0.24	0.40

WTS: Waste transfer station, SC: Students' centre, AR: Aurum residence

However, after farther consultation with the estates department of the school, it was revealed that the two sites that is the SC and WTS had been earlier on earmarked as future parking spaces reducing their relevance to meeting the project's objectives and hence the low priority scores of 0.094 and 0.168 respectively leaving the AR site with the highest score of 0.738 with respect to current and expected land use pattern as a selection criterion.

The site near the WTS has a large available area bigger than the other 2 sites. Hence the WTS site ranks highest with regards to area as a selection criterion with a score of 0.480. The AR and SC sites scored 0.352 and 0.168 respectively.

The biogas generated at the site near the Aurum residence is meant for heating at the residence which has been an ongoing concern especially during the cold winters. And the biogas

that would be generated near the students' centre is proposed to be used for cooking at one of the canteens where they are currently relying on electricity and natural gas. Near the waste transfer station, the closest point of use for the generated gas are the laboratories in the neighbourhood whose gas demand is not so high but would find occasional application on Bunsen burners. Comparing all the three applications, the use of the biogas at the Aurum residence gave the highest energy yield followed by cooking at the students' centre and finally the laboratories near the waste transfer station hence the scores of 0.643, 0.283 and 0.074 for the AR, SC and WTS respectively with respect to biogas application and energy saving impact as a selection criterion

Evidently, the site near the waste transfer station is the closest to the feedstock source which is the waste transfer station therefore ranking highest compared to the rest with respect to proximity to substrate source scoring 0.669 followed by the site near the Aurum girls' residence at 0.243 and the farthest and least ranked is the students' centre site at 0.088.

By way of visual inspection and preliminary surveys combined with stakeholder consultation, the probabilities of each of the sites having underlying service lines within the envisaged space were obtained and used as the respective scores with respect to presence of below-ground utility lines as a selection factor. The higher the probability, the lower the priority score and vice versa. The AR site had the highest probability hence a low priority score of 0.140. The other two sites scored 0.516 and 0.344 for the WTS and SC sites respectively.

All three sites are located within the same vicinity under 1000 m radius and are owned by the University of Johannesburg whose drive towards process energy and environmental engineering research supports the establishment of the biogas plant. This implies that all sites experience similar climate and therefore all score equally, the ownership details of all the sites are clear since they all belong to the university. In addition, all proposed sites are within a community that will embrace the envisaged technology and therefore all score equally with regards to community attitudes as a selection factor too.

There are existing sewer lines close to the WTS and AR sites to which the digestate could be directed after the digestion processes hence both sites scoring equally at 0.414. The SC site is relatively farther from possible disposal points for the generated digestate. This gives the SC site the lowest score at 0.172.

The SC and WTS sites are both fresh green sites covered by grass on natural soft ground making them rather easy for plant establishment especially where deep excavations will be involved. Hence the two sites score equally at 0.414 with regard to ground conditions. On the other hand, the site behind Aurum residence is partly paved in some areas with an asphalt

concrete surface making any envisaged excavations for civil works harder hence scoring lowest at 0.172.

The site near the students' centre has clearer access routes that don't require farther modification and therefore scores highest at 0.46. However, the WTS and AR sites both have constraints to a certain degree as regards accessibility with the AR site having easier access scoring 0.319 and lastly the WTS site with 0.221.

The biogas from the site near the waste transfer station is proposed to be used in the nearby laboratories that are quite far from the site making it the least ranked site scoring 0.095. The other two sites are relatively close to their intended points of use hence almost at equal ranking but the one at Aurum ladies' residence is much closer and therefore most highly ranked at 0.49.

After obtaining the aggregate scores of the alternatives based on their relative scores per factor vis-a-vis the relative importance of the individual factors, the site near the Aurum residence turned out to be the highest ranked amassing a total score of 0.40 followed by the WTS and SC sites scoring 0.36 and 0.24 respectively. Hence the most suitable site for the proposed biogas plant is the AR site followed by the one near the current waste transfer station (WTS) and lastly the one near the students' centre (SC).

It should however be noted that the accuracy of the findings can further be improved through the undertaking of detailed site surveys including investigative procedures such as geotechnical surveys to obtain more in-depth information.

4. Conclusions

This paper presents the use of DS tools applying mathematics and psychology to solve multi-dimensional decision making problems. The SMART and AHP techniques of Multiple-criteria decision analysis were used to select a suitable biodigester model and site respectively based on a case study at the University of Johannesburg's Doornfontein campus in Johannesburg, South Africa. The most preferred model was the Puxin digester to be established near the Aurum ladies' residence to supply biogas for heating purposes.

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