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SUSTAINABLE FOOD WASTE MANAGEMENT: A MULTI-CRITERIA APPROACH FOR ASSESSING THE USE OF FOOD WASTE DISPOSAL UNITS (FWDS) AND THE ANAEROBIC CO-DIGESTION OF SEPARATELY COLLECTED FOOD WASTE WITH SEWAGE SLUDGE

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Abstract

Purpose: In face of the need for sustainable solutions in the field of food waste management, the use of food waste disposal units (FWDs) and the anaerobic co-digestion of food waste with sewage sludge have recently been attracting more attention as an alternative to landfill.

Methods: In this study a sustainability framework was developed in order to aid decision making in food waste management for these two options using a multi-criteria approach. This framework was applied in the Anglian region in the UK as a case study.

Results: the anaerobic co-digestion of food waste with sewage sludge could be more sustainable than the use of FWDs. Nevertheless, this result only provides guidance to stakeholders, as the different primacies originating from them could possibly lead to a reversal in the overall outcome.

Conclusions: the successful use of the sustainability framework depends largely on the thorough collection of detailed data. Data are essential components for the comprehensive assessment of the two food waste management options, as it matters when decisions are to be made especially for food waste management processes that require a large-scale of investment costs to be incurred. A holistic appraisal of the environmental, economic and social aspects of the use of FWDs and the anaerobic co-digestion of food waste with sewage sludge based on area-specific characteristics and practices is recommended for facilitating successful application of the sustainability framework and consequently the support of sound decision-making.

Keywords: Food waste, food waste disposal units (FWDs), co-digestion, sustainability framework, multi-criteria approach

1. Introduction

Environmental protection has been a key driver of changes in solid waste management. The establishment of the revised EU Waste Framework Directive (rWFD) in 2008, emphasising the need for choosing appropriate technologies for improving the protection of human health and the environment by promoting waste prevention, reuse and recycling [1], and in conjunction with the targets set by the earlier EU Landfill Directive in 1999 for diverting biodegradable waste from landfill, has started to make a positive impact in the field of food waste management [2].

New municipal waste management has come into practice by local authorities (LAs) and the waste industry, as a result of the new GHG emission targets, targets relating to waste reuse, recycling and the diversion of waste from landfill, as well as other policies related to sustainability. Food waste in the UK constitutes 38% of the total municipal solid waste and is currently its most challenging component considering the fact that most of it ends up in landfills, with food waste being amongst the most challenging. Two options considered by LAs for managing food waste are the use of food waste disposal units (FWDs) and the separate collection of food waste followed by anaerobic co-digestion of food waste with sewage sludge. The sustainability potential of these two food waste management options depends on the area-specific characteristics and practices and as such, this paper focuses on devising a tool for their sustainability comparison based on these [2, 3]. Furthermore, the current debate on the use of FWDs and associated impacts, the value of food waste, and the effectiveness of food waste collection schemes and the feasibility of anaerobic co-digestion with sewage sludge has made decision-making regarding food waste management a challenging task. Therefore, this study aims to assist LAs and the water industry to identify the impacts of these food waste management options to their operations, in order to inform and facilitate the decision-making process.

Multi-criteria analysis is frequently applied to compare and assess the impacts of different policies and waste management options, and, as such, has been selected for food waste management in the context of sustainability [4-10]. Nevertheless, there are many tools and approaches available for the assessment of the sustainability and technical aspects of a food waste management strategy, such as life cycle assessment (LCA). The LCA approach involves the evaluation and assessment of the environmental impacts encountered during the life cycle of a process, product or activity and, as such, requires a large amount of detailed data, time and knowledge for its application [11]. The multi-criteria approach, on the other hand, allows the comparison of alternative options on the basis of a set of criteria, using a mixture of qualitative and quantitative data, making it appropriate for environmental decision-making [8, 10, 11]. Because environmental problems are often associated with uncertainty, the possibility of taking some uncertainties into account as offered by the multi-criteria approach, makes its use even more attractive8.

2. Strategic multi-criteria comparison methodology

To compare the sustainability of the food waste management options environmental, economic and social aspects must be taken into account. Therefore, a multi-criteria framework was developed (Figure 1) [4, 6, 10, 11]. Reflecting sustainability, environmental, social and economic criteria were selected for the comparative assessment of the two alternatives (**Figure 1**).

