**Article:**

Hussain, Z, Mishra, J and Vanacore, E (2020) Waste to energy and circular economy: the case of anaerobic digestion. Journal of Enterprise Information Management, 33 (4). pp. 817-838. ISSN 1741-0398

https://doi.org/10.1108/JEIM-02-2019-0049

Emerald Journal of Enterprise Information Management

# Waste to Energy and Circular Economy: The Case of Anaerobic Digestion



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| Journal: | *Journal of Enterprise Information Management* |
| Manuscript ID | JEIM-02-2019-0049.R2 |
| Manuscript Type: | Research Article |
| Keywords: | Circular Economy, Waste to Energy, Anaerobic Digestion, Small and Medium Enterprises (SMEs) |
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# Waste to Energy and Circular Economy: The Case of Anaerobic Digestion

## Abstract

- Purpose

This paper highlights how biological waste materials can be used for generating much needed energy and obtaining nutrient rich compost for agriculture through Anaerobic Digestion (AD). The paper further highlights the importance of Small and Medium Enterprises (SMEs) in using AD for Waste-to-Energy (WTE) leading to many environmental benefits as well as clean energy generation. It would help to reduce pollution, water acidification and carbon emissions that eventually lead to climate change.

- Design/methodology/approach

The researchers undertook an in-depth study to highlight the role played by an SME in converting WTE and helping towards achieving circularity. An exploratory case based approach was used to understand value leakage for an AD plant operating on WTE principles in the UK. The plant is still currently active and it is located in the Midlands, England. 15 semi-structured interviews were undertaken with different stakeholders.

- Findings

This paper reveals the importance of WTE and the significant role played by AD in converting food waste into useful matter. It reports further into the value leakage issue faced in the AD plants. It demonstrates the importance of technological innovation in SME to capture value leakages in a circular model. Most importantly, it demonstrates how SMEs gain competitive advantage and generate value proposition, while they aim for zero waste to landfill objective.

- Research limitations/implications

The research involves a case study based on a SME, operating on a circular business model. It will be worth investigating how other businesses could gain competitive advantage. For SMEs interested in AD for WTE, this paper introduces further technological innovation to the AD process to leverage further potential for reuse of waste liquid. Any SMEs entering WTE market ought to take into consideration such design implications.

- Practical implications

The paper reveals how the use of waste by SMEs would lead to many environmental benefits as well as clean energy generation. It would help to reduce pollution, water acidification and carbon emissions that eventually lead to climate change. It is useful for addressing the needs of waste food producers and is a cheap raw material for generating energy. The benefits to the public are that it reduces the need for landfill and increases recycling.

- Originality/value

  Despite SMEs being the powerhouse of the European economies, there is limited research investigating how Circular Economy (CE) could unlock their potential. Moreover, development of AD in the UK has lagged behind other EU countries. We highlight value leakages and argue how technological innovation should be used to close the value chain loop in the WTE production process. This paper, therefore, demonstrates the important role of an AD process, which involves decomposition of biodegradable materials. It shows that AD is an economically viable and environmentally friendly process of obtaining clean energy at low cost.



*Keywords:*

Circular Economy, Waste to Energy, Anaerobic Digestion, Small and Medium Enterprises (SMEs)


**Introduction**

Our current linear economic system of "take-make-use-dispose" is unsustainable (EMF, 2012) as it revolves around the use of indefinite resources, and non-renewable and polluting sources of energy (McDonough and Braungart, 2009; Stahel, 2010; Webster, 2013). Moreover, it results in the production of high volumes of waste (Jurgilevich et al., 2016; Huysman et al., 2017). Circular Economy (CE) has emerged as a viable solution to the linear economy where waste is drawn out from the system, resource use is optimised, materials are used at their highest value, renewable energy is harnessed, and natural resources are constantly replenished (EMF, 2012). It is apparent that such a shift implies the engagement of the whole economic system, specifically, businesses should generate new ideas and integrate them coherently with processes, methods, tools and solutions (Mentink, 2014). Businesses should capture value leakage in their normal activities and their supply chain. One such method is Waste-to-Energy (WTE).

