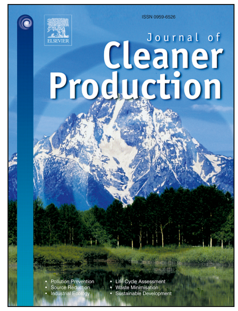
Journal Pre-proof



A model for partner selection criteria in Energy from Waste projects

Victoria Uren, Tim Miller, Raffaello Da Campo, Aba-Sah Dadzie

PII: S0959-6526(20)33627-1

DOI: https://doi.org/10.1016/j.jclepro.2020.123582

Reference: JCLP 123582

To appear in: *Journal of Cleaner Production*

Received Date: 11 October 2019

Revised Date: 30 July 2020

Accepted Date: 31 July 2020

Please cite this article as: Uren V, Miller T, Da Campo R, Dadzie A-S, A model for partner selection criteria in Energy from Waste projects, *Journal of Cleaner Production*, https://doi.org/10.1016/j.jclepro.2020.123582.

Victoria Uren: Investigation, Writing – original draft, Methodology, Supervision, Visualization. **Tim Miller:** Supervision, Methodology. **Raffaello Da Campo:** Methodology, Writing – Review and Editing. **Aba-Sah Dadzie:** Writing – Review and Editing, Visualization.

10,586 words including references

A model for partner selection criteria in Energy from Waste projects

Victoria Uren (Corresponding Author)
v.uren@aston.ac.uk
Operations and Information Management Department, Aston Business School, Aston University, Aston Triangle, Birmingham B4 7ET, United Kingdom

Tim Miller
t.miller1@aston.ac.uk
Energy and Bioproducts Research Institute (EBRI), Aston Triangle, Birmingham B4 7ET, United Kingdom

Raffaello Da Campo
r.dacampo@bham.ac.uk
Energy and Bioproducts Research Institute (EBRI), Aston Triangle, Birmingham B4 7ET, United Kingdom

Aba-Sah Dadzie
aba-sah.dadzie@ed-alumni.net
Operations and Information Management Department, Aston Business School, Aston University, Aston Triangle, Birmingham B4 7ET, United Kingdom

Abstract

Energy from Waste is being deployed in both developed and developing economies as a route to reduce dependency on fossil fuels whilst making positive use of resources which might otherwise be landfilled. Energy from Waste supply chains are complex, with a rich diversity of partners and stakeholders involved. For this purpose, the selection of appropriate criteria to guide supply chain design, and in particular the selection of suppliers, is critical for success. In this study, a three-stage process was conducted to identify, refine and validate an evidence-based model. The evidence based model proposed comprises seven categories of criteria used in the design of these supply chains, namely Economic, Environmental, Location, Operations management, which has a sub-category of Plant operation, Political/Legal and Social. The work reported here supports practitioners and researchers involved in supply chain partner selection to systematise their thinking in relation to the criteria that may impact their study or project.

Keywords

Supply chain, Energy from Waste, Partner selection criteria

1 Introduction

Energy from Waste (EfW) projects take waste products, such as agricultural wastes, food waste or Municipal Solid Waste (MSW), and use them to generate energy and other valuable bioproducts. The design of supply chains for EfW projects requires multiple partners to be brought together in relationships which generate value for all the partners, to ensure stable and sustainable operations over the decades of operating life expected from a power plant. The European Bioenergy Research Institute (EBRI) at Aston University, UK, has identified more than thirty types of partners that may be required in an EfW supply chain (Abba-Dabo, 2018). These include technical services, such as engineers, plant operators, construction, safety systems suppliers and lab services. Ancillary services include finance, accounting, legal services, accreditation consultants and IT. Logistical support is required to transport waste, while collection and concentration services are needed to accumulate and safely store waste until it is needed. External stakeholders, including the public, lobbying groups and policy makers, also influence decisions. Taking a qualitative and interpretative approach, we develop and present an evidence based model which should help policymakers, legislators, and planners to explore and evaluate the socio-economic landscapes in which they operate. We aim at providing a usable model for decision makers to effect change and make rational choices.

Supplier selection can be defined as *"entering one or more supply chains and involving the selected partner in the company's current supply chain(s)"* (Rezaei, 2015). The problem can be addressed by a number of theoretical approaches. Methods for supplier selection include multi-criteria decision making, mathematical programming and Artificial Intelligence (AI) methods (Chai et al., 2013). Green supplier selection methods, which consider potential partners' environmental performance, are reported to include the use of Analytical Hierarchy process, Data Envelopment Analysis and fuzzy set theory (Govindan et al., 2015). A review of methods for optimising biomass to bioenergy supply chains covered mathematical programming, heuristics and multi-criteria decision making (De Meyer et al., 2014). Geographical Information System (GIS) approaches (Clarke, 1986) focus on optimisation with respect to spatial factors, for example plant location (Jeong & Ramirez-Gomez, 2018; Tavares et al., 2011) or the location of pick-up points for feedstock (Haddad & Anderson, 2008). Learning curve studies model factors which can be improved as a technology matures and production increases, including cost reduction (Anzanello & Fogliatto, 2011; Yelle, 1979). Learning curve has been shown to be of value in technologies related to this study, including the production of short rotation wood crops for bioenergy (de Wit et al., 2013), alternative kinds of bioenergy plants (Junginger et al., 2006), and the production of bioethanol (Cavalett et al., 2017). Lifecycle assessment (LCA) analyses the environmental impacts of a project through the whole life of the plant from inception to decommissioning. LCA provides a key argument in the justification of most EfW projects, which are expected to contribute to improved environmental outcomes (e.g. Cleary, 2009; Evangelisti et al., 2014; Fan et al., 2011).

All the above theoretical approaches share a need to understand what influences the performance and sustainability of supply chains in order to take the initial step of selecting appropriate criteria to include in their models. As might be expected, given the number of approaches, many criteria have been identified in the literature. In just one example, Govindan et al. (2015) provide a list of 122 criteria for green supply chains. Therefore, gaining a clear view of the criteria relevant to the success of EfW supply chains presents a significant challenge.

Often, theoretical works focus on the selection and refinement of the analytical process (e.g, cost benefit, Analytic Hierarchy Process (AHP), or GIS). Many papers fail to report the method by which the criteria used in the analysis were selected. From among those that do, three sources can be identified. The first, and the most typical source, is literature review. Examples are provided by Govindan et al. (2015) who tabulate criteria found in literature sources, and Lohri et al. (2016) in which review and discussion precede analytical work. Lohri et al., however, like many others, do not detail how or why particular criteria were selected. The second source is stakeholders' requirements, with examples provided by (Scott et al., 2015), (Wang et al., 2018) and (Ho et al, 2011). Methods such as interview (Wang et al., 2018) and the House of Quality product development matrix (Ho et al, 2011) are reported to have been used for knowledge elicitation from stakeholders. The third source mixes pragmatism with expertise and local accounting policies to select, from among the data actually available for a particular plant or proposed project, those criteria which are most important, reliably measured and representative. This approach is rarely discussed in academic literature, but a report by Iaboni and Stefanis (2007) describes the use of available data, which differs from plant to plant depending on local accounting practices, and how comparability issues can be tackled by normalising data. This work presented here partially addresses the paucity of discussion around how evaluation criteria should be selected, by identifying categories of criteria in a methodical way which uses both literature and domain expert sources. The result is a model which we believe is novel, in the sense that it provides a holistic view that takes into consideration aspects that are not usually all dealt with in a single paper. It provides a rounded picture aimed at defining and understanding different stakeholders' interests.

Experience of real world cases complements theoretical study. Anecdotal evidence suggests that over the long service life of EfW plants, typically decades, the operating context will change, and that this can impact sustainability. To illustrate this point, we consider the case of the Anaerobic Digester (AD) plant at Ludlow, Shropshire, UK (anaerobic-digestion.com, 2019; Foxall, 2012). The site incorporated a small-scale AD plant, which consumed food waste collected from local households, and an educational facility. At its peak it fed 700MWh of electricity per year back to the National Grid, directly created two fulltime jobs in an economically challenged, rural area, and produced agricultural fertilizer. The plant was considered a technical success in demonstrating the feasibility of AD for pure food waste (anaerobic-digestion.com, 2019). The on-site education facility served a social function, succeeding in building a positive public perception of the plant and its contribution to environmental sustainability, to the extent that there were protests against its eventual closure in 2014 (Shropshire Star, 2014). Curiously, this closure coincided with development of a national AD strategy (DEFRA, 2011), so why did the project reach the end of the road? Contributory factors for the closure appear to include operating issues (Foxall, 2012), political considerations including changes to the structure of local government (UK Government 2008), and economies of scale (anaerobic-digestion.com, 2019).

