Considerations for choosing appropriate healthcare waste management treatment technologies: a case study from an East Midlands NHS Trust, in England

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Abstract

Through their decision-making processes, organisations can play a key role in addressing global environmental challenges. However, to be effective, these processes need to be based on evidence. This paper aims to evaluate the 'optimum' healthcare waste treatment technology, using a National Health Service organisation in the East Midlands region of England, as the case study organisation. Using analytic hierarchy process as the research tool, this research determined that the 'optimum' approach was a mix of technologies. However, this result was largely driven by costs considerations. Thus the findings suggest the need for a holistic approach to the decision-making process for the procurement of their healthcare waste management services. The use of analytic hierarchy process generally worked well in informing the decision-making process.

Key words

Healthcare waste management, Waste treatment technology, Analytic hierarchy process, National Health Service, Decision-making

1.Introduction

Globally, there are a number of key environmental challenges, including climate change, resource depletion, pollution, increasing waste quantities, and environmental health concerns, which require urgent attention (IPCC, 2013; UNEP, 2015a; 2015b). Indeed, in April 2016, over 130 global leaders gathered at the United Nations headquarters in New York, to sign the Paris Agreement. In December 2015, all 196 Parties to the United Nations' Framework Convention on Climate Change adopted the Paris Agreement, at COP21, agreeing to work to limit global temperature rise to well below 2°C (UNEP, 2015a).

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By their nature, organisations can play a key role in addressing these challenges and realise significant socio-conomic and environmental benefits (Fisher *et al*., 2012; Caniato *et al.,* 2015; Long and Young, 2016). Specifically for healthcare organisations, mitigation can enhance public and environmental health, and save money (Nguyen *et al.,* 2013; Pollard *et al.,* 2014; DOH, 2015). However, the effectiveness of the mitigation approaches is dependent on having sound evidence (Garcia *et al.*, 2016; Kishita *et al.,* 2016; Vučijak *et al.,* 2015). Developing a strong evidence-base for such decision-making and the rationales for these decisions is therefore crucial.

Using an National Health Service (NHS) organisation in the East Midlands region of England as the case study, this project sought to inform the decision-making processes within the organisation as regards to 'optimal' choice for selecting its waste treatment technologies (Saaty, 2008). Deep landfill, incineration and autoclaving were the three technologies examined, as they were the most commonly deployed within the United Kingdom (UK), at the time of the study (DOH, 2014a).

1.1 The case study organisation

The NHS is one of the largest organisations in the UK and due to the nature of its activities it is energy intensive and a high generator of waste (Tudor, 2013; GIB, 2014). It is also a major consumer of resources and emits around 18 $MtCO_{2e}$ (carbon dioxide equivalent), per annum (SDU, 2016). There are a range of legislative and financial drivers in place to help it to become a low carbon, sustainable organisation, while still maintaining patient and staff safety. For example, in line with UK Government targets, it has set itself a target to reduce CO_2 emissions by 80%, by 2050 (Tudor *et al.,* 2015). However, it is expected that patient numbers, service provision and thus resource consumption levels within the NHS will significantly increase in the coming years, thus further increasing consumption and outputs (DOH, 2015). At the same time, the organisation is facing significant financial constraints, in order to meet an anticipated £30 billion deficit by 2020 (NHS, 2014). Thus it faces a number of competing legislative, compliance and financial challenges, which will become even more stringent in future.

At the time of the study, the case study NHS organisation had over 8,800 staff. It provided services in a variety of settings, ranging from the community and mental health, through to acute wards, as well as secure settings, including prisons. These services were delivered over a radius of around 120 miles. Given the organisation's size, number of staff and geographical reach, its service provision therefore had significant environmental and economic impacts.

The framework used by the case study organisation to approach contractual decisions was influenced by the Purchasing Managers' Strategic Framework, which advocates 16 separate factors which may influence a purchasing decision (NHS Supply Chain, 2015). Of these factors, four were applicable to the decision process relating to the selection of appropriate waste treatment technologies, namely:

- Legal and Compliance
- Sector specific guidelines (Guidelines)
- Mandatory reporting requirements (Environment, Sustainability & Carbon Reporting)
- Cost of purchased solution (Economics)

These four factors were therefore used as the basis for examining the selected waste treatment technologies and informing the decision-making processes.

2.Evaluating the treatment technologies

2.1 Decision-making tools

Decision-making tools have been employed in a range of environmental management scenarios to inform decision-making, including for general sustainability (Garcia *et al.,* 2016), air quality (Martenies *et al.,* 2015), Environmental management systems (Guerrero-Baena *et al.,* 2015), and specifically related to this study, waste management (Vučijak *et al.,* 2015). . For example, Martenies *et al.* (2015) used a range of environmental and economic health impact assessments (e.g. the number of cases of adverse outcomes avoided, disability-adjusted life years (DALYs), benefits per tonne of emissions reduced, and cost-benefit ratios), to inform policy and decision making related to air quality. Guerrero-Baena *et al.* (2015) employed a novel decision-making approach based on the multi-criteria method of Analytic Network Process (ANP), in order to evaluate and prioritise the implementation of environmental management system alternatives. While Vučijak *et al.* (2015) utilised multi-criteria decision making tools to select the best municipal solid waste management scenario from six different alternatives. The decision tools have also been utilised more widely, for example, in the area of planning. For example, Rojas-Zerpa and Yusta (2015) combined the application of two multi-criteria decision-making methods, namely, the Analytical Hierarchy Process (AHP) and Compromise Ranking method (VIKOR), to select the best solution for electrical supply of remote rural locations, involving technical, economic, environmental and social criteria.