WTE is a viable CE model that helps towards achieving the energy demand (Pan et al., 2015). CE business models are argued to be essential to generate energy in urban environments too (Pan et al., 2015). Due to a worldwide increase in urbanisation, there is a substantial increase in energy and material consumption, which has also led to anthropogenic waste generation (Mohan et al., 2016). Food waste is an increasingly critical issue as the projected food waste derived from households and sectors such as hospitality, food, retail and wholesale is approximately 10 million tonnes per year, corresponding to a value of £17 billion and 20 million tonnes of greenhouse gas emissions (WRAP, 2017b). It has been estimated that 60%

of food waste could have been avoided. 85% of this comes from households and the remainder from supply chains (WRAP, 2017b). Organisations should integrate different technologies as it acts as leverage in boosting CE and improving resource use efficiency (Monlau et al., 2016). There are different technologies available for WTE viz., combustion, gasification and anaerobic digestion (AD).

AD is amongst the cheapest methods of energy generation and is environmentally friendly (EMF, 2013; Silvestre et al., 2015; Ledda et al., 2016; Chu et al., 2017). Fischer et al. (1981) stated, "anaerobic digestion was useful for producing methane gas of feed materials containing suitable organic materials". Biogas or bio methane produced from AD is a versatile and environment-friendly fuel (Prajapati et al., 2013; Budzianowski et al., 2016; Khan et al., 2017; Materazzi et al., 2019). AD has been used for decades, where the recent technological progress has led to its wider use, in both developed and developing countries, at small and large scales (Curry and Pillay, 2012; Zhang et al., 2016). EMF (2015a) argues that AD is a vital process for enabling a CE. Specifically, this applies to the biological cycle where organic matter is processed in a sustainable way and kept in a closed loop (2015a). Therefore, issues such as waste to landfill, non-renewable energy and chemical fertilisers are overcome (Tiwary et al., 2015). Although in recent times CE has seen a rise in demand in the UK, EU and internationally, it is mostly associated with large organisations. CE focus has often been on large footprint plants and there is limited research on how SMEs operating AD plants can be more circular (Gueterbock and Sangosanya, 2017).

SME is an important context because in Europe and the UK in particular, SMEs represent a majority of business enterprises (Gray et al., 2012; Cohen et al., 2017; Tassabehji et al., 2019) and many are engaged in sustainability initiatives, such as WTE (Sainidis and Robson, 2017; Cohen et al., 2017; Choudhary et al., 2017). UK, when compared to the EU, has lagged in the development of AD (Gueterbock and Sangosanya, 2017) and, hence, there is a need for further research and investigation into how SMEs can adopt CE business models as it could help SMEs in terms of resource efficiency and closing loops (Rizos et al., 2016). SMEs can help to reap a fuller potential of AD and CE by optimising the use of finite resources and feeding precious nutrients back into food production, ensuring energy and food security. While also fighting climate change, improving air quality and supporting the economy, which are yet to be achieved. There is, however, a need to pay attention to the cost of running the AD, including cost of storage, and of handling digestate (Tiwary et al., 2015). One of the ways in which SMEs can generate value is by adopting innovation (Halila, 2007; Potting et al., 2017; Kaur et al., 2018; and Schroeder et al., 2019). Thus, we will draw upon the technological innovation to identify how SMEs could hone innovation to be competent with large players. An in-depth case study approach is used to show how SMEs can play an important role towards circularity and can set up initiatives to support sustainable and cleaner production of energy. This paper contributes to the wider literature in CE by demonstrating how a SME which is already built on circular business model could still have value leakages that could be captured using innovation. Technological innovation could reduce the operational cost and increase capital productivity (Potting et al., 2017; and Schroeder et al., 2019). Our research emphasised the importance of collaboration among stakeholders across boundaries, especially for SMEs.