It can be argued that cases such as the Ludlow AD plant contribute to the learning curve of EfW technology and that practical insights from such projects need to be communicated, in addition to theoretical studies, so that researchers, managers and engineers can develop a view of EfW plant supply chain design, which builds on practical experience. This study is intended to address that need by highlighting the kinds of criteria that matter when making supplier selection decisions. The proposed model aims to guide researchers and managers who wish to systematise their thinking about partner selection decisions. We base our model on the premise that supply chains are built by people, operate within societies, and serve social as well as economic needs. Hence they are socio-economic phenomena.

1.1 Research Philosophy and Methodology

To benefit from theoretical and practical perspectives, we take an approach that allows us to extract both implicit and explicit knowledge from domain experts. The data collected, derived from literature and semi-structured interviews with experts, is arguably in part subjective, and potentially limited by the social constructs in which each case study is based, and therefore, in which practitioners acquire their world view. We counter this by, among others, increasing breadth by collecting data spanning multiple time horizons and geographies. While this does not undermine the value in or applicability of the data collected, we further validate the empirical data using a sequential, multi-method study, typical in qualitative research, to triangulate the evidence collected. This provides a degree of objectivity and increases reliability of the results, and therefore, potential for transfer and reuse in further research and application (Kelliher, 2005, Golafshani, 2003, Saunders et al., 2016).

The research design used a combination of inductive and deductive approaches; figure 1 summarises the different components of the study and the approach taken to analyse and validate the findings over its three stages. The first comprised a systematic analysis of relevant literature, which identified commonly used categories of criteria (section 2). The analytical approach at this stage was pragmatist and inductive, with the coding of categories driven by what was found in the data (Braun and Clark, 2012). The second stage was the expert interviews. A primarily deductive approach (Braun and Clark, 2012) was taken to the analysis of interview data, which was guided by the categories identified in the literature review, but was open to the identification of new categories or changes to those already identified. Sampling of experts was purposive (Kelliher, 2005, Golafshani, 2003), and aimed to improve the generalisability of the study by soliciting different professional perspectives, namely those of operations and technical experts, who had worked on a wide range of projects. Validity testing in the context of qualitative research aims to produce a *"more credible and defensible result"* (Johnson, 1997). The third and final step, therefore, validated the categories by using them to develop case studies with two further experts, who had not been involved in the second stage. Section 3 presents the methods for the second and third stages of the process. Section 4 presents findings of the second and third stages. Section 5 summarises the conclusions.

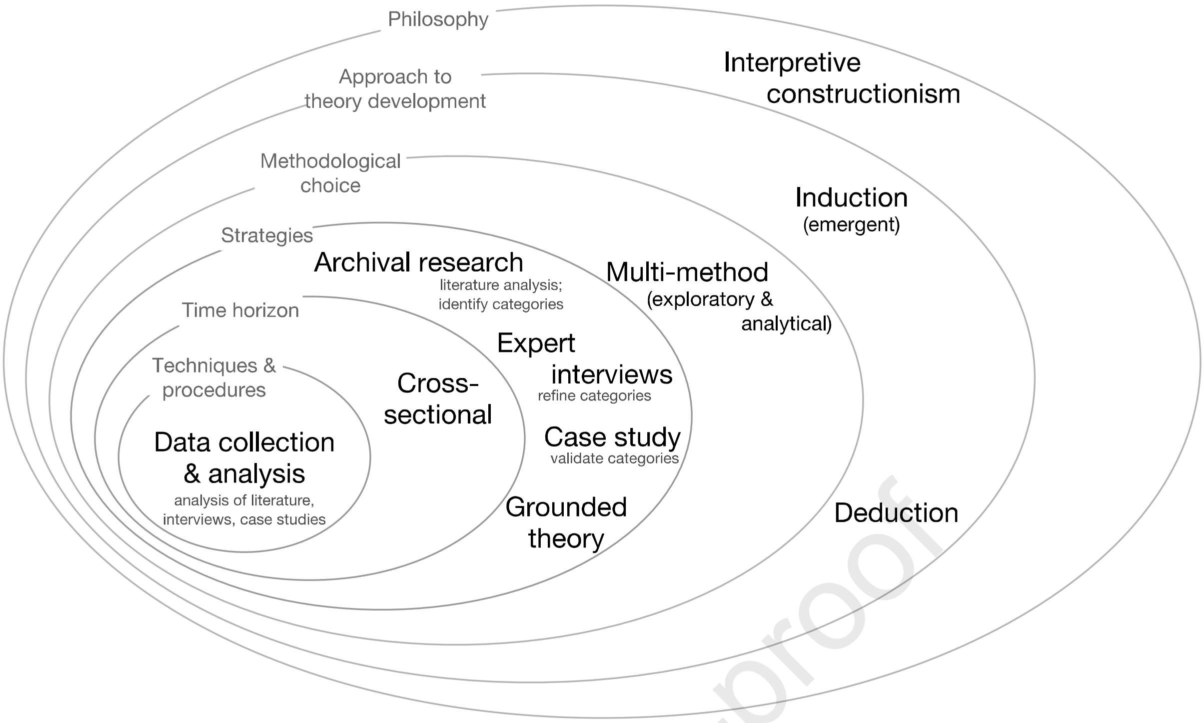


Figure 1 Flow of the stages of research, illustrated using an adaptation of the research onion discussed in Saunders et al., (2016).

2 Analysis of Literature

In order to gain an understanding of the supplier criteria used in studies of EfW and related technologies, and to identify potential categories, a systematic review and analysis of relevant academic literature was conducted. This stage takes a theoretical perspective through the examination of published work which tackles the issue of supply chain management and design for EfW and related technologies.

A Web of Science (WoS) search for combined compound terms representing supply chain design, criteria and bioenergy was carried out (see table 1) across all the available WoS databases with no date restriction. The broader bioenergy concept was searched, as well as the narrower one of EfW, because the number of articles returned for EfW alone was relatively low. We found, on expanding the search, that criteria identified for EfW could be supplemented with related process types, especially when qualified by the more specific EfW terms. A total of 45 articles were retrieved of which 7 were judged irrelevant and excluded from the review. The remaining 38 relevant articles were examined using a qualitative content analysis approach.

Table 1 WoS Search criteria

Search	Compound term	WoS Hits
#1 Process	“waste to energy” OR “energy from Waste” OR bioenergy OR ((waste) AND ((energy OR power OR heat) AND (combustion OR pyrolysis OR anaerobic OR digest))	31,285
#2 Indicators	criteria OR criterion OR indicator OR “key performance indicator” OR KPI	1,369,790
#3 Supply chain	(supply chain management) OR “supply chain management” OR “supplier	33,300

	selection" OR "supply chain design	
#4 Final	#1 AND #2 AND #3	45

In the first round of analysis, each article was read in the order of its ranking in the WoS results (most highly ranked first) and notes made on its content, with the aim of identifying the types of criteria considered in the article. The notes were reviewed to identify categories which aligned to types of criteria. In the second round, the articles were revisited in order of first author name (reordering has the effect of refreshing the view and allowing the reader to spot new themes), with the aim of categorising them and producing a definition of each category. In the third round, following the assignment of categories, the articles were subdivided into sets based on the power generation process/es discussed.

2.1 Categories

The first round identified 8 candidate categories that were taken into the second round of analysis. These were: Economic, Environmental, Location, Operational, Political, Legal, Social and Supplier. In the second round, these were narrowed to a working set of 6 Categories that resulted from merging the Political/Legal and Operational/Supplier categories, which had significant overlap in their content. In the third round, occurrence of the categories in the papers was recorded: 8 articles concerned Bioenergy in general, typically discussing several processes in the same article or high level issues, 10 articles concerned EfW, 19 concerned biofuels, of which 10 concerned forestry or wood as an energy source, 6 of these concerned the harvesting of forestry residues, which may arguably be viewed as a waste product.

The categories identified associated with each process subset are summarised in figure 2. All the criteria categories were identified in all the subsets. This is taken as indicative that the categories have a sufficient level of generality, i.e. the categories are not specific to a particular energy process.