Thus, multi-criteria decision-making tools are a useful and appropriate approach to finding appropriate solutions for different criteria or in the event of conflicting points of view.

2.2 Multiple criteria decision analyses

Multiple Criteria Decision Analysis (MCDA) is a field of operations management research that has evolved organically alongside disciplines where structured decision making is required (Zeleney, 1982). Increases in computational power, and the requirements for advanced decision making in poorly constrained numerical environments (e.g. fuzzy), have meant that most models of MCDA are often software based (Masud, 2008; Abassi, 2013).

Various approaches enable criteria selection including: (1) AHP, which focuses on group decision making and seeks to prescribe and 'optimal' outcome based on available data and inputs where criteria are independent from each other and distinct (Saaty, 2008; Abassi, 2013); (2) ANP, which prescribes a network where interdependence between variables is accepted, similarly considered criteria can be enhanced or rejected (if below 3% relevant typically) and inputs can be adjusted (Abassi, 2013); (3) Evidential Reasoning Approach (ERA), is a mechanism of MCDA which allows both qualitative and quantitative inputs to be considered in the form of decision matrices, and allows for statistical variation (randomness) (Bartlett and Ghoshal, 1990); and (4) Potential Pairwise Ranking (PPR) which allows for pairwise comparison of alternatives ranked additively taking into consideration the preferences of the participants undertaking the ranking (Vlasev, 2013). Critics of this approach argue that whilst allowing greater user choice, it can introduce too much 'noise' into results as decisions between criteria become obscure (Barzilai, 2002).

AHP was the most relevant to this study, as inter-dependence between the criteria is minimal, it enables both qualitative and quantitative inputs, and a step-wise process is employed within the context of the overall problem or situation (Saaty, 2008). Researchers have made extensive use of AHP for predicting or prescribing 'optimal' results in complex situations (Armstrong and Kotler, 2011; Rojas-Zerpa and Yusta, 2015; Wijenayake *et al*., 2016), even in situations involving significant unknowns, or poorly constrained variables (Bartlett and Ghoshal, 1990; Bhushan, 2004).

AHP is not without its criticisms and does suffer from known issues, particularly around the mechanism applied to priorities derivation (Ishizaka and Lusti, 2006), the comparison scale (Barzilai, 2002) and the rank reversal problem (Johnson, 1979; Saaty, 2008). The option selected for priorities derivation is a topic of intense academic debate, polarised between the proponents of eigenvalue method (Harker and Vargas, 1987; Ishizaka and Lusti, 2006; Saaty, 2008) and the geometric mean method (Barzilai, 2002; Bhushan, 2004).

2.3. Waste treatment approaches

2.3.1 Landfill

Landfilling of hazardous (infectious) healthcare waste was outlawed by the EU Landfill Directive (EC, 1999). However, 'deep landfill' (cell separated landfill) of offensive waste (referred to in the European Waste Catalogue (EWC) as 18.01.04) (EC, 2008), is still permitted at landfill sites with the appropriate licences, and makes up a significant volume of segregated healthcare waste (DOH, 2014a). However, opponents have highlighted that landfills contribute to greenhouse gases (GHGs) (Nwachukwu and Anonye, 2012), and the significant scrubbing required of landfill gas, further increases its carbon inefficiency (Nock and Walker, 2014). In addition, the EU Landfill Directive requires a reduction to 35% of the 1995 level of biodegradable landfill waste by 2016 (2020 derogation at the latest) (DOH, 2014a). The lack of supply will limit its availability to meet demand in the long term (Evangelisti and Clift, 2014).

2.3.2 Thermal treatment technologies

Many UK hospitals from the turn of the 21st century onwards were built with small-scale incinerators on their premises for their healthcare waste (Blenkarn, 1995). With improved requirements for regulatory compliance the last two decades has seen the closure of many of these incinerators. This has condensed the remaining ownership into mostly private hands with 22 licensed premises in the UK at the time of the study (DEFRA, 2014). Incineration can thermally process in the 800 - 1,000^{o}C range to treat the entire chapter 18 healthcare wastes (both hazardous and non-hazardous except chemical and mercury containing wastes) and is the only technology within the UK able to do so (DOH, 2014a). However, building and operating incinerators requires high capital expenditure, requiring lengthy tie-ins and agreed contractual rates to be viable. Thus even with secondary sale of residual heat, disposing of healthcare waste via this route is significantly more expensive than deep landfill, usually by a factor of three to five times per unit volume (DOH, 2014b).

Pyrolysis achieves considerable volume reduction of waste compared to traditional incineration, and the resultant gas can be combusted to provide heat, or injected into a grid for use elsewhere, however volumes attained may not make this feasible (Christenson, 2010). The key limitation of gasification and pyrolysis is the high-activation energy of the processes, with the challenge being to obtain a positive gross energy output coefficient (Christenson, 2010). There are working examples of both small and larger scale pyrolysis facilities within the UK being applied to healthcare waste treatment. However, gasification is still limited to the residual food waste fraction of MSW in its commercially operated settings (DPSGlobal, 2014). Whilst not directly applied to healthcare waste within the UK there is no legal or practical reason why plasma arc gasification couldn’t be (DEFRA, 2014a).

2.3.3 Alternative treatment technologies

Alternative technologies offer a less costly option than incineration, with a lower environmental impact and a reduction in the volume of residual waste which requires landfilling (Goodbody and Walsh, 2013).