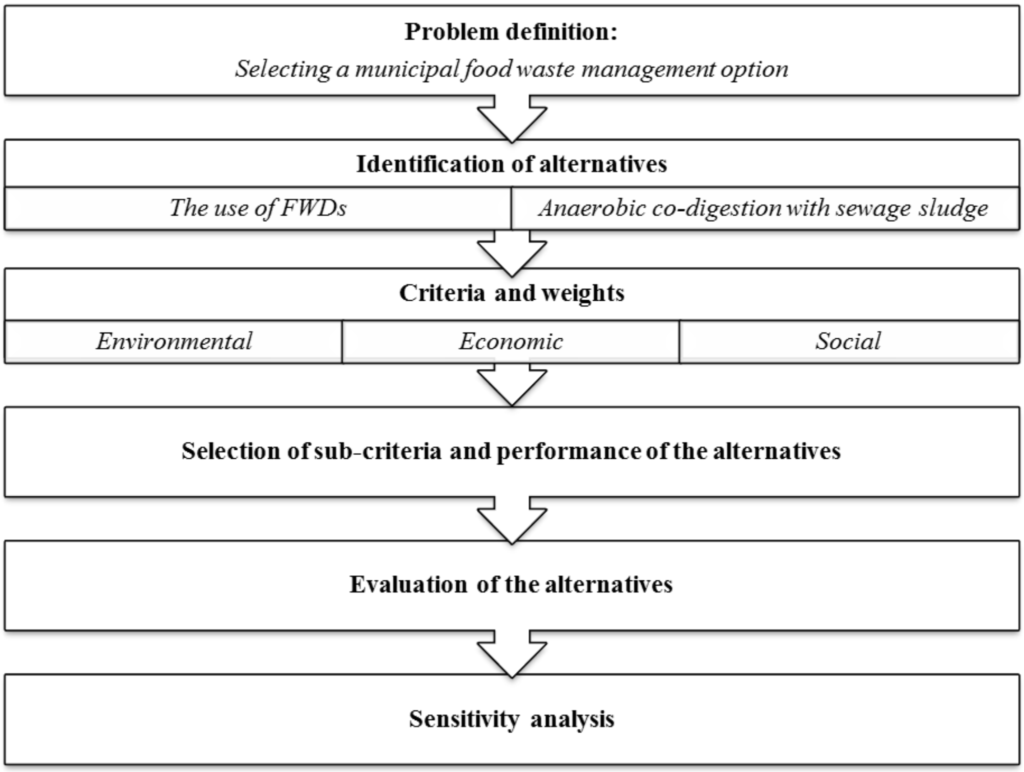
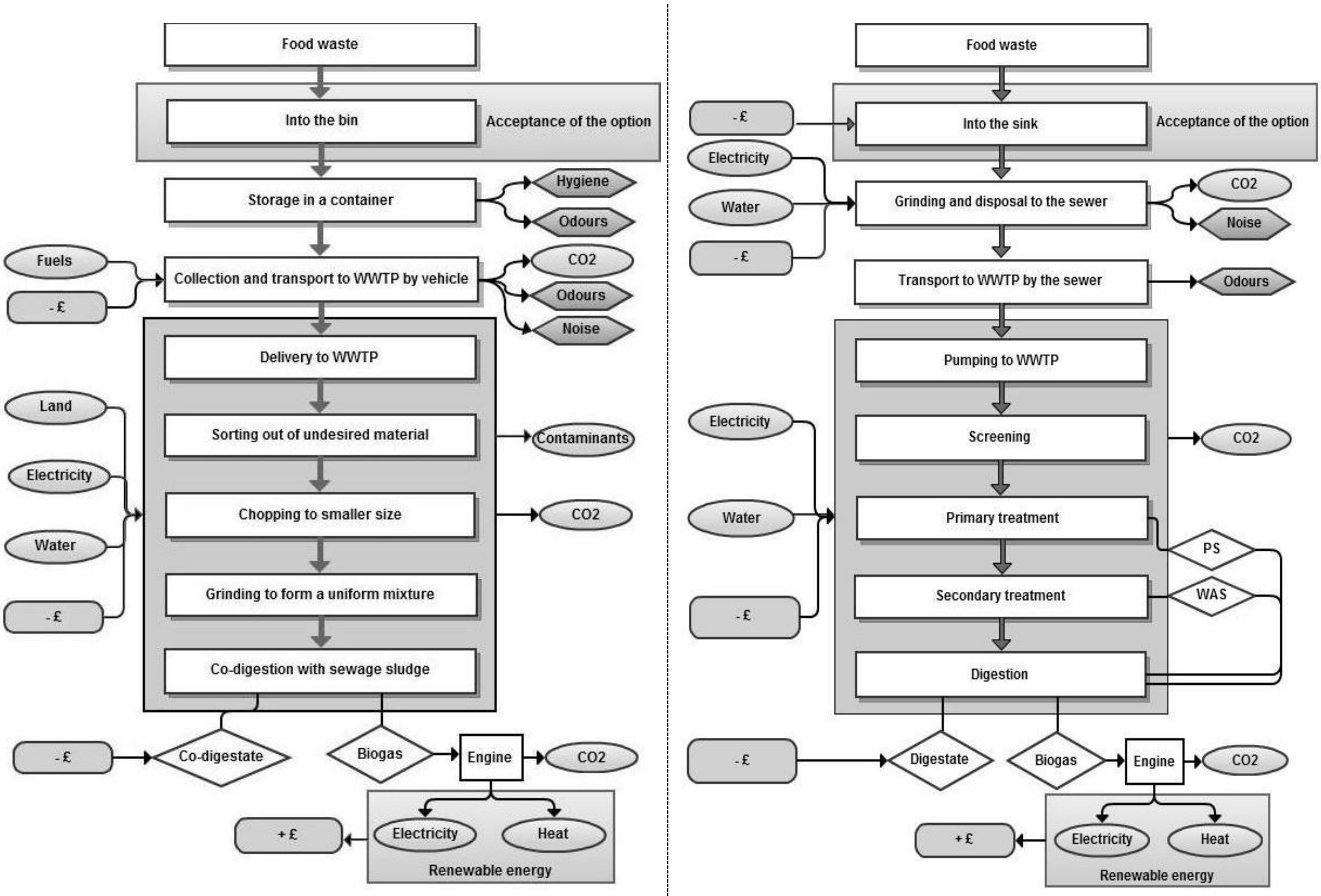