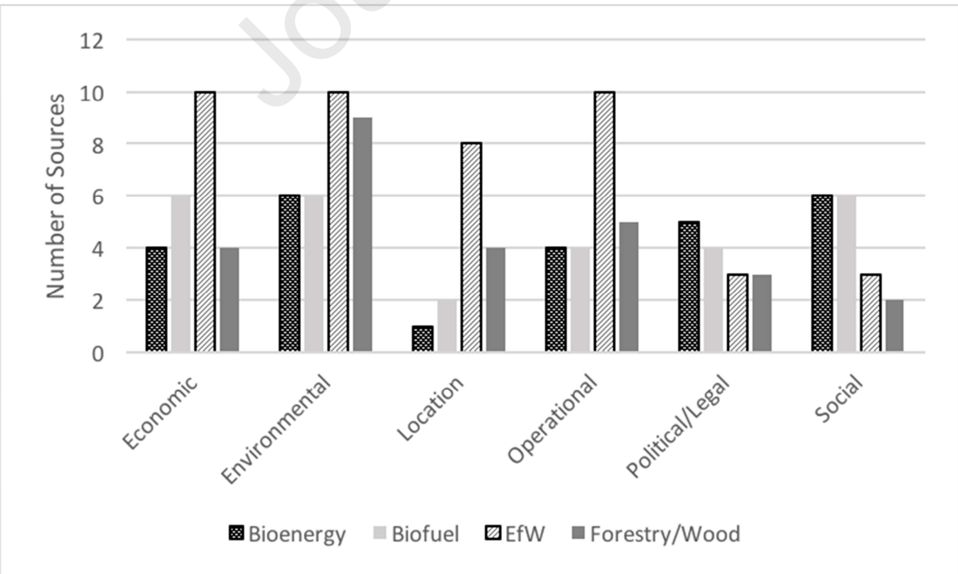


Figure 2: Number of sources containing criteria from each category by process.

The fourth and final step of the review involved examining the subset of ten papers most closely related to EfW in detail. This subset is itemised in table 2 (see appendix). [For readability, this paragraph uses the ID numbers of the references from table 2 in place of author date references]. The spectrum of EfW processes covered by the subset includes bioenergy (which may include waste biomass as feedstock) [Paper IDs 1, 2, 3, 7, 10], MSW [4, 8, 9], conversion of waste to char [5], and pyrolysis of agricultural wastes [6]. The methods used are primarily quantitative, comprising fuzzy approaches [1, 2, 3, 9], multi-objective programming [1, 2, 4, 7], goal programming [6], and multi-criteria assessment in GIS [8]. The remaining papers used a Pugh technology assessment matrix, incorporating technical, financial and environmental/health aspects [5] and a systems dynamics simulation [10]. The papers also covered scenarios with a wide geographic spread, encompassing Europe [1, 2, 4, 8], Asia [6, 9, 10] and Africa [5, 7]. Therefore, while the number of papers in the subset is limited, its scope is substantial.

This subset of ten papers was analysed to identify examples of typical criteria in each of the six categories (see table 2 - appendix). This provided a further indication that the categories could be associated with EfW supply chains, but also contributed to producing definitions of the working criteria to be used in the expert interviews, as will be outlined below. The definitions of the working set of categories were:

- Economic – Criteria concerning all financial issues and the economic viability of facilities and their associated supply chains. Examples include costs, revenue, profits, and demand for energy.
- Environmental – Criteria concerning impacts on the environment. Examples include Greenhouse Gas Emissions (GHG), soil, air and water quality, habitat and biodiversity, and reduction of landfill.
- Location – The geographical siting of facilities, and its effects on costs, social impacts on populations, availability of infrastructure required for operations, and so forth. Examples include distance for feedstock suppliers, access to the electrical grid.
- Operational – A range of technical factors occur in this class. Examples include transportation, reliability of feedstock supplies, capacity of facilities, and scale of operations, supplier financial robustness and credibility.
- Political/Legal – Issues related to law and governance. Examples include contract conditions, incentive payments or taxes, forestry accreditation schemes, the capacity to enforce laws, and civil rights of populations.
- Social – Criteria concerning effects on populations. Examples include public health, employment, availability of skilled workers, access to lands and the preservation of special sites for aesthetic, biodiversity or cultural reasons.

3 Method

The second stage of the model development process refined the categories identified from the literature review by a process of model review and adaptation, driven by knowledge and opinion elicited from experts with different perspectives. The expert opinion added a practise-based perspective to the theoretical one obtained from the literature. This stage confirmed many of the categories identified from the literature review. It also allowed the model to be refined in structure and detail. The third and final stage of the model development process used the resulting seven refined categories to structure two case studies. This stage aimed to validate the model by providing evidence that these seven categories provided a balance between a sufficiently high-level model and, by summarising and triangulating the observations of various experts and practitioners, coverage of our focus sub-topics. Analysis of the data collected further highlighted links between the seven categories not previously explicitly defined, and at the same time delineation between the categories, confirming the validity of each as a distinct category. Specificity, coverage and relevance were validated using two project cases which had not previously been discussed in the expert interviews. Further details of the methodology follow.

3.1 Expert Interviews – Refine Categories

Seven interviews were conducted with experts. Three, considered for the purposes of this study as technical experts due to their deep knowledge of EfW projects, comprised an agricultural engineer with a background in sustainability assessment and socio-economics, and two chemical engineers. One of the chemical engineers is a member of a related UK government advisory panel. Three experts were operations management specialists with knowledge of circular economy and green operations. One of the operations experts had a background in chemical engineering, and one in production engineering. The seventh participant was a logistics specialist with experience in reducing the environmental impact of freight transportation, an essential part of many EfW projects. Although several of the experts had international experience, many of their comments related specifically to the UK, which is their current working base. Projects in the USA, Kenya, Mexico and Brazil were also discussed, increasing confidence in breadth and relevance across differences in perspective and implementation across geographies (environments), and therefore, socio-economic and socio-political spheres.

The interview protocol worked from general to specific with the aim of gathering as much information as possible, avoiding constraining the participants' responses too soon, while getting specific input on the categories. First, each interview established the expert's background and their familiarity with multi-partner EfW projects. Then they were presented with six cards, each bearing the name of one of the categories identified in the literature review: Economic, Environmental, Location, Operational, Political/Legal and Social. Each participant was asked to confirm whether the categories looked familiar, and to discuss what they meant in the context of their experience. This allowed the participants to discuss the categories in whatever order felt natural to them. They were not asked to order or group the cards; some participants however did so, in which case we captured and fed into our analysis the interpretation they associated with doing so. The next step involved flipping the cards to reveal the working definitions which were printed on the back of each card. Now the participants were asked to read and critique the definitions, suggest changes, new categories or criteria, etc.

The interviews were transcribed, and initial notes were made on each interview summarising the background of the participant, and a preliminary view of emerging themes and comments. The transcripts were then analysed using a process which was both deductive and inductive. The deductive analysis coded references to the six categories identified in the literature review. Inductive analysis identified new information beyond the initial categories, such as critique of categories, emerging themes and links between categories (section 4.1.7).

3.2 Case Study – Validate Categories

The third stage built two case studies using the identified categories to systematize the material. Case information came from two unstructured interviews, one with an operations expert and one with a technical expert, neither of whom had been interviewed previously. The experts were asked to talk about one relevant project in which they had been involved. Following the interviews, the experts approved summary notes, which form the basis for the cases (sections 4.2.1 and 4.2.2). Notes from the interviews have been supplemented by reference to relevant literature and legislation.

4 Findings

This section reports the findings of the second (refine) and third (validate) stages of the model development process.

4.1 Expert Interviews – Refine Categories

With the exception of the Operational category, the experts responded positively to the definitions, and were able to discuss all the categories in the light of their own experience, offering refinements and suggestions of criteria. The most important emergent theme concerned links between the categories, these were identified, unprompted, by all the experts. Given the generally positive response, the sections below will focus on responses which led to changes in the definitions, new examples, and links between criteria. Each subsection closes with the final category definitions and examples of criteria.