At the time of the study, the most common form of mechanical alternative treatment in commercial operation for healthcare waste treatment in the UK was a form of rotary auger for shredding the material leading to either an immersion stage in a chemical, a steam autoclave, or sometimes both (DOH, 2014b). Augurs can manage the infectious fraction of healthcare waste which deep landfill cannot. However, they are limited in their application to chapter 18 healthcare waste, as unlike the thermal technologies they require soft materials only, and cannot treat any pharmaceuticals (DOH, 2014a). They are, however, low users of energy and whilst not producing a secondary energy or fuel product for re-use elsewhere do produce a sterile floc which has potential use as a refuse derived fuel (Pressley and Barlaz, 2014).

Chemical processes, whilst often used in support of mechanical or thermal treatment technologies, can be deployed in their own right particularly in the form of alkali hydrolysis (AH) (Christenson, 2010; Hansen, 2012). AH has significant potential to render safe biologically and pharmaceutically active wastes. However, to build a facility to treat adequate volumes of hazardous healthcare waste is costly (DOH, 2014).

Table 1 highlights the applications of these various technologies to the current list of healthcare wastes by EWC code. It should be noted that only technologies marked with an * existed with enough certainty to be considered within the analysis. The rest either being too theoretical or with insufficient data to include.

TABLE 1 HERE

3.Methods

3.1 Constructing the AHP

The first stage in constructing the AHP was to visualise how the decision scenario would look as a hierarchy (Fig. 1).

FIG. 1 HERE

The aim was to compare four key criteria against three alternative technology options to determine the optimal disposal technology for the organisation (Goal/ Objective) (Table 2). These criteria were extended from the Purchasing Managers Strategic Framework publications, which legally constrain the information required for submission when awarding under a framework for a contracting decision (DOH, 2014b).

TABLE 2 HERE

Of the six alternative waste technologies considered, only small pyrolysis, large pyrolysis and steam auger/rotary autoclave were advanced enough for consideration as viable options for healthcare waste treatment, and of these three, only steam auger/ rotary autoclave technology was commercially deployed in the UK and available to the organisation at the time of the study (DOH, 2014b).

It is through the process of analysing this hierarchy that the relative priority (or weighting) of each criteria and alternative were evaluated. The decision stages entailed a comparison of the criteria: 1) against the alternatives; and 2) to the goal/objective. The result was a score for each criterion against 1.000 in total, and for each alternative a score out of 1.000 in total, which provided a rank which in turn enabled determination of the most suitable option. The highest scoring option out of 1.000 is the most preferred.

To deduce the priority (ranking) between the factors (known as 'nodes' in AHP language) it was necessary to perform 'pairwise comparison' on them. This is a less rigorous statistical measure than a paired difference test. However, it works well in situations where there is an obvious equal status between factors, or a significant preference of one over another from either a qualitative or quantitate perspective (Saaty, 2008). The mechanism applied to this analysis was the fundamental scale for paired comparison, which was selected due to the availability of the AHP decision software (Table 3).

TABLE 3 HERE

Based on Ishizaka and Lusti (2006) a measure of principal eigenvalue was applied to each decision matrix (based on the mean of normalised values), supported by the eigenvector solution iterations and delta. In addition, the consistency ratio and comparison number for incorporation into the priorities derivation, were also calculated.

1.) Comparison of criteria against alternatives

For the assessment of criteria against the alternatives, tables were constructed of the most relevant points, based on judgement for the qualitative data and ranking for quantitative data (Saaty, 2008). It was then necessary to complete the following comparisons of alternatives vs. criteria for each of the four key criteria:

- Deep Landfill (DL) vs. Incineration (HTI)
- Deep Landfill (DL) vs. Alternative Technology (AT) (autoclaving)
- Incineration (HTI) vs. Alternative Technology (AT) (autoclaving)

The relative scores of one key criterion over the other (or assigning them 'equal' weighting), were determined and transferred into a square-matrix. The highest number was recorded in its designated co-ordinate, and the reciprocal (or multiplicative inverse), in the position of the corresponding lowest number. Third, the priorities were calculated based on the relative strength or weakness of one criterion over another, to determine the principal eigenvalue (Harker and Vargas, 1987; Ishizaka and Lusti, 2006).

The priorities percentage ranking was converted into a factor against one, to compare between criteria by providing an overall score for comparison. This was done by dividing the percentage priority by 100. This process was repeated to analyse all four criteria.

2.) Comparison of criteria to the goal/ objective

This stage followed a very similar method to that used for analysing the criteria against the alternatives, except it now was used to infer the relative priority between the criteria themselves. This enabled the scores assigned to the alternatives to be appropriately weighted towards the goal/ objective (Ishizaka and Lusti, 2006). First, the same mechanism of paired comparison and scoring system were applied to this stage. Second, as with the key criteria inter-comparison it was necessary to derive these results into a square matrix. Therefore a fourth row and column were added to incorporate the additional variable, increasing the number of paired comparisons from three to six (Saaty, 2008). This information was then inputted into the AHP decision software to determine the relevant consistency factor and measures of statistical proof. To compare between criteria by providing an overall score for comparison, the priorities percentage ranking was converted into a factor against 1, by dividing the percentage priority by 100.

3.) **Concluding the AHP process**

The priority of the alternative treatment technologies against the goal/ objective was determined (i.e. to 'make' the strategic decision) (Bartlett and Ghoshal, 1990; Bhushan, 2004; Saaty, 2008). Each of the alternatives was then isolated and their scores summarised against the key criteria, to enable ranking of the technologies.