Figure 1 Sustainability decision-making framework using multi-criteria approach to evaluation of the problem

These criteria were given the same weight [6, 8], and were further evaluated using key strategic sub-criteria. Resource consumption and reduction of environmental pollution were considered for the environmental criterion the cost of a waste management option and the associated revenues were considered for the economic criterion, whereas for the social criterion the behaviour of a waste management system towards society was used [12]. The latter suggests sub-criteria related to noise, smell and health impacts, but also acceptance of the implemented food waste management option.

In order to be holistic and include all the pros and cons of the performance of the two alternatives an all-inclusive mass balance approach was used (**Figure 2**) [13-17].



Anaerobic co-digestion of food waste with sewage sludge **Use of Food Waste Disposal units (FWDs)**

Environmental sub-criteria Economic sub-criteria Social sub-criteria

Figure 2 An all-inclusive mass balance approach of the performance of the two food waste management alternatives

The conceptualisation of the two food waste management options (**Figure 2**) shows the flow of food waste from the source of generation to its final treatment and disposal. For the environmental criterion these sub-criteria are recourse consumption including land, water and energy -in the form of fossil fuels or electricity- consumed in the implementation of both food waste management options [12, 18] (**Figure 2**), greenhouse gas emissions in the form of CO_2, which can be either direct, through the combustion of fuels, fugitive losses from the anaerobic reactor and the utilisation of biogas, or indirect through energy consumption in the form of fuel, electricity and heat, and the production of materials, used for the manufacturing of FWDs or the construction of the facility (upstream), and from the digestate and its use (downstream) [19] (**Figure 2**), and renewable energy in the form of electricity and heat (**Figure 2**), generated by the use of biogas (or methane, CH_4) produced during the anaerobic digestion (AD) process. This energy is considered a resource that can outweigh the impact of energy consumption. In this study the AD process is assumed to be the most dominant sewage sludge management option in water industry operations.

Two sub-criteria can be extricated for measuring the net performance of the economic criterion. These are the operational cost indicated as '- £' (**Figure 2**), which includes the costs of investment, operation and maintenance, which are the most commonly used in assessing waste management options [18], and the so called revenue indicated as '+ £' (**Figure 2**), which is the benefit generated from recovered energy (renewable energy) or materials, and from the reduction in cost of municipal waste collection and transport [12]. It must be underlined, that both operational and revenue costs depend on area characteristics (architectural and geographical), and the practices followed in the water industry operations.

Public acceptance indicated as 'acceptance of the option' in the mass balance approach (**Figure 2**), health and smell impact, indicated as 'hygiene' and 'odours', respectively (**Figure 2**), and noise implications indicated as 'noise' (**Figure 2**) were used to measure the net performance of the social criterion. When householders are directly involved in a food waste management option in terms of adopting new handling concepts, including the use of technology, or in terms of waste separation and collection, the potential acceptance of each option is an important social–cultural consideration [18]. The hygiene associated with each option is detrimental to its successful implementation, due to implications that it might cause to householders [20], as also is the annoyance caused by unpleasant odours or noise during the implementation of each food waste management option [21]. However, both unpleasant odours and noise, are difficult to measure because people respond to them in different ways, depending on factors such as previous exposure, personal health, sensitivity and social background [20].

It must be highlighted, that the performance of the alternatives with regards to the different sub-criteria is a complex process that differs between regions and depends on data availability and regional characteristics and practices. To facilitate the application of this process, examples and mechanisms to calculate their performance are summarised in **Table 1**.

Table 1 Conceptual framework of evaluating the performance of food waste management options