4.1.1 Economic

Economic viability was seen as the foundation of successful supply chains and EfW projects. Bioenergy was identified as more costly than other renewables, while facing the lack of price differentiation between electricity generated from different sources, leading to lower profit margins. Hence, participants acknowledged the benefit of incentives to encourage initial investment and to improve projected return on investment (RoI), providing a link to the Political/Legal category. The logistics expert introduced the concept of “cost to serve” as a baseline for ensuring the financial viability of a contract from the supplier perspective. It was noted that all energy projects are sensitive to changes in the oil price, leading to energy pricing being added as an example criterion. One participant identified the duplication within some economic criteria, such as cost and profit within RoI, pointing to the need to select non-overlapping criteria to avoid inflation of the influence of one factor.

> Economic: Criteria concerning all financial issues and the economic viability of facilities and their associated supply chains. Examples include return on investment (RoI), costs, revenue, profits, cost to serve, energy pricing, supply and demand for energy, and availability of incentives.

4.1.2 Environmental

Environmental issues were seen as a driver of EfW projects which provide justification of relatively low economic viability. The discussion separated climate related environmental emissions from those which may be viewed as pollution, and from those impacting biodiversity. Concerning climate, it was noted that taking carbon reduction as a decision-making criterion could favour different energy technologies compared to taking greenhouse gas emissions as the criterion, and that this was driven by policy (a link to the Political/Legal category). The need to consider the environmental impact of the whole value chain/lifecycle was raised, for example, one circular economy expert pointed to the need to improve the efficiency of feedstock producing processes, potentially reducing feedstock supply. The logistics expert identified the importance of tackling efficiency and sustainability of feedstock transportation. Pollution was mentioned in the contexts of contamination of wastes and air pollution associated with logistics operations, but also positively in relation to soil remediation through growing feedstock crops to clean up contaminated land. Biodiversity issues raised included assuring and auditing the provenance of feedstocks. Landfill reduction was identified as a sub-criterion of soil quality, rather than a separate criterion, in the context of the need to avoid overlap between decision-making criteria.

> Environmental – Criteria concerning impacts on the environment, specifically climate, pollution and biodiversity. Examples include Greenhouse Gas Emissions (GHG), carbon reduction, lifecycle assessment, air and water pollution, habitat and biodiversity, impacts on soils such as remediation by growing biofuel crops or reduction of landfill.

4.1.3 Location

The technical experts were alert to the need to gain public acceptance for the siting of facilities, in a particular location, as well as the advantages of siting energy facilities close to feedstock sources, especially for organic waste streams, such as sewage sludge, that are prone to degrade. However, it was logistics and operations experts who discussed it in the most depth and perceived it as a critical factor. For the logistics expert, geography lay at the root of transportation, something which was expressed in the use of spatial words (e.g. space, landscape, geography) throughout the interview, metaphorically as well as in literal usage. This participant described the clustered nature of the UK logistics industry, as well as its growth over thirty years from serving local to global clients. This linked to the Political/Legal context in relation to understanding the requirements of multiple jurisdictions for specialist cargo, such as feedstock, and the legal expertise within logistics partners. The cost of transportation of feedstocks further links Location to Economic factors. However, one technical expert noted the export of municipal waste from the UK to the Netherlands and Germany for incineration as an example of perverse geographical outcomes in the sector. From the operations experts, it was seen that both generators of waste and energy producers would be looking around their local area for partners whose location facilitated logistics. One operations expert also raised the importance of political stability for international projects (a further link to Political/Legal), especially in light of the long-term nature of energy investment. The availability of infrastructure was not generally seen as a dominant issue for the experts, at least in a developed world context, with the exception of the small number incineration plant in the UK, alluded to above.

Location – Criteria concerning the geographical siting of facilities, its effects on costs, impacts on populations etc. Examples include transport distance, exploiting logistics clusters, availability of skills, e.g. specialist logistics expertise, public acceptance of energy facilities, political stability.

4.1.4 Operational

The factors discussed by technical experts in relation to the Operational category were strikingly different to those raised by operations experts. This observation led to a decision to split this category into two. It is worth noting that this does not reinstate the Supplier category which was merged with Operational factors earlier; given the focus of our discussions on partner selection, suppliers were implicitly at the heart of all the discussions. Instead, the split teases apart operations management criteria from criteria relating to (technical) plant operation. Operations experts and the logistics expert spoke primarily of establishing strategic objectives and of the “nitty gritty” of managing the ongoing supply chain relationship. It was noted that the initial selection of partners might need to evolve during the course of a project, for example to facilitate scaling up the project or to adapt to changing market conditions. For example, one operations expert suggested a project might wish to change its marketing partner from a local to a national provider if it scaled up its operations. These experts tended to discuss the whole supply chain, for example by addressing the reduction of feedstock wastes produced by earlier processes. The technical experts saw operational issues primarily in terms of operating an EfW plant and directly related activities such as preprocessing of feedstock. The strategic step, for them, was making a match between available feedstock and an appropriate technology, a step which would determine the scale of the operation and its technical robustness. Issues relating to feedstock were of particular interest for this group. Waste was seen as a “tricky” feedstock with some EfW processes (e.g. incineration) being more robust to variability in feedstock supply than others (e.g. anaerobic digestion). Links were noted between plant operating conditions and both legal requirements to avoid polluting emissions (Political/Legal), and the knowledge required to operate plants (see Social). As it was observed that the responses of the technical experts were focused on one segment of the operational system, that directly around the plant itself, while operations experts looked at the wider supply chain, two categories were developed, namely Operations management and Plant operations. Plant operations is modelled as a sub-category of Operations management.

Operations management – Criteria contributing to setting operational strategy and the ongoing management of the supply chain. Examples include operations strategy factors (cost, quality, speed, reliability, flexibility), scalability, supplier financial robustness and credibility, agreement of terms of service.

Plant operations – Technical criteria that affect the efficiency and reliability of EfW facilities. Examples include matching of technology to available feedstock, capacity of facilities, reliability of feedstock supplies, feedstock processing and control of emissions.

4.1.5 Political/Legal

Political and legal criteria can sometimes be seen as constraints, for example, when political volatility makes building stable value networks difficult. However, policy initiatives can also drive interest in EfW projects and, as discussed above, there is a link to the Economic category when incentives and taxation mitigate the relatively low economic viability of projects. This category links to Location through the political circumstances of regions or the interaction between different jurisdictions in a supply chain. For example, different clean air regulations in different regions of the UK were noted by the logistics expert. Laws governing polluting emissions are particularly relevant to the handling of waste feedstocks which were described as “tricky” by the technical experts. Specifically, the Waste Incineration Directive (European Parliment, 2000) was identified as an example of legislation which would impact details of Plant operation, like feedstock suitability, preprocessing and incineration conditions. The need to have processes in place to audit the compliance of a supply chain was also noted. However, forestry accreditation schemes were seen as less relevant to UK based EfW projects. The capacity to enforce laws and civil rights of populations were not seen as particularly problematic in a developed world context. Contract issues were discussed more in the context of Operations management than in relation to law, reflecting their use to set service conditions.

> Political/Legal – Criteria related to policy, national and regional jurisdictions, law and governance. Examples include environmental policy, political stability, availability of information to prove compliance.

4.1.6 Social

The public perception of EfW projects was noted as a theme affecting the viability of projects involving what one interviewee termed “semi-undesirable facilities”. Potential public opposition links Social with Operational and Location categories. Factors associated with employment were quite diverse. The logistics expert noted that recruitment of skilled staff was a current challenge in the UK. One of the operations experts with international experience brought up the need to think about the exploitation of staff. Another mentioned the generation of new employment opportunities, linking entrepreneurship with social resilience. Socio-economic issues raised included energy poverty, linked to energy pricing, changing behaviour around waste separation at the household level and changing perceptions of waste as a commodity with value. The issue of access to land, though not disputed, was not discussed in depth in any of the interviews, suggesting a lower priority to the participants.

> Social – Criteria concerning effects of EfW operations on populations as well as factors relating to employment. Examples include public perception of facilities, supportive behaviour, such as household waste separation, employment conditions or opportunities, availability of skilled workers.

4.1.7 Links Between Categories

It has been noted that certain criteria were seen by the experts as linking between two or even three categories. To give a few pertinent examples: the availability of incentives is Political, but often critical to Economic viability of the project, public perception of the siting of facilities links the Social category to Location, while employment opportunities can be seen as a Socio-economic outcome of projects. A hierarchical taxonomy of criteria is therefore insufficient to model the data, as criteria can be associated with more than one category. However, structure would be helpful to decision makers when using the categories to help select relevant criteria for a specific project to assist in identifying and systematizing the criteria that need to be considered for a particular case.