3.2 Carbon accounting

The carbon emissions were calculated to determine which technology had the highest carbon emissions per tonne of waste processed, and therefore enable ranking. The key stages were:

1.) Establish the quantity (weight in tonnes) of healthcare waste produced by the organisation.

This was achieved through: (1) The quarterly returns for hazardous wastes the organisation submitted through its contractor to the Environment Agency; (2) The inter-active 'live-time' reports the organisation can generate remotely through the web portal system; (3) Reports from the invoicing database; and (4) the Estates Returns Information Collection (ERIC) annual report on key metrics within NHS Facilities (DOH, 2014b). These were all located within or through the Environmental Management System (ISO 14001:2004 accredited) store of healthcare waste disposal records.

2.) For each of the three technologies establish the necessary conversion factor to translate tonnes of waste to tonnes of CO_2 equivalent.

The total volume of material processed per annum (in tonnes), was multiplied by the relevant conversion factor for the type of material, to establish a value in $kgCO_{2e}$. For example, a tonne of healthcare waste (deemed most likely to reflect the averaged conversion factor values for paper and plastic with a 5% moisture content (DOH, 2011)) would work as follows (eq 1):

$$1.000\ (t)\ X \left(\frac{21.0\ (kgCO_2e)}{1000} \right) = 0.021\ kgCO_{2e} \qquad \text{(eq. 1)}$$

The impact of the fuel used to initiate or sustain the combustion process, or technology process was then established, if applicable. The two most likely sources of energy used as primary input would be natural gas and electricity. The value relating to 'Primary Input – Energy/ Fuel' deals with kWh, not weight, to provide a figure of $kgCO_{2e}$. Therefore a further calculation was required to establish the amount of energy used per tonne of waste, to add meaningfully to the $kgCO_{2e}$ established for a tonne of waste processed. For example, in the case of natural gas:

Annual Primary Energy Input (kWh) = Total number of kWh consumed

0.184973 ($kgCO_{2e}$ Natural Gas) X Total number of kWh consumed = Total Annual carbon from Primary Energy Input ($kgCO_{2e}$ of Total kWh).

$$\frac{\text{Total annual carbon from Primary Energy Input } (kgCO_{2e} \text{ of Total kWh})}{\text{Total tonnes of waste processed (t)}}$$

= Carbon from Primary Energy Input per tonne of waste in $kgCO_{2e}$

This figure was then added to the number established for the carbon embodied in processing a tonne of waste (0.021 $kgCO_2e$) to provide a meaningful comparison between the carbon intensity of the technologies. These values were projected for a further five years beyond the study, to 2019.

Several assumptions were made. Transport of material to the intended treatment facility was discounted, as the contractor utilised technologies within an agreed 'disposal radius' with the host organisation (except during periods of known shut down for essential maintenance/ emergencies etc.). At the time of the study, all three technologies were available within the agreed disposal radius. Thus no additional carbon could be incurred to deliver the waste, so this was discounted as a comparison between the technologies, but not from the overall carbon footprint of healthcare waste disposal. Embedded carbon was discounted from this study, even though a significant portion of the carbon involved in healthcare waste is from the consumables used to contain the waste materials (DOH, 2014a). At the time of the study, there was no published figure for the precise waste that made up typical materials disposed of as healthcare waste to deep landfill. However, this material is coded as 18.01.04 and is usually, but not always, highly biologically active and frequently saturated with high moisture content (DOH, 2014a). This minority category of waste is not reflected in the Scope 3 emissions table published (DEFRA, 2015; DECC, 2015), so as an approximation, the average of given figures for 'biologically active' material was used instead. This removed bias in the landfill CO_{2e} values from inert materials and construction and demolition wastes. The weight of waste produced was divided between the disposal technologies which can legally or mechanically process it, as certain technologies can only ever take certain waste types (with only incineration being able to take them all). Hence, to apply the entire waste weight to each technology would not be realistic.

Step 3 of the process was to apply the figures of waste weight to the above conversion factors by multiplication against:

- the maximum amount (gross tonnage)
- the fraction that can legally be processed through it (by EWC code)
- a single tonne of waste
- the "true - as is" situation (the weighted mixture of disposal technologies currently used, to compare to the organisations external published amounts as a measure of methodology robustness).

The results of this step supplied a comparable volume of data to inform the AHP as regards the 'Environmental and Carbon' advantages/ disadvantages of each disposal technology for comparison.

3.3 Economics (Cost)

There are several common pricing mechanisms used by healthcare organisations to broker contracts for healthcare waste treatment. These include price per litre, price per item or waste type (bag, bin, etc.), price per container (larger wheeled external waste receptacles), price per weight (closely linked to price per container) or price per collection. The host organisation used a cost per container mechanism to pay for its waste collections, which normalised the costs across different waste types to a fixed price regardless of disposal technology used. This meant that for wastes which can be treated in both incineration and alternative technology the direct cost to the organisation was the same. For wastes which can only be treated via incineration, the cost was capped at a multiplied equivalent rate as if it could be treated via alternative technology. This flat rate application between the two mechanical technologies, and an inability to access refined data relating to profit margins and overheads, tied these two technologies when scored. The only waste which attracted a different rate of payment when analysed was 18.01.04 waste to deep landfill, which was approximately ¼ of the price per tonne disposed of this way (Table 4). These values were projected for a further five years beyond the study, to 2019.

TABLE 4 HERE

4.0 Results

Table 5 shows the conclusion of the synthesised AHP, and the weighted priority of the key criteria against the alternative (treatment technology) to determine which is considered, on the balance of all available information, the best.