Criteria	Sub-criteria	FWDs	Anaerobic co-digestion
Environmental	Net resource consumption	Calculated based on: • Water consumption for grinding (household) • Energy consumption for food waste grinding (household) • Energy consumption for water treatment and distribution, wastewater pumping and treatment and sludge management and disposal (water industry)	Calculated based on: • Fuel consumption for collection and transport (LAs) • Land requirements for waste processing facilities (water industry) • Energy consumption for food waste processing (water industry) • Additional energy consumption for heating-up the digester (water industry)
	Net greenhouse gas emissions	Calculated based on energy consumption for: • The grinding of food waste (household) • The treatment of the additional water used for the grinding of food waste • The pumping and treatment of additional wastewater generated (water industry) • The management of the additional sludge produced (water industry) • The burning of fossil fuel for the disposal of the produced digestate (water industry)	Calculated based on: • The burning of fossil fuels for the collection and transport of food waste to the pre-treatment facilities (LAs) • Energy consumption at food waste processing facilities (water industry) • Additional digester heating for treatment of food waste together with sewage sludge (water industry) • The burning of fossil fuels for the disposal of the produced digestate (water industry)
	Net renewable energy	Calculated based on the biogas/CH_4 generation as a result of the additional sewage sludge digested, produced at the wastewater treatment plants (WWTPs) due the use of FWDs	Calculated based on the biogas/CH_4 generation from the digestion of food waste together with sewage sludge
Economic	Net operational cost	Calculated using the cost of: • Purchase and installation of a FWD (householder) • Maintenance of the FWD (householder) • Energy consumption for using the FWD (householder) • Water treatment and distribution (water industry) • Wastewater treatment (water industry) • Sludge management (water industry) • Digestate disposal (water industry)	Calculated using the cost of: • Collection of food waste (LAs) • Transport of food waste to the waste management facilities (LAs) • Gate fee for food waste delivery at WWTPs (LAs) • Investment cost for the waste management facilities (water industry) • Operational cost of food waste processing (water industry) • Additional heating of the digester due to the addition of food waste (water industry) • Digestate disposal (water industry)
	Net revenue	Benefit of reduction in cost of collection and transport (LAs) Benefit from renewable energy generation from the additional sludge digestion (water industry)	Benefit from additional renewable energy generation (water industry)
Social	Public acceptance Health impacts Smell impacts Noise impacts	These criteria are usually measured by conducting a survey that involves the public's participation. Generally, PA is critical due to technology involvement, HI depend on peoples' sensitivity and area-specific characteristics, and the response of the public to SI and NI differs due to sensitivity, culture, habits and previous exposure.	These criteria are usually measured by conducting a survey that involves the public's participation. Generally, PA is relied on people willingness to separate their food waste from other residual waste, HI depends on people sensitivity and area-specific characteristics, and the response of the public to SI and NI differs due to sensitivity, culture, habits and previous exposure.

The relative contribution of the sub-criteria to the criteria is presented in **Table 2**. The weighting of each sub-criterion corresponds to the number of sub-criteria of each criterion. For instance, the sub-criteria of the environmental, economic and social criterion are three, two and four and as such, they have a weighting of ⅓, ½ and ¼, respectively.

Table 2 Sub-criterion weighting for the two food waste management options

Criteria	Sub-criteria	Weighting	Individual weighting (%)
Environmental	Resources Consumption	⅓	11.11
	Greenhouse gas emissions	⅓	11.11
	Renewable energy	⅓	11.11
Economic	Operational cost	½	16.67
	Revenue	½	16.67
Social	Public acceptance	¼	8.33
	Health impacts	¼	8.33
	Smell impacts	¼	8.33
	Noise implications	¼	8.33
Total			100

The individual weighting for each sub-criterion is calculated by multiplying the weight of the criterion by the weight of each individual sub-criterion within each group (**Table 2**). The sum of the individual weighting of all sub-criteria must then be equal to 100%, to ensure the consistency of the weighting assignment.

3. Application of the sustainability decision-making framework to evaluate food waste management in the Anglian region

In order to assess the sub-criteria, data from Anglian Water services and from the LAs in the Anglian region were collected and used. When these were not available, data based on UK figures were adopted from the literature. For the sub-criteria to be comparable, the overall evaluation was done per tonne of food waste, in both processes. Additionally, it was assumed that FWDs can grind everything and that no regulatory constraints limit any stage of the two processes. The performance of the alternatives for the different sub-criteria is presented in an impact matrix (**Table 3**).

It has to be highlighted that while the data that has been collected from the literature came from different sources not fully reflecting the process in its entirety, this data was sufficient for the analysis, which aimed to demonstrate how the sustainability framework developed could be applied in the Anglian region.

Because of the lack of data as to appropriately calculate water consumption for the use of FWDs and land requirement for the anaerobic co-digestion of food waste with sewage sludge, these were omitted from the analysis and as such, Resources Consumption was limited to energy consumption estimates expressed in kWh per tonne food waste in both processes (**Table 3**). In the use of FWDs, the energy consumption was calculated based on the electricity required for grinding food waste, based on the energy consumption per use, the frequency and duration of use of the unit for the grinding of 0.5kg food waste generated [22], and its subsequent treatment in the wastewater treatment plant (WWTP) [22]. Because energy consumption rates in the WWTPs were not available, these were calculated based on the cost of electricity (in the WWTPs) and the UK industrial electricity price of 7.89p per kWh, for which details can be found in the Anglian Water Services June Return 2010-11 [23-25]. For anaerobic co-digestion of food waste with sewage sludge, energy consumption was calculated based on the amount of fuel consumption during the collection and transport of food waste, which was expressed in kWh per tonne food waste using a conversion factor of 10.89 kWh per litre diesel burnt, and also from the processing of food waste at the waste management facilities using a figure of 68.6kWh per tonne food waste [26-28]. At this point it must be stressed that although water consumption and land requirements were not included in the analysis, they would constitute an important aspect of the overall assessment, as water consumption, even at small quantities, can be detrimental to some regions, as, for instance, in the Anglian region, which is one of the driest regions in the UK. Land requirements for the construction of waste management facilities and the upgrading of anaerobic digesters is also important, as it can create a negative attitude over the implementation of anaerobic co-digestion of food waste with sewage sludge. However, the magnitude of this aspect depends on the area specific-characteristics, and the technologies to be adopted, as some technologies require less space than others. Additionally, the energy consumption associated with the water consumption and land requirements would lead to increases in the energy use, which would be associated with increases in Greenhouse Gas emissions and Operational Cost. Operational costs is very important, as many decisions rely on the economic viability of a process. Maintenance cost as part of the operational cost, associated with the use of FWDs and the anaerobic co-digestion of food waste with sewage sludge, even though not included in the analysis, constitutes an important cost that would have to be assessed.