Further evidence that a taxonomic approach is insufficient comes from indications that the categories are not all of equivalent types. Operations experts recognized the Economic, Environmental and Social categories as the components of the Triple Bottom Line (Elkington, 1997) which can be viewed as *outcomes*, or realised as Key Performance Indicators (KPIs) of projects, as well as being factors which influence project success. One of the circular economy experts further identified *implementation* factors, like where to locate plant, how to manage it, the technology choices etc. which could contribute to achieving the desired *outcomes*. Political/Legal factors, on the other hand are not directly controllable by the project (although might be influenced in the long-term e.g. by lobbying or societal pressure for change). However, these determine the context in which a plant operates and influence project choices. These structural insights lead us to propose the model below (figure 3) in which boxes represent categories, with examples of links to demonstrate how specific selection criteria may bridge different categories.

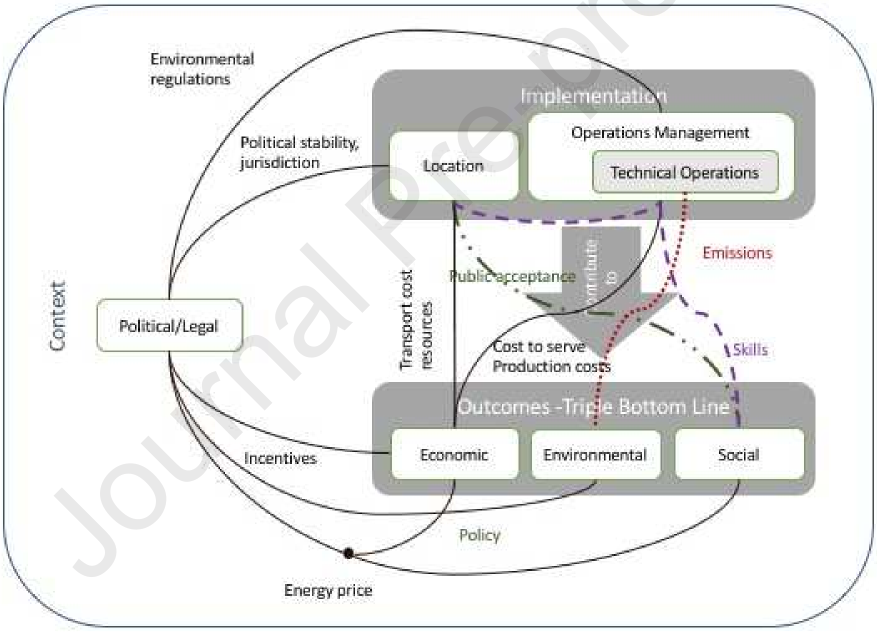


Figure 3: Model of selection criteria categories showing examples of linking criteria, (colour and line type are used to distinguish crossing lines and matching labels).

4.2 Validating Cases

The third and final stage of the model development process validated the model by providing evidence that the seven categories were relevant to two cases which had not previously been discussed in the expert interviews. These cases are primarily based on the perceptions of the two interviewees, with additional evidence drawn from documentary sources where indicated. The two cases concern developing and developed world contexts, and have bioenergy and bioproducts project foci respectively. This helps to demonstrate the transferability of the model to different contexts.

4.2.1 Waste Straw Case

The project concerns energy generation from field stubble in NW India. The initial project involved a small-scale pyrolysis plant which produced bio-char (35%), bio-oil (35%) and non-condensable gas (30%)(Nixon et al., 2014). Three villages were set up with pyrolysis plants and stubble burning in these villages has stopped. A follow-on project is being developed around a technologically simpler process in which stubble waste is transformed into pellets and sold to local coal-fired power generation plants. The pellets are typically smaller than pieces of coal but can be mixed with it as feedstock, reducing fossil fuel dependency. The supply chain in this case goes from the village level of the farmers, via middle men to the power plants which buy the pelletised fuel.

Economic - The most referenced category in the interview was Economic, reflecting the central importance of economic viability in ensuring long-term sustainability of EfW projects. Although labour is cheap in India, clearing stubble from fields is not financially sustainable unless there is some economic return. The interviewee reported that the pyrolysis plants had an RoI period of about 4 years and that the pyrolysis unit itself was the highest cost item. Income came from a number of sources, for example the pyrolysis oil can be mixed into diesel oil at up to a third of the content and be used as standard diesel. It was estimated that pyrolysis oil cost about 0.18 $/kg to produce, where diesel cost about 0.9 $/kg (Nixon et al., 2014). As diesel is used widely in rural India, for example to run electricity generators and agricultural plant, this produces savings. However, the initial investment in the plant was too great for a village cooperative which could not normally raise the level of capital invested by the project. Machinery that does stubble extraction, soil separation, drying and pelletising was the first pre-processing stage of the original process. The follow-on project focusses on that stage. Just setting up the pelletisation machinery requires less investment, while still producing a viable product. The lower upfront cost means the time to RoI is reduced. It is particularly important where the cooperatives, or in general smaller companies, are involved that RoI should not be too long. It was the interviewee's opinion that only very large companies, such as big energy producers, can sustain an RoI of 10 years.

Environmental - Stubble burning is a traditional practise which prepares soil for multiple crops in one year and puts carbon fertilizer, as char, back into the soil. However, it emits GHG, and particulate pollution which has a significant health impact (estimated at $18.5 per household in the Punjab (Nixon et al., 2014))(see Social). Burning also kills beneficial bacteria in the soil, damaging long-term fertility and soil health. The EfW project addresses both the pollution and the GHG issues locally. It also allows the coal-fired power station to meet its corporate social responsibility obligations through reducing the use of fossil fuel. Stubble burning is a common practise in India and other parts of the developing world. Reducing stubble burning globally would be beneficial from an environmental perspective.

Location - A difference between India and the UK is that India's National Grid is relatively new (Shah, 2014) and it was not complete in the early stages of this project. Therefore, energy is often generated locally and supply of fuel from the local area is a good solution in this scenario, also reducing transport costs as India's coal reserves are primarily in the south central and eastern regions of India (Central Statistics Office, 2019, p.19).

Operations management - The interviewee observed that successful supply chains need a player who acts as a driver. The oil supply chain, for example, is vertical, with most activities driven and controlled by the big oil companies. EfW supply chains are at an early stage of development and are often fragile. A large player will need to take the driver role if the supply chains are to work in the long term. In the straw pellets supply chain, the coal-fired plant, as pellet customer, may be appropriate to fill the driver role.

Plant operation – The stubble processing machinery is not especially complex and can be maintained by most people with a reasonable level of mechanical knowledge. At the energy plant, some operating parameters need to be adjusted to incorporate pellets into the fuel mix alongside coal. For example, there may be volatile components like oil released or a different amount or chemical composition of ash produced. Hence, some technical changes may be needed to the coal-fired power plant to operate with the new fuel mix.

Political/Legal – Large Indian companies have a legal obligation to engage in CSR activity (Parliament of India, 2013, Section 135). For the power plant, the use of stubble pellets counts towards their CSR obligations. One factor which the participant remembered prevented the initial pyrolysis plant scaling up is that local legislation banned independent production of fuel oil. The pellet production process is not affected by this legislation.

Social – Indian villages suffer from depopulation as people migrate to cities to work due to lack of development and opportunities at home. For any development activity, energy is an essential component. Local energy projects open up the potential to create local employment and development opportunities. These can reduce the push factors for migration away from villages. Reducing stubble burning is directly beneficial to the health of the local population. If stubble burning can be reduced more widely the improved air quality will also be beneficial for the health of both rural and city populations.

4.2.2 Spent Grain Case

The project concerns supporting UK brewers and distillers to develop business models which generate value from brewing wastes by producing biochar. Work is underway with several companies in both urban and rural locations in England and Scotland. Biochar is a stable, carbon rich material which is the output from thermal treatment of biomass in an oxygen deprived atmosphere. It can be used as cooking fuel (Lohri et al 2016) for water treatment, various industrial applications and soil amendment (Anderson et al. 2016, Watkinson 2019, p.13). SMEs in the brewing and distillery sectors of the UK are investigating biochar as a means to dispose of, and get value from, wastes such as brewery spent grains, draff (whisky distiller's spent grains), and grape residues. The "ideal" situation would be a circular economy model, with waste producers running char reactors at the same sites that they are brewing, and selling the char to farmers in their own value chain to close the circle.