TABLE 5 HERE

Table 6 illustrates that deep landfill had the highest priority, followed by autoclaving and finally incineration. It should be noted that the overall score slightly exceeds one due to rounding of the summed numbers.

TABLE 6 HERE

Carbon accounting

Figure 2 shows that the organisation was producing a significantly declining volume of 18.10.03 (infectious, soft bagged) waste and that this was being converted into an increasing volume of 18.01.04 (non-infectious, soft bagged) waste. There was also an increasing volume of all other types of waste. Based on the future projections, it is expected that these trends will continue.

FIG. 2 HERE

Table 7 suggests that incineration should be considered the most effective per tonne technology from a carbon perspective based on existing utilisation, with deep landfill in third. Of note is that when the organisation's existing treatment situation is removed from the equation, and the 'pure' carbon efficiency of the technologies is considered only (technical rank), alternative treatment is the best. This is followed by incineration with deep landfill considered the worst from a carbon perspective.

TABLE 7 HERE

Economics (Cost)

Figure 3 illustrates that the cost of disposing of most classes of healthcare waste will increase in the future. Due to the identical costs paid for 18.01.08 and 18.01.09 (Table 4), these have been plotted directly underneath the line for 18.01.03/09. The reason for this pairing in prices is because these three wastes can be treated via 'incineration only', and so linked very closely to projected price increases for this technology.

FIG. 3 HERE

Deep landfill, despite government taxes and limited availability, will increase significantly in price by percentage as the Landfill Tax escalator is designed to do. However, it will not outpace the above inflation price rises anticipated for the energy consuming technologies (Figure 4). The declining costs of disposing of 18.01.03 (infectious, soft bagged) waste is less significant than the smaller increases in the cost of deep landfill. This is because the organisation produces so much more 18.01.04 (non-infectious, soft bagged) waste destined for deep landfill, and therefore is more exposed to the small price increases. Despite the known increases in the cost of deep landfill, and the relatively small volume of 'incineration only' wastes produced, deep landfill remains cheaper than utilising other disposal technologies, due to the fixed pricing band structure.

FIG. 4 HERE

5. Discussion

5.1 Optimal technology

The results suggest that deep landfill should be considered the 'optimal' disposal technology, followed by alternative technology, with incineration in 3rd place. This outcome supports a position against the hypothesis in that the optimal situation for treatment technologies is a 'mix' of several, rather than the practically preferred 'single option' solution. The ranking reflects the economic priorities and less so the carbon, legal and guideline priorities in the AHP. With the costs being equitable between HTI and AT, the organisation is in reality less incentivised than the contractor to select between these two, and can merely state a preference for the lower carbon AT under existing contractual arrangements.

5.2 Explanation of the findings

Broadly speaking, the findings confirm the reality of strategic decision making processes within the NHS. With 'Cost' as a variable weighted under the economics criteria to the same level as it usually receives in the organisation's Official Journal of the European Union (OJEU) tenders for third party services (at typically 40-45% of contract by value (DOH, 2014b)), evidently highlighted lower-cost treatment options. Weighting cost in the same way as the organisation did mean less space for the equally important aspects of legal compliance and carbon/ environmental impacts, and this is reflected in the ability of deep landfill, despite being the highest carbon and most environmentally detrimental technology, to come in first place.

Legal and compliance is shown to favour incineration strongly over deep landfill, mainly because it is secure for the strategic window being considered. In addition, incineration can process the complete range of healthcare wastes. However, when compared to the gross tonnages, the vast majority of the organisation's waste by weight (18.01.04) could be processed by all three technologies (60.4%). Deep landfill may be time-constrained legally but it is not an illegal treatment route, switching destination sources away from this route when it is eventually closed down would have no upstream impacts.

Guidelines proved to be insignificant as a criterion (0.048 out of 1.000). This validates in part the difficulty organisations face in relation to choosing a waste treatment technology should they have weak legal understanding. In addition, with guidelines trying to accommodate every situation, they cannot be overly prescriptive. That said, the two mechanical treatment technologies reflected on more positively than deep landfill which attracts negative coverage from several sectors, however is widely supported for its economic benefits to the 'cash-strapped' NHS (DOH, 2014). It can be concluded that regardless of what guidelines dictate to the host organisation, if a proposed treatment solution is not illegal, it will be endorsed at this time of budgetary austerity, and guidelines to the contrary will be disregarded (DEFRA, 2014).

From the position of carbon accounting, the results concluded in line with expectations that deep landfill is by far the most significant producer of CO_2 (EC, 2008; DEFRA, 2014). Even including the potency of the additional GHGs from incineration, the decay of this material in an anaerobic environment is significantly higher per tonne (Bagchi, 2004). The impact of the organisation's corporate social responsibility (CSR) and taxable obligations factored into the scoring well from a decision perspective, as broadly the treatment technology producing the most exposure to reputational risk and environmental harm was congruent with that which produces the most GHGs.

5.3 Efficacy of AHP

AHP proved to be a robust methodology, well adapted to the needs of strategic decision making in a waste disposal technology selection situation. With the level of complexity among inputs being resolved well, the outcome matched predictions, but crucially provided 'evidence, transparency and justification' (Bhushan, 2004). The results suggest that the decision relating to selecting an 'optimum' healthcare waste treatment technology was indeed dependent on the four key criteria selected, and is of adequate complexity to justify the chosen methodology. No key criteria were irrelevant, but acknowledgement was given to the varying degrees of relevance exposed by the AHP method which had previously been obscured. No inconsistency resolved higher than 5.6%, which is within the agreed measure of proof for this test of <10% (Bhushan, 2004), and no principal eigenvalue determined higher than 4.121 with an average of 3 against 3 iterations. This provides further certainty that the method for the AHP was consistently followed and congruently scored by the practitioner (Ishizaka and Lusti, 2006).