Greenhouse Gas emissions were expressed in carbon emission equivalents (kgCO_2) (**Table 3**). Carbon emissions from the burning of fossil fuels (diesel) and electricity consumption were evaluated using the latest conversion factors of 2.67 kgCO_2 per litre diesel and 0.525 kgCO_2 per kWh, respectively [28].

Diggleman and Ham (2003) reported that, when using FWDs, 4.8kg of CH_4 could be generated from 100kg of food waste [29]. A tonne of food waste digested was reported to give 260 m^3 of biogas of which 60% was CH_4 [30]. Based on these, and using the CH_4 calorific value of 13.93 kWh/kg, the RE was calculated for both processes (**Table 3**) [31].

The cost of electricity for grinding food waste was estimated based on the UK domestic electricity price conversion factor of 12.89p per kWh. This cost, together with the cost of sewage collection and treatment and sludge treatment and disposal, based on the latest data provided by the Anglian Water [25], was used to calculate the operational cost for the use of FWDs (**Table 2**). Because of the difficulty in separating the maintenance and investment costs to the water industry, these were embedded in the aggregated operational cost. Sewer cleansing and maintenance, while constituting an important cost, were not calculated in the analysis mainly because there are no direct costs associated with the disposal of food waste in the sewer. The operational cost for the anaerobic co-digestion of food waste with sewage sludge was calculated based on the cost of food waste collection, transport and treatment (**Table 3**). The cost of waste collection was based on data from LAs in the Anglian region adopted from the study of Iacovidou et al. (2012), whereas the cost of transport was calculated based on a figure of 6.5 litres per tonne food waste transport and a gate fee cost of £523 [32, 33]. The operational cost of pre-treatment and digestion was based on a figure of £55 per tonne food waste processed, which covered the cost of plant construction, operating and disposal of by-products [24, 34]. The revenue from RE was based on the recent renewable energy price of £100 per 1MWh generated [35]. RN from reduction in cost of collection when using FWDs was not included in this analysis, so as to keep results comparable (**Table 2**).

Social sub-criteria were evaluated based on a qualitative analysis. For this analysis, data collected from the literature with regards to the public's response to and acceptance of the implementation of each food waste management option, and in health, smell and noise concerns, were used. Because of the inherent difficulty in differentiating the public's response into a wider scale of measurement, it was considered appropriate to use a scale of two degrees of measurement (+/++), with + being used for the process with the least positive response, and ++ for the process with the higher positive response.

In terms of Public Acceptance, the use of FWDs was reported to be associated with some unwillingness, as a number of people find their use annoying due to noise implications of using the unit on a daily basis, or even laziness [36]. With regards to the anaerobic co-digestion of food waste with sewage sludge, the implementations of a separate food waste collection scheme was reported to cause the unwillingness of some people to participate, mainly because of concerns associated with hygiene, odours and vermin issues [33]. However, the majority of people involved in separate collection responded positively to it. However, it was assumed that, in the UK, the ignorance of people with regards to the use of FWDs and the difficulties associated with their installation in some household types is likely to make anaerobic co-digestion of food waste with sewage sludge more publicly acceptable than the use of FWDs (**Table 3**).

Health Impacts arising from the storage and rotting of food waste can occur through the inhaling of odorous emissions such as volatile organic compounds (VOCs), sulphur compounds, amines and aromatic hydrocarbons [20]. VOCs, such as methane thiol (MeSH) and hydrogen sulphide (H_2S), can cause nausea, bronchitis and gastrointestinal problems to a high level exposure [20]. Also, the personnel involved in the collection and treatment of food waste are subject to certain health impacts [37]. Health Impacts related to the disposal of food waste into the sink have not been as widely reported. However, in the study of Evans (2007) it was reported that the use of FWDs might be critical to the attraction of rats, although this has not been proved yet [36]. Therefore, it was assumed that the use of FWDs has a more positive effect to human health than anaerobic co-digestion with sewage sludge (**Table 3**).

The storage of food waste in households and its subsequent collection and handling can be associated with Smell Impacts [37]. Food waste grinding into the FWDs has been reported not to release any kind of unpleasant odours, though food waste disposed into the sewer has the possibility of producing some. The anaerobic degradation of food waste particles in the sewer leads to the production of sulphide, which then forms H_2S, the principal cause of malodours, even at very low concentrations [2]. Based on these, it was assumed that FWDs have a more positive effect on malodours compared to the anaerobic co-digestion with sewage sludge (**Table 3**).