Economic - The economic goal of equipment manufacturers in the UK is to sell equipment (charcoal retort, gasifiers, heat exchangers etc.) to breweries and distilleries to enable them to make char on site. Some equipment manufacturers offer plant operation and testing services to minimize clients' capital expenditure, as well as providing specialist skills (Social). The economic drivers in UK supply chains tend to be the waste producers, who are looking to find ways to dispose of problematic wastes, and are attracted by the potential to generate value from it. The main issue with establishing this business model is that there is no established bulk market for biochar in the UK. It is sold to domestic gardeners in small quantities as a soil improver but is not currently used at large scale in agriculture. One factor impeding the establishment of a large-scale biochar market may be that there is insufficient cost benefit to farmers (Bach et al., 2016).

Environmental - Biochar is highly porous, allowing it to retain water and nutrients as well as reducing fertilizer leaching. Historical dark earths in Amazonia and Africa show that it can remain in soils for thousands of years, providing a carbon sink as well as high fertility. The IPCC has considered biochar as a method of carbon storage (Rogelj et al., 2016), and the UK Parliament has discussed how it could be used to help meet emissions reduction targets (Political/Legal) (POST, 2010). However, there is a research gap around its long-term behaviour in soils (Bach et al., 2016).

Location - Rural breweries and distilleries traditionally give away, or sometimes are even able to sell (Economic), spent grains as animal feed. For urban breweries, there are logistical issues for farmers to collect the waste as often as needed and a contract with a waste management company is required, generating location related costs (Economic). The interviewee observed that waste disposal issues can particularly affect distilleries located on islands. Conditions for biochar spreading on land are set by the UK Environment Agency ("Guidance, Storing and spreading biochar to benefit land: LRWP 61', Environment Agency, 2019), including limits on the amounts that can be stored at any time and location of storage relative to watercourses (Political/Legal) which impacts the location, design and scale of storage facilities for both biochar producers and their customers.

Operations management - Brewers are working all year around and therefore produce regular flows of feedstocks, providing an advantage over seasonal biochar feedstocks such as straw. Biochar can generate a lot of dust, and is black or brown, making it a messy substance to store. Furthermore, it is volatile (powdered charcoal is one component of gunpowder) and requires careful handling, packing and storage.

Plant operations - The technology for biochar production is quite well understood, but there is no "standard" process. The combinations of variables needed to produce biochar with different desired properties (e.g. waste material type, temperature, time, pretreatment and post-treatment) are highly variable. Equipment manufacturers therefore need to work closely with potential customers to demonstrate the viability of the process with trial batches for each waste type.

Political/Legal - Biochar can contain contaminants such as heavy metals which can be harmful to both the environment and human health (Environmental, Social). Therefore, it needs to be tested and categorized prior to use. The International Biochar Initiative standards are used to certify biochar in the UK (IBI 2015).

Social – It is estimated that there are 10,000 people directly employed in the Scottish whisky industry, with 7,000 of them in rural locations (Scotch Whisky Association, 2019). Being seen to establish a circular economy for spent grains could enhance social perception of firms which are often active in the tourism industry as well as being a cornerstone of local economies. In addition to the various safety and health considerations already noted, biochar dust is a fine powder, which can be harmful if breathed in (Political/Legal) (Anderson et al. 2016).

4.3 Summary

Criteria were observed in every one of the seven categories for both cases, providing support for the validity of the model. Differences between the cases and the second stage interviews occur at the level of criteria. This is not unexpected, in any particular case, specifics of context and technology choices can be expected to involve some unique criteria.

Some criteria were particularly important in driving the change from the pilot pyrolysis plant towards production of pelletised fuel. Of these, reducing initial investment (Economic category) for the cooperatives at the start of the supply chain and legislation (Political/Legal) limiting oil production are stand-out examples. Some criteria important to this case were not observed in the stage 2 interviews, e.g. the need to address rural depopulation. The experts interviewed at stage 2 (model refinement) were all currently working in the context of the UK, which has some differences to the developing world context of the waste straw case. While the model is context dependent at the level of criteria, which is to be expected, at the level of categories it mapped well to the developed world case.

In the spent grain case, we note the emphasis on char as a bioproduct over char as a fuel. Within the UK economy, bioproducts of EfW processes are interesting because they have potential to generate higher revenues. As was noted in the stage 2 interviews, the economic margins of EfW projects are small, partly due to a lack of price differentiation between electricity from renewable and fossil fuel sources. There was relatively little discussion of Social or Location issues for this case. This may be because the dominant model is to locate the plant on pre-existing industrial sites making public acceptance less problematic, or because of generally positive perceptions of brewing and distilling industries in the UK. In either case, we argue that lower levels of discussion for these categories for one case are insufficient to justify their removal from the model as they helped to systematise those criteria that were discussed. Reinforcing this argument is the importance of social acceptance for EfW plants as a long-term benefit for the environment, often an important deciding factor for policy and politically-motivated incentives to counter the economic argument for continued focus on fossil fuels.

5 Conclusions

A three-stage qualitative research process of literature analysis, expert interviews and case study was conducted to derive the model. The results supported the identification, refinement and validation of seven categories which systematise the rich diversity of criteria relevant to the design and sustainable operation of EfW supply chains, namely the *Economic*, *Environmental* and *Social* categories familiar from the Triple Bottom Line, plus *Location*, *Operations management*, with its sub-category of *Plant operations*, and *Political/Legal*. The expert interviews further indicated the existence of links between categories, with some criteria relevant to multiple categories, implying that a hierarchical taxonomy would not fit the data. A model organising the categories into *Context*, *Implementation* and *Outcomes*, that permits criteria to be associated with more than one category, is therefore proposed.

The proposed model should be helpful to policymakers, legislators, and planners by providing them with context-sensitive tools to explore and evaluate the socio-economic landscapes in which they operate. We aim at providing a usable framework for decision makers to effect change and make rational choices. Furthermore, for researchers, the model provides an organising framework for selection of the criteria to include, which prompts researchers to take a broad perspective on the factors that affect EfW supply chains. For example, in on-going work, we are using the model in the development of a software tool to support partner selection in EfW supply chains.

This research employed a mixed methods approach, using inductive and deductive approaches to analyse the qualitative data collected from academic publications and expert interviews. Initial findings were validated using further information collected from two case studies. With activity involving any degree of subjectivity, as is the case here, practical constraints mean that it is not possible to claim 100% validation of the model. The two cases allowed us to corroborate our findings, and provide evidence to support the validity of the model, within the constraints stated. The findings summarise experts' *perceptions* of which criteria are important in the development and operation of EfWs, highlighting also where differences in perspective, due to domain expertise and practical experience, influence the significance of each concept for the individual. In particular, we noted differences of emphasis between technical and operations experts, illustrating the ambiguous, and socially constructed, nature of theory.

Constraining the criteria to seven categories may appear to be an oversimplification of the issues at play. However, Saunders et al (2016) highlight the need to identify core criteria around which to focus emergent themes and theory, and to aid, further, the identification of relationships between these. When one observes past work, such as that of Govindan et al. (2015) with their 122 different criteria, the need for an organizing framework with a graspable number of categories becomes apparent. The exact number of categories in any conceptual model will always be open to discussion and will be influenced by the perspective of the researcher. Subsuming detail in a relatively high level set of concepts further supports extension during reuse; for example, economists could examine the Economics category in greater detail, refining it for their purposes. The categories selected reflect our motivation towards enabling an effective, practical approach that provides an organising framework able to serve the wide range of partners who participate in EfW projects. Based on prior experience in similar work, we recognise also that a much greater number of categories quickly morphs into an unwieldy model, hindering usability.

This work forms part of a bigger effort to support companies seeking involvement in the EfW sector. EBRI is facilitating the networking of potential project partners in the West Midlands region of the UK, taking a Digital Business Ecosystems (DBE) approach (Nachira et al., 2007). In support of this activity, an ontology based supplier selection prototype has been demonstrated (Dadzie et al., 2018). The model provides evidence-based organising principles for further systems to support the DBE approach taken by EBRI. For organisations developing or managing EfW projects, the model provides a thinking tool, which can act as a set of prompts for managers and technical experts to discuss the factors that contribute to project success. Future work will involve the testing of the model for criteria selection in theoretical studies and in the development of systems. It will also be used to structure case studies, such as the two presented here, to communicate best practise to practitioners.