The AHP struggled to resolve economics as between the three technologies there are only two distinctions (costs) applicable to the iterations. This is due to the organisation having agreed fixed costs across broad ranges of different waste types, irrespective of differences that might in fact exist. This makes the scale very absolute in determinations of superiority based on cost. However, it does accurately reflect the pricing mechanism as facing the organisation, so it has high validity. This issue is compounded in terms of the overall synthesis of the priority by the substantial weighting that economics attracts in keeping with the organisation's perspective of its own strategic decision, as instructed by the EC purchasing managers index and the DOH (DOH, 2014a). In addition, the analysis of the economics of each technology was limited by the lack of profitability information between the two mechanical technologies, however as both rely on a broadly equitable power source, it is likely that the costs are comparable (Christenson, 2010).

However, as the AHP is constructed to assist with strategic decisions it remains valid even with these limited inputs. Factoring the cost against the quantity in the detailed economic comparison highlights just how significant a low price treatment technology can be against the relative weight the organisation needs to be disposed of. This shows that against the current situation, a solution favouring deep landfill is very strong against the waste arising, and will continue to be so for the strategic horizon under consideration. There is a stronger than expected growth in the longer term impacts of 18.01.09 waste (suitable for incineration only) which is fixed at this cost, as there is no other way to dispose of it (DOH, 2014). Ultimately, as with all waste types, organisations must consider multiple technologies as the 'optimal' solution against the criteria.

5.4 Limitations of approach employed

From the perspective of the suitability of the criteria to select between the alternatives, the overall 'feel' of the model is correct. Very few other category level criteria came to light during the running of the AHP which could not be adequately factored for under the chosen four. However, in future iterations of this method it might be worth considering a separation of 'Carbon' as its own criteria, possibly titled 'Greenhouse Potency'. Accepting however, that this will require the considerations of environmental and sustainability to be included with legal and compliance, which might be too narrow in scope to accept the wider qualitative implications (Armstrong and Kotler, 2011).

Only a limited number of criteria were included. Additional criteria for evaluation might include transport. Specifically this might be in relation to technology proximity, and how this might be affected by a 'multiple technology' strategic best fit, as road haulage of healthcare waste attracts a 1.1kgs per mile addition to the carbon factor values. This may seem very small, however in a rural locale with numerous small clinics requiring frequent collections this value could prove significant on a site-by-site basis. On a wider scale, the proposed methodology could potentially also be employed where there are only sanitary landfills or where there are no existing appropriate measures in existence.

6. Conclusions

Two key conclusions can be drawn. First, there is no ‘optimum’ technology for treating of healthcare waste. Due to the overriding influence (or even contradiction) between the key criteria, and the inability of some waste types to be disposed of by all options considered, a ‘mix’ of technologies should be chosen. However, an important point to note is that deep landfill is evidentially a viable option for the 18.01.04 (i.e. offensive waste), stream. This is particularly important given the limitations in finance that are available to most NHS organisations. Second, the process used has highlighted that the method chosen to answer this strategic question (AHP) worked, but highlighted several areas for improvement at the same time.

Three key recommendations can be made, namely:

Equitable costs between waste types for treatment (whilst convenient for the customer) disguise the ‘true’ price of using a particular treatment technology, making it difficult to resolve cost discrepancies. Organisations should therefore seek clarity from their sub-contractors on the margin they are paying above the actual cost to examine how this varies by technology option.

Consideration should be given to involving an expert practitioner in strategic decision making, even if this individual is external. This will provide a useful source of information to facilitate scoring, and remove over-reliance on ‘guidelines’ which have proven in the course of this research to be reasonably unreliable sources of information.

Depending on the organisation’s geography, demography and access to technology by distance, the key criteria selected here might not be the most relevant. Thus practitioners should be cautious about following the prescribed tendering guidelines when making a decision about treatment technologies as the factors affecting a rural clinic, versus a major city centre hospital, are likely to be different (particularly around the transport ‘cost’ of carbon).

Globally, a more sustainable approach to managing waste is crucial, if issues associated with tackling climate change are to be adequately mitigated. Within this context, decision-making on appropriate waste treatment technologies requires a strong evidence base. Evidently, costs are a key driving factor in purchasing decisions. However, the results indicate how this lead to a choice of technology that had the highest environmental impact. It is important therefore that in the decision-making process, healthcare organisations take a broader approach to procurement and employ a multi-technologies strategy. This approach should be informed by sound evidence, which the use of AHP can provide. It is only in this way that a more sustainable and long-term approach can be employed, which not only delivers financial value, but also safeguards resources and public health.