Noise associated with the use of FWDs inside households can be of a greater magnitude as when coming from the outside and, thus, be more annoying. In the study of Evans (2007), it was reported that a number of people chose not to use a FWD, mainly because of the noise implications related to it [36]. As such, and with limited evidence in the literature with regards to the public annoyance by the noise generated during the collection of food waste, it was assumed that anaerobic co-digestion with sewage sludge has a more positive effect to noise implications than the use of FWDs (**Table 3**).

Table 3 Impacts matrix of the two food waste management options

Criteria	Sub-criteria	Unit (per tonne food waste)	FWDs	Anaerobic co-digestion
Environmental	Resources consumption	kWh	188.34	265.71
	Greenhouse gas emission	$kgCO_2$	99.26	84.27
	Renewable energy	kWh	668.64	2173.08
Economic	Operational cost	£	68.47	192.97
	Revenue	£	66.86	217.31
Social	Public acceptance	+/++	+	++
	Health impacts	+/++	++	+
	Smell impacts	+/++	++	+
	Noise implications	+/++	+	++

While there are many ways to analyse the matrix calculations and rank the alternatives, the weighted summation analytical method was chosen to rank the two food waste management alternatives. The weighted summation is a well-established method, widely used because of its ease. The standardised score of each criterion is multiplied by its assigned weighting, and rankings of the alternatives are then determined based on the weighted sum of the standardised scores of each alternative [9, 38]. According to the weighted summation, the anaerobic co-digestion of food waste with sewage sludge could be more sustainable than the use of FWDs in the Anglian region (**Figure 3**).

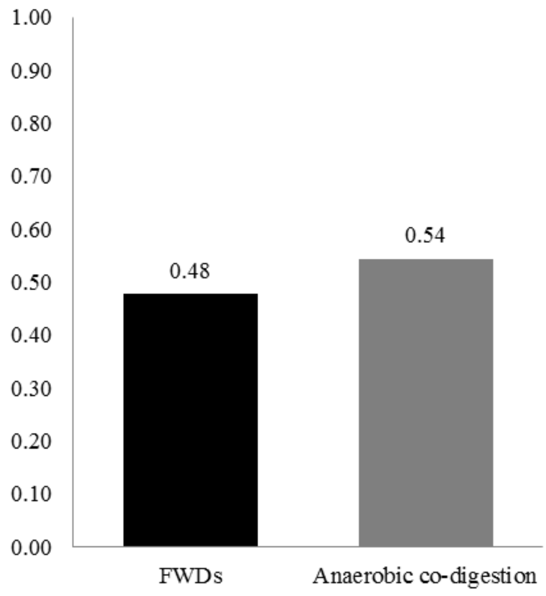


Figure 3 Overall score of the evaluation of the alternatives

The performance of the evaluation of the two alternatives based on the selected criteria was additionally assessed, with anaerobic co-digestion presenting higher sustainability in terms of environmental and economic criteria than the use of FWDs, with an equal performance in terms of the social criterion (**Figure 4**).