Funding Sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgements

The authors gratefully acknowledge the contribution of the experts who generously gave their time and insight for the interviews.

References

Abba-Dabo, A.-A. (2018). *Energy from Waste (EfW) market review*, EBRI, Birmingham, UK.

anaerobic-digestion.com. (2019). UK Food Waste Anaerobic Digestion Plant History of the Ludlow Digester, Retrieved from https://blog.anaerobic-digestion.com/food-waste-anaerobic-digestion-plant/. Accessed on 5 June 2020

Anderson, N.M., Bergman, R.D., Page-Dumroese, D.S. (2016) A supply chain approach to biochar systems., *Biochar: A Regional Supply Chain Approach in View of Mitigating Climate Change,* 25-26.

Anzanello, M. J., & Fogliatto, F. S. (2011) Learning curve models and applications: Literature review and research directions. *International Journal of Industrial Ergonomics, 41*, 573-583.

Bach, M., Wilske, B., Breuer, L. (2016) Current economic obstacles to biochar use in agriculture and climate change mitigation, *Carbon Management*, 7(3-4) 183-190.

Balaman, S. Y., Scott, J., Matopoulos, A., & Wright, D. G. (2019). Incentivising bioenergy production: Economic and environmental insights from a regional optimization methodology. *Renewable Energy, 130*, 867-880.

Balaman, S. Y., Wright, D. G., Scott, J., & Matopoulos, A. (2018). Network design and technology management for waste to energy production: An integrated optimization framework under the principles of circular economy. *Energy, 143*, 911-933.

Braun, V. & Clark, V. 2012. Thematic Analysis. In: Cooper, H. (ed.) *APA Handbook of Research Methods in Psychology: Vol 2 Research Designs*. American Psychological Association.

Cavalett, O., Chagas, M. F., Junqueira, T. L., & Watanabe, M. D. B. (2017). Environmental impacts of technology learning curve for cellulosic ethanol in Brazil. *Industrial Crops and Products, 106*, 31-39.

Cebi, S., Ilbahar, E., & Atasoy, A. (2016). A fuzzy information axiom based method to determine the optimal location for a biomass power plant: A case study in Aegean Region of Turkey. *Energy, 116*, 894-907.

Central Statistics Office 2019. *Energy Statistics 2019*. Government of India.

Chai, J., Liu, J. N. K., & Ngai, E. W. T. (2013). Application of decision-making techniques in supplier selection: A systematic review of literature. *Expert Systems with Applications, 40*, 3872-3885.

Clarke, K. C. (1986). Advances in Geographic Information Systems. *Computers, Environment and Urban Studies, 10*(3-4), 175-184.

Cleary, J. (2009). Life cycle assessments of municipal solid waste management systems: A comparative analysis of selected peer-reviewed literature. *Environment International, 35*, 1256-1266.

Cucchiella, F., D'Adamo, I., & Gastaldi, M. (2014). Strategic municipal solid waste management: A quantitative model for Italian regions. *Energy Conversion and Management*, *77*, 709-720.

Dadzie, A.-S., Uren, V. S., Miller, T., & Abba Dabo, A.-A. (2018). Value-driven partner search for Energy from Waste projects. *Procedia Computer Science, 137*, 21-32.

De Meyer, A., Cattrysse, D., Rasinmaki, J., & Van Orshoven, J. (2014). Methods to optimise the design and management of biomass-for-bioenergy supply chains: A review. *Renewable and Sustainable Energy Reviews, 31*, 657-670.

de Wit, M., Junginger, M., & Faaij, A. (2013). Learning in dedicated wood production systems: Past trends, future outlook and implications for bioenergy. *Renewable and Sustainable Energy Reviews, 19*, 417-432.

DEFRA. (2011). *Anaerobic digestion strategy and action plan*. Retrieved from https://www.gov.uk/government/publications/anaerobic-digestion-strategy-and-action-plan

Elkington, J. (1997). *Cannibals with forks: the triple bottom line of 21st century business*. Capstone, Oxford

Environment Agency (2019). *Guidance, Storing and spreading biochar to benefit land*: LRWP 61 (Retrieved from https://www.gov.uk/government/publications/low-risk-waste-positions-landspreading/storing-and-spreading-biochar-to-benefit-land-lrwp-61, accessed on 23 May 2020).

Evangelisti, S., Lettieri, P., Borello, D., & Clift, R. (2014). Life cycle assessment of energy from waste via anaerobic digestion: A UK case study. *Waste Management, 34*, 226-237.

Fan, J., Kalnes, T. F., Alward, M., Klinger, J., Sadehvandi, A., & Shonnard, D. R. (2011). Life cycle assessment of electricity generation using fast pyrolysis bio-oil. *Renewable Energy, 36*(36), 632-641.

Foxall, M. (2012). Building an anaerobic digestion plant in partnership. Retrieved from https://www.local.gov.uk/building-anaerobic-digestion-plant-partnership

Golafshani, N. (2003). Understanding reliability and validity in qualitative research. *The Qualitative Report*, 8, 597-607.

Govindan, K., Rajendran, S., Sarkis, J., & Murugesan, P. (2015). Multi criteria decision making approaches for green supplier evaluation and selection: a literature review. *Journal of Cleaner Production*, 98, 66-83.

Haddad, M. A., & Anderson, P. F. (2008). A GIS methodology to identify potential corn stover collection locations. *Biomass and Bioenergy, 32*, 1097-1108.

Ho, W., P.K. Dey, and M. Lockström (2011) Strategic sourcing: a combined QFD and AHP approach in manufacturing. *Supply Chain Management: An International Journal*. **16**(6): p. 446-461.

Iabonis, V. and P. de Stefanis (2007) *Aspetti economici del recupero energetico da rifiuti urbani*. 2007, ENEA Ente per le Nuove Tecnologie l’Energia e l’Ambiente.

IBI (2015) Standardized product definition and product testing guidelines for biochar that is used in soil. International Biochar Initiative (https://www.biochar-international.org/wp-content/uploads/2018/05/ IBI_Biochar_Standards_V2.1_Final.pdf, accessed 23 May 2020)

Jeong, J. S., & Ramirez-Gomez, A. (2018). Optimizing the location of a biomass plant with a fuzzy-DEcision-MAking Trial and Evaluation Laboratory (F-DEMATEL) and multi-criteria spatial decision assessment for renewable energy management and long-term sustainability. *Journal of Cleaner Production, 182*, 509-520.

Johnson, B. R. (1997). Examining the validity structure of qualitative research. *Education*, 118, 282-292.

Junginger, M., de Visser, E., Hjort-Gregersen, K., Koorneef, J., Raven, R., Faaij, A., & Turkenburg, W. (2006). Technological learning in bioenergy systems. *Energy Policy*, 34, 4024-4041.

Kelliher, F. (2005) Interpretivism and the Pursuit of Research Legitimisation: An Integrated Approach to Single Case Design. *The Electronic Journal of Business Research Methodology*, 3, 123-132.

Lohri, C. R., Rajabu, H. M., Sweeney, D. J., & Zurbrugg, C. (2016). Char fuel production in developing countries - A review of urban biowaste carbonization. *Renewable & Sustainable Energy Reviews, 59*, 1514-1530.

Nachira, F., Dini, P., Nicolai, A. (2007) A network of Digital Business Ecosystems for Europe: roots, processes and perspectives, 1-20. European Commission,

Nixon, J. D., Dey, P. K., Davies, P. A., Sagi, S., & Berry, R. F. (2014). Supply chain optimisation of pyrolysis plant deployment using goal programming. *Energy, 68*, 262-271.

Parliament of India, 2013, Companies Act, Retrieved from https://www.mca.gov.in/Ministry/pdf/CompaniesAct2013.pdf, accessed 5 June 2020.

Perez-Fortes, M., Lainez-Aguirre, J. M., Arranz-Piera, P., Velo, E., & Puigjaner, L. (2012). Design of regional and sustainable bio-based networks for electricity generation using a multi-objective MILP approach. *Energy, 44*, 79-95.

Perkoulidis, G., Papageorgiou, A., Karagiannidis, A., & Kalogirou, S. (2010). Integrated assessment of a new Waste-to-Energy facility in Central Greece in the context of regional perspectives. *Waste Management*, 30, 1395-1406.

POST (2010) Biochar, POSTNOTE 358, Houses of Parliament, Parliamentary Office of Science and Technology.