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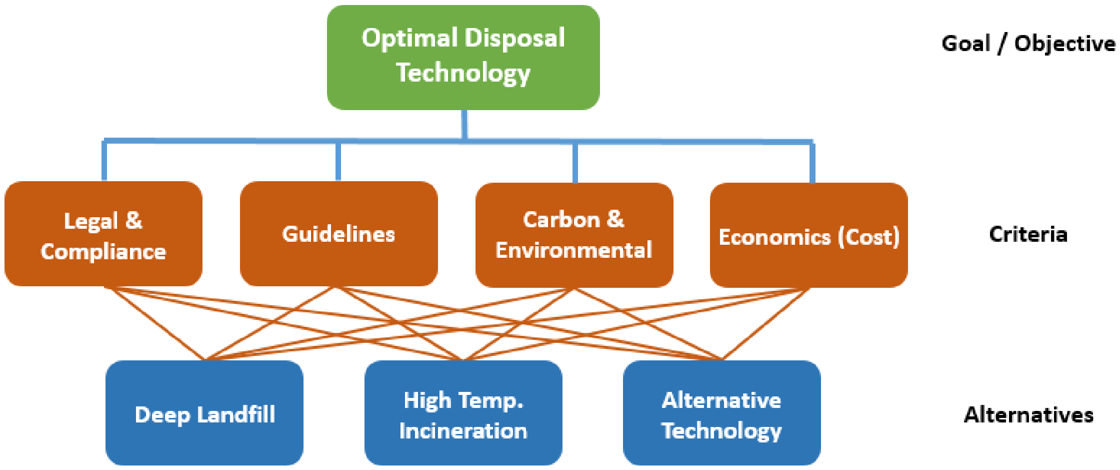

Fig. 1: Hierarchy of goals, criteria and alternatives

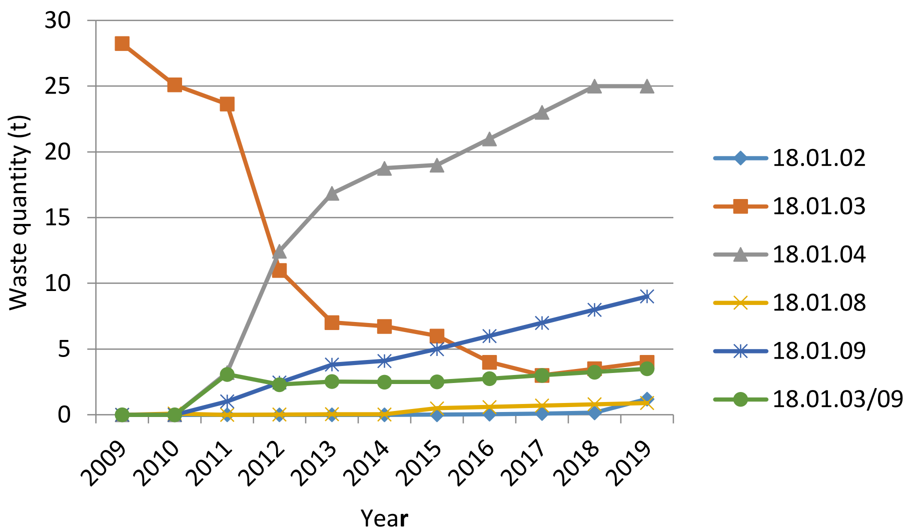

Fig. 2: Existing and projected quantity of healthcare waste up to 2019

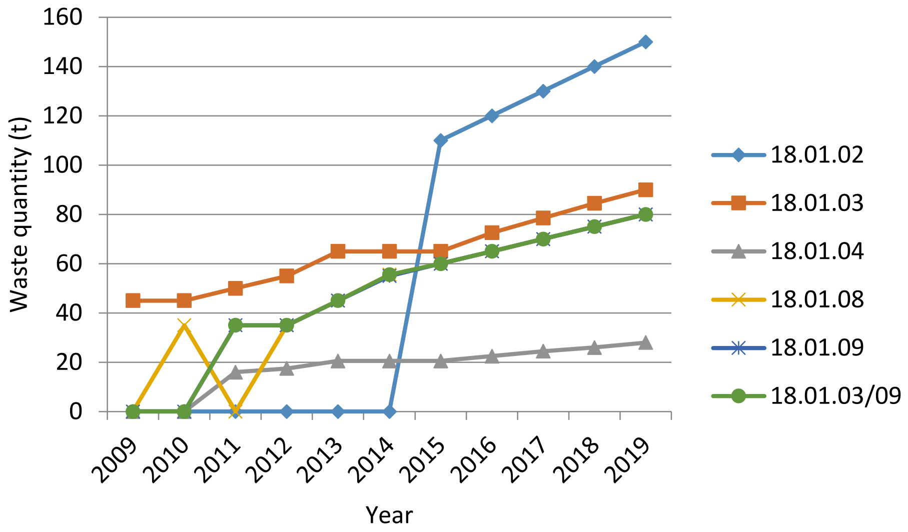

Fig. 3: Existing and projected cost of healthcare waste disposal by EWC over time

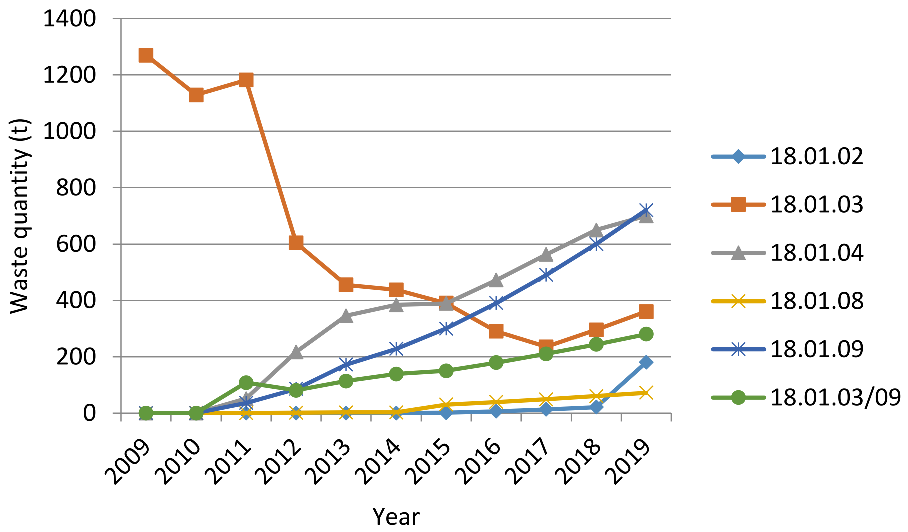

Fig. 4: Existing and projected annual waste arisings (in tonnes)