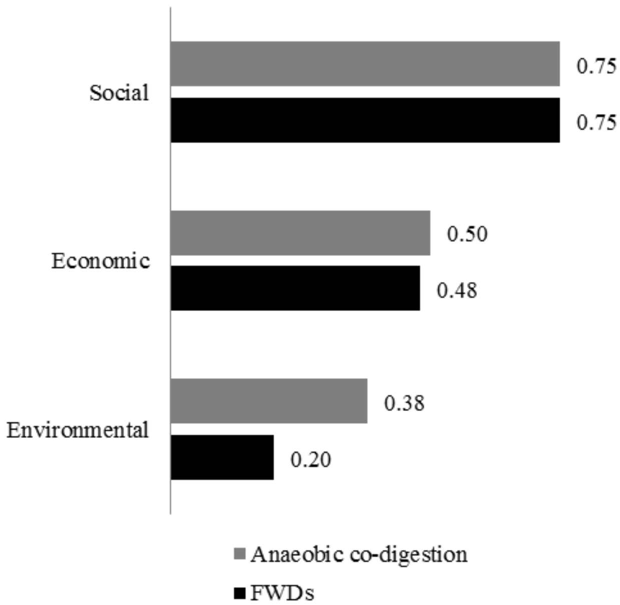
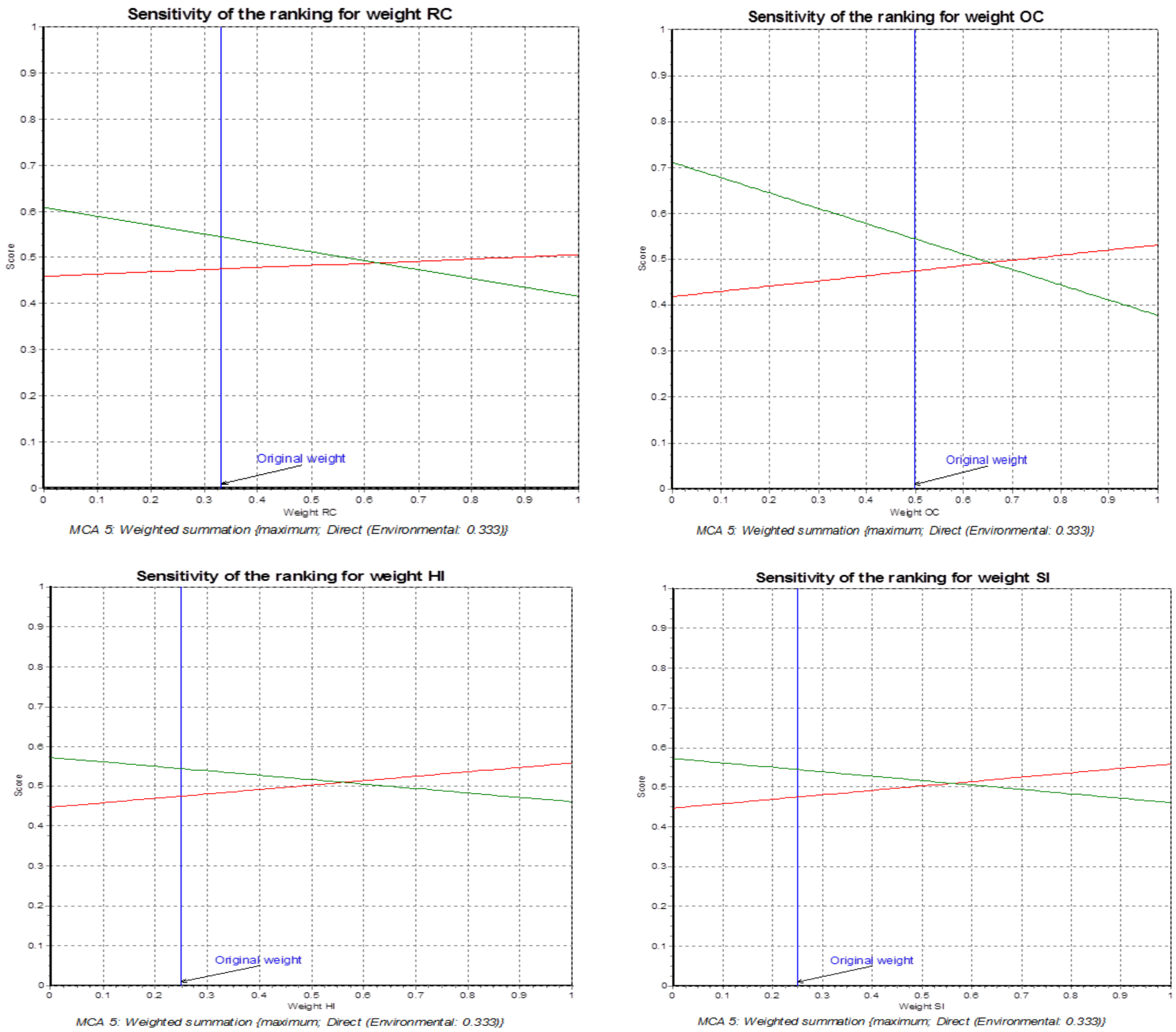


Figure 4 Criterion-specific score of the evaluation of the alternatives

After evaluating the performance of the alternatives in relation to the identified sub-criteria, a sensitivity analysis was carried out. This analysis can help decision makers to better understand the consequences of their decisions and how these can affect the overall results of the comparison [9]. It can be performed by changing the weights as a way to reflect the response of the alternatives to the relative importance of the sub-criteria to the criteria and identify the sub-criteria which could result in a ranking reversal [9, 21]. By increasing or decreasing the weight of the individual criteria or sub-criteria, the ranking of the alternatives can be observed and its stability can be assessed. If the ranking is found to be highly sensitive to small changes in the criteria weights, a careful review of the weights is recommended [21].

The sub-criteria of resources consumption (RC), operational cost (OC), and smell and health impacts (SI and HI, respectively) were the most sensitive to changes in the weights, and could cause a reversal in the ranking of the alternatives (**Figure 4**). As evidenced from the sensitivity analysis, the assignment of specific weightings to the sub-criteria would be of substantial importance to the ranking of the alternatives.



[a] The green line represents anaerobic co-digestion of food waste with sewage sludge, and the red line represents the use of FWDs

Figure 4 Results of sensitivity analysis of sub-criteria with variation in their weightings

4. Discussion

The application of the sustainability framework developed in this study and tested using the Anglian region in the UK as a case study, demonstrated that the anaerobic co-digestion of food waste with sewage sludge could be more sustainable than the use of FWDs. Notwithstanding the strength of the framework developed, it must be highlighted that a major limitation of the presented approach and thus of its results, lies on the subjectivity of assessing the contribution of the sub-criteria to the selected criteria. This is evidenced by the sensitivity analysis, which revealed that changes in the relative importance of some sub-criteria, such as those of resources consumption (RC), operating cost (OC), health impacts (HI) and smell impacts (SI), could change the outcome.