Rezaei, J. (2015). A two-way approach to supply chain partner selection. *International Journal of Production Research*. 53. 1-15.

Rogelj, J., D. Shindell, K. Jiang, S. Fifita, P. Forster, V. Ginzburg, C. Handa, H. Kheshgi, S. Kobayashi, E. Kriegler, L. Mundaca, R. Séférian, and M.V. Vilariño (2018) Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* Masson-Delmotte, V., P. et al. (eds.).

Saunders, M. N., Lewis, P. and Thornhill, A. (2016), *Research Methods for Business Students*, 7th edn, Pearson Education Limited.

Scotch Whisky Association (2019) *Facts & figures*, https://www.scotch-whisky.org.uk/insights/facts-figures/, accessed 5 June 2019.

Scott, J., Ho, W., Dey, P.K., Taluri, S., (2015) A decision support system for supplier selection and order allocation in stochastic, multi-stakeholder and multi-criteria environments. *International Journal of Production Economics*, **166**: p. 226-237.

Shah, P. (2014) Indian power system becomes largest operating synchronous grid in the world. *The Times of India*, 2 January 2014.

Shropshire Star (2014) Ludlow waste site to close despite public outcry. (Jan. 14 2014). *Shropshire Star*. Retrieved from https://www.shropshirestar.com/news/2014/01/31/ludlow-waste-site-to-close-despite-public-outcry/

UK Government (2008) *The Shropshire (Structural Change) Order 2008* https://www.legislation.gov.uk/uksi/2008/492/contents/made, Accessed on 5 June 2019.

Tavares, G., Zsigraiova, Z., & Semiao, V. (2011). Multi-criteria GIS-based siting of an incineration plant for municipal solid waste. *Waste Management, 31*, 1960-1972.

Wang, C.-N., Nguyen, V. T., Duong, D. H., & Thai, H. T. N. (2018). A Hybrid Fuzzy Analysis Network Process (FANP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) Approaches for Solid Waste to Energy Plant Location Selection in Vietnam. *Applied Sciences-Basel, 8*.

Watkinson , I. (ed.), (2019) *Linking your business into the Energy-from-Waste and Bioproducts supply chains, and beyond*, EBRI, UK (https://bioenergy-for-business.org/wp-content/uploads/2019/08/EBRI-Fusion-Guidev2.pdf, accessed 23 May 2020).

European Parliament (2000) *The Waste Incineration Directive* 2000/76/EC.

Yelle, L. E. (1979). The Learning Curve: historical review and comprehensive Survey. *Decision Sciences, 10*(2), 302-328.

Zhao, R., Liu, Y., Zhang, Z., Guo, S., Tseng, M.-L., & Wu, K.-J. (2018). Enhancing Eco-Efficiency of Agro-Products' Closed-Loop Supply Chain under the Belt and Road Initiatives: A System Dynamics Approach. *Sustainability, 10*.

Appendix

Table 2 Example Criteria for EfW projects

ID - Title (ref)	Economic	Environmental	Location	Operational	Social	Political/Legal
1 - Incentivising bioenergy production: Economic and environmental insights from a regional optimization methodology (Balaman, Scott, Matopoulos, & Wright, 2019)	Energy prices, Unit investment costs, Biomass purchasing cost	GHG emissions	Candidate locations for plants and facilities	Plant capacity, energy conversion technology		Value of incentives
2 - Network design and technology management for waste to energy production: An integrated optimization framework under the principles of circular economy (Balaman, Wright, Scott, & Matopoulos, 2018)	Transportation unit cost, operational unit cost, Revenue from electricity sales, revenue from heat sales	GHG emissions	Biomass source sites, candidate locations for plants	Plant capacity, conversion rate, capacity of transportation vehicle, biofuel production		Incentives
3 - A fuzzy information axiom based method to determine the optimal location for a biomass power plant: A case study in Aegean Region of Turkey (Cebi, et al., 2016)	Cost of land, unit transportation cost, Average unit cost of biomass		Distance to power distribution network, Infrastructure and transportation facilities	Capacities of production facilities, Average calorific value of biomass		
4 - Strategic municipal solid waste management: A quantitative model for Italian regions (Cucchiella, et al., 2014)	Investment cost, selling price of electricity, interest rate, delay costs	Contribution of waste incineration, landfill reduction	Candidate Italian regions	Lower heating value		

ID - Title (ref)	Economic	Environmental	Location	Operational	Social	Political/Legal
5 - Char fuel production in developing countries - A review of urban biowaste carbonization (Lohri et al., 2016)	Capital cost, operating cost, gas recovery (recycled to fuel kiln)	Pollutant emissions, tar recovery		Pretreatment, Portability of plant, labour intensity, controllability, lifespan		
6 - Supply chain optimisation of pyrolysis plant deployment using goal programming (Nixon et al., 2014)	Capital cost, equipment cost, levelised cost of electricity, Sale price of char, cost of storing feedstock, wages	CO2 emissions, particulate emissions	Village location vs district location, number of plants	Availability of feedstock, plant capacity, tractor speed		
7 - Design of regional and sustainable bio-based networks for electricity generation using a multi-objective MILP approach (Perez-Fortes, et al., 2012)	Interest rate, Investment, fixed and variable costs	Life cycle assessment	Communities network configuration, transportation distance, Cassava waste production per Ghanaian region	Energy consumed in feedstock processing, Gasifier efficiency	Number of communities, number of processes installed in each community	
8 - Integrated assessment of a new Waste-to-Energy facility in Central Greece in the context of regional perspectives (Perkoulidis, et al., 2010)	Transport cost, Treatment cost, Annual capital cost, Revenue from electricity sales	Landfill reduction, GHG emissions	Greek regional MSW management scenarios	Capacity, Produced electrical energy, Netto efficiency		

ID - Title (ref)	Economic	Environmental	Location	Operational	Social	Political/Legal
9 - A Hybrid Fuzzy Analysis Network Process (FANP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) Approaches for Solid Waste to Energy Plant Location Selection in Vietnam (Wang et al, 2018)	Construction cost, Operations and maintenance cost	Impact on the ecological environment	Alternative plant locations in Vietnam, distance to urban locations, distance to electricity network, Regional economic benefit		Effect on life quality of residents	
10 -Enhancing Eco-Efficiency of Agro-Products' Closed-Loop Supply Chain under the Belt and Road Initiatives: A System Dynamics Approach (Zhao et al., 2018)	Acquisition price, Marketing price	Total carbon emissions		Biomass to energy conversion factor, Product inventory, energy consumption	Farmer's incomes	Incentive policies

A model for partner selection criteria in Energy from Waste projects

Victoria Uren (Corresponding Author)
v.uren@aston.ac.uk
Operations and Information Management Department, Aston Business School, Aston University, Aston Triangle, Birmingham B4 7ET, United Kingdom

Tim Miller
t.miller1@aston.ac.uk
Energy and Bioproducts Research Institute (EBRI), Aston Triangle, Birmingham B4 7ET, United Kingdom

Raffaello Da Campo
r.dacampo@bham.ac.uk
Energy and Bioproducts Research Institute (EBRI), Aston Triangle, Birmingham B4 7ET, United Kingdom

Aba-Sah Dadzie
aba-sah.dadzie@ed-alumni.net
Operations and Information Management Department, Aston Business School, Aston University, Aston Triangle, Birmingham B4 7ET, United Kingdom

Abstract

Energy from Waste is being deployed in both developed and developing economies as a route to reduce dependency on fossil fuels whilst making positive use of resources which might otherwise be landfilled. Energy from Waste supply chains are complex, with a rich diversity of partners and stakeholders involved. For this purpose, the selection of appropriate criteria to guide supply chain design, and in particular the selection of suppliers, is critical for success. In this study, a three-stage process was conducted to identify, refine and validate an evidence-based model. The evidence based model proposed comprises seven categories of criteria used in the design of these supply chains, namely Economic, Environmental, Location, Operations management, which has a sub-category of Plant operation, Political/Legal and Social. The work reported here supports practitioners and researchers involved in supply chain partner selection to systematise their thinking in relation to the criteria that may impact their study or project.

Keywords

Supply chain, Energy from Waste, Partner selection criteria

Declarations of Interest for A model for partner selection criteria in Energy from Waste projects

Victoria Uren: Declarations of interest: none

Tim Miller: Declarations of interest: none

Raffaello de Campo: Declarations of interest: none

Aba-Sah Dadzie: Declarations of interest: none