Table 1: Suitability of healthcare waste (by EWC) for different types of alternative technologies

Waste type by EWC code	Alternative Waste Treatment Technology					
	Small Pyrolysis*	Large Pyrolysis*	Gasification	Plasma Arc	Steam Auger*	Alkali Hydrolysis
18.01.01	Potentially	Yes	Yes	Yes	Yes	Yes
18.01.02	No	Potentially	Potentially	Yes	No	Yes
18.01.03	Yes	Yes	Yes	Yes	Yes	Yes
18.01.04	Yes	Yes	Yes	Yes	Yes	Yes
18.01.06	No	Potentially	Potentially	Potentially	No	Potentially
18.01.07	No	Potentially	Potentially	Potentially	No	Potentially
18.01.08	No	Potentially	Potentially	Yes	No	Yes
18.01.09	Potentially	Yes	Yes	Yes	No	Yes
18.01.10	No	No	No	No	No	No
18.01.03/09	Potentially	Yes	Yes	Yes	No	Yes

Table 2: Components of the AHP

Goal/ Objective	Key Criteria	Alternatives (Technology Option)
To select the 'Optimal Disposal Technology' for organisational endorsement on the balance of 4 key criteria	- Legal & Compliance - Guidelines - Environment, Sustainability & Carbon Reporting - Economics (cost)	1.) Deep Landfill 2.) Incineration 3.) Alternative Technology

Table 3: the fundamental scale for paired comparison table

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two elements contribute equally to the objective
3	Moderate Importance	Experience and judgement moderately favour one element over another
5	Strong Importance	Experience and judgement strongly favour one element over another
7	Very Strong Importance	One element is favoured very strongly over another; its dominance is demonstrated in practice
9	Extreme Importance	The evidence favouring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6 and 8 can be used to express intermediate values. Intensities of 1.1, 1.2, 1.3 etc. can be used for elements that are very close in importance		

Modified from (Saaty, 2008; Armstrong and Kotler, 2011).

Table 4: Cost for comparison for 1100 litre volume of each waste by type

Waste type by EWC code	Incineration	Alternative Treatment	Deep Landfill

18.01.01	£55.50	£55.50	N/A
18.01.02	£111.00	N/A	N/A
18.01.03	£65.00	£65.00	N/A
18.01.04	£65.00	£65.00	£20.50
18.01.06[1]	N/A	N/A	N/A
18.01.07[1]	N/A	N/A	N/A
18.01.08	£55.50	N/A	N/A
18.01.09	£55.50	N/A	N/A
18.01.10	Ad hoc only, minimal volume, no fixed price	N/A	N/A
18.01.03/09	£55.50	N/A	N/A

Table 5: Results of the priority ranking

Key Criteria	Priority vs. Goal/ Objective	Alternative	A		B	C
Legal & Compliance	**0.221**	**Deep Landfill**	**0.069**	**X**	**0.221**	0.015
		Incineration	**0.681**	**X**	**0.221**	0.150
		Alt. Treatment	**0.250**	**X**	**0.221**	0.055
			1.000			**0.221**
Guidelines	**0.048**	**Deep Landfill**	**0.105**	**X**	**0.048**	0.005
		Incineration	**0.499**	**X**	**0.048**	0.023
		Alt. Treatment	**0.396**	**X**	**0.048**	0.019
			1.000			**0.048**
Environmental, Sustainability & Carbon	**0.312**	**Deep Landfill**	**0.058**	**X**	**0.312**	0.018
		Incineration	**0.278**	**X**	**0.312**	0.086
		Alt. Treatment	**0.663**	**X**	**0.312**	0.206
			1.000			**0.311**
Economics (cost)	**0.419**	**Deep Landfill**	**0.818**	**X**	**0.419**	0.342
		Incineration	**0.091**	**X**	**0.419**	0.038
		Alt. Treatment	**0.091**	**X**	**0.419**	0.038
			1.000			**0.419**

Table 6: Priority of each treatment vs the key criteria

	Priority with respect to				
Disposal Technology	Legal & Compliance	Guidelines	Env, Sust & CO_2 Reporting	Economics (cost)	Goal/ Objective
Deep Landfill	**0.015**	**0.005**	**0.018**	**0.342**	**0.381**
Incineration	**0.150**	**0.023**	**0.086**	**0.038**	**0.299**
Alt. Technology	**0.055**	**0.019**	**0.209**	**0.038**	**0.322**
Totals:	**0.221**	**0.048**	**0.311**	**0.419**	**1.00**

Table 7: Ranked carbon realised from each treatment technology

Carbon from Treatment Technology	D.L	H.T.I	A.T
Theoretical Maximum (all waste)	**14.599**	**2.522**	**1.509**
Legal Maximum (just permitted EWC's)	**8.830**	**2.522**	**1.240**

% representation of Legal Maximum against Total Tonnage from 1.)	**60.5%**	**100%**	**82.20%**
Single Tonne	**0.47**	**0.08**	**0.04**
Existing breakdown across all 3 technologies (% & T)	**60%** **8.830**	**40%** **1.008**	**0%** **0**
Technology rank against current optimal breakdown by Carbon	**3**	**1**	**2**
Technical Rank	**3**	**2**	**1**