A participatory approach with all stakeholders involved in all stages of the use of the two food waste management practices is needed in order to assign the right weights on the criteria and sub-criteria. Although this participatory approach, may offer flexibility to decision-makers to evaluate both food waste management options based on their interests and needs, it may also trigger controversy between stakeholders with opposing interests. To avoid this disagreement, a transparent method of assessment and evaluation and consideration of all criteria and sub-criteria that matter to all stakeholders is needed. To this end, collaboration of all the authorities involved in the assessment is required, in order to decide on the evaluation procedure and the adoption of a sustainability decision-making framework developed based on their common needs and individual requirements. Thus, results of this study provide only insights to the importance of comparing different food waste management options based on sustainability aspects, as the different primacies originating from these options and the areas in which they are implemented could possibly lead to different outcome.

The qualitative analysis undertaken for examining some sub-criteria was a simplistic evaluation process which may have led to the under- or over-estimation of some of the sub-criteria. An example, is public acceptance, which is the prerequisite of the successful implementation of a food waste management option. Public acceptance entails the engagement of the public in doing what is required for a food waste management option to be successfully implemented. If this obligation is not met, it creates implications for the actual sustainability of the implemented food waste management option. Poor food waste separation is likely to reduce anaerobic co-digestion process efficiency, leading to a reduction in the revenue from renewable energy generation, which could also be affected by contaminants present in food waste. With the use of FWDs, the separation of food waste is easier and more reliable, since other wastes would be difficult to grind, but on the other hand the noise implications and laziness associated with operating the units might result in the disposal of food waste into the residual waste stream. This would result in food waste ending up in landfill, thus reducing the amount of energy that could be recovered and also contributing to negative environmental effects. This behaviour presents a challenge as it could exceed the potential of the two food waste management options to be sustainable. Food waste should be regarded as an opportunity that can provide valuable and viable solutions if properly managed at source and subsequently utilised by the appropriate authorities. If this is realised, then such challenges can be overcome and the value of food waste can be recognised. This must be carefully planned in order to pursue sustainability. The interrelationship between water-energy-food must be grasped as the system through which justifiable solutions can be provided, building the foundations of a greener and sustainable future.

Proper consideration of the environmental, economic and social impacts according to the area-specific characteristics and practices followed is necessary, both for the appropriate evaluation of the sustainability performance of each food waste management alternative, as well as their subsequent comparison that aids decision-making. This proper consideration can also help LAs and the water industry to integrate economically feasible and socially acceptable practices holistically, along with key environmental benefits such as the minimisation of GHG emissions, reduction of energy use and increased renewable energy generation. Nonetheless, challenges related to either the implementation of the use of FWDs or the anaerobic co-digestion of food waste with sewage sludge will continue to exist as a result of increasing population, urbanisation, an ageing infrastructure and technological development. As such, both authorities and the industry must be ready to adapt to changing circumstances.

However, it is not just the responsibility of LAs and the water industry to decide on the sustainability of a food waste management option, but also of the public. An integrated approach is required to address all relevant challenges more holistically. Taking into account the relationship between water provision, energy security and resource efficiency, and implications both in terms of availability and demand, water and environmental challenges often prove complex to address. Nonetheless, these links provide the potential to convey beneficial synergies for the water industry and LAs or contractors responsible for food waste management that could deliver real benefits and cross-sectorial solutions, if carefully applied [40]. Food waste should be realised as a material than can be turned into a resource rather than simply being discarded. Therefore, the involvement of the public and its opinion over the waste management option implemented in each area is of great importance for adopting measures that may take us a bit closer to sustainability. This is because, in order for a food waste management option to be considered sustainable, it must maintain socially acceptable levels of service, providing benefits to the community and reducing impacts to the environment in both the long- and short-term.

5. Conclusions

The sustainability framework developed in this study to inform and facilitate decision-making by both LAs and the water industry on the use of FWDs and the anaerobic co-digestion of food waste with sewage sludge based is a useful tool that stakeholders can expand and use according to their area-specific characteristics in order to address and meet their common, as well as individual, needs and requirements. The process of delivering the answer, which includes selection of environmental, economic and social criteria, the availability and collection of reliable data based on area-specific characteristics, the weighting assignment, and finally, the evaluation (including sensitivity analysis) process, are important prerequisites to the assessment of the overall performance of the decision-making framework. Even with these requirements being met, the sustainability assessment of the two food waste management alternatives would still be affected by variations in stakeholders' interests. While the flexibility provided by the multi-criteria approach is essential, it could lead to controversies among the relevant stakeholders with regards to selecting the most sustainable alternative. In the context of sustainability, which requires embracing the problems in an interdisciplinary, integrated and holistic approach, a balanced communication and collaboration of all the relevant stakeholders, who, beyond their own interests and needs, take into serious consideration the opinion and needs of the public would further facilitate the selection and implementation of the most viable solution for food waste management. Only then such frameworks could provide viable solution that are founded based on a common evaluation procedure developed according to all stakeholders' shared and individual needs and concerns, laying the foundations of a sustainable future.

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