The remainder of the paper is structured as follows: in the next section, we will provide a review of literature on linear and circular systems and highlight AD, followed by a review of technological innovation in WTE. We then state our methodological approach and findings, followed by discussion. We conclude by highlighting theoretical contributions and practical implications.

## Literature Review

*Linear: Take-Make-Use-Dispose*

The linear model can be typically described as a "Take-Make-Use-Dispose" economic model, and is characterised by production of output with no consideration of use of the resources or type of energy employed (typically fossil fuels). The linear economic system has severely impacted our environment and human health (Kelishadi, 2012). Scientists worldwide have been observing, documenting and warning on acute and escalating issues such as air pollution, water acidification, land eutrophication, carbon emissions and their effect on climate change, and biodiversity loss (IPCC, 2015). It has been estimated that globally only 25% of waste is reintroduced in the production system (Bank of America Merrill Lynch, 2013). Unutilised waste represents not only a source of pollution, but also a considerable loss of potentially precious resources that could be reprocessed for further economic cycles (EMF, 2012, 2013).

Since the beginning of 21$^{st}$ century price volatility levels for commodities have been higher than in the 20th century and this trend is likely to continue (Webster, 2013). Certain non-renewable resources have increased in demand by some 450% since 1960 and there is no sign of this trend stabilising. Those resources (e.g. oil, copper, lithium, etc.) that are crucial commodities for production are becoming scarcer, and are often located in geopolitically unstable and dangerous countries, pushing the extractions costs upwards. This situation tends to slow down the economy while causing severe environmental damage (Lacy and Rutqvist, 2015). Moreover, the world's population of 7.5 billion in 2019, is expected to reach 8.5 billion by 2030 and 9.7 billion by 2050 (World Economic Forum, 2017). It has also been estimated that new middle-class consumers will increase by 2.5 billion units by 2030 (EMF, 2012). These factors are exposing business to several risks, including cost increases, revenue decreases, shortage of raw materials, and financial investments uncertainty (EMF, 2012), and will result in businesses struggling to meet global demand (Lacy and Rutqvist, 2015). The linear economy is intrinsically not sustainable in the long run and intrinsically contradictory as it aims at producing infinite output with finite resources (Webster, 2013). There is a need to accelerate the change from the current linear economy towards a circular economy (CE), which is regenerative by intention and design while keeping the consumer in mind (Antikainen et al., 2016).

*Circular Economy*

A circular economy is regenerative and restorative by design, where inputs and materials are kept in economic cycles for longer at their highest value (via closed loops) and waste is designed out (EMF, 2012; Singh and Ordoñez, 2016; Charter, 2018; Garmulewicz, 2018). Waste is considered as input for further cycles. It allows decoupling economic growth from resource use (EMF, 2012, 2013, 2014) and thrives with diversity. It embraces a systems' view of economy, where it considers diverse systems as resilient and adaptive in relation to nature (EMF, 2012).

CE distinguishes two types of materials or components, namely the "biological nutrients" and the "technical nutrients". The former relates to biological components that can re-enter the biosphere safely; the latter refers to human made components. CE relies on three key principles: 1) Preserve and enhance natural capital by managing natural capital and replenishing it; 2) Optimise use of resources, materials and components to yield highest value; 3) Foster system effectiveness by tackling negative externalities with an aim of eradicating them from the economic system and lifestyles (Jackson, 2012; EMF, 2015).

However, in order to maintain resource efficiency, "new forms of value creation must be developed if the world is to maintain and increase prosperity" (Preston, 2012; Mishra et al., 2018). Park et al. (2010) argue that value creation within a supply chain can provide the impetus for organisations to adopt CE for competitiveness. Ghisellini et al. (2016) noted that CE has received worldwide attention, credited to its focus on closing the loop in production patterns within an economic system. WTE is one of the prime examples of a closed loop, which enables reuse of waste for generating energy and also producing raw materials to be used environmentally, thus it fits the CE agenda well (EMF, 2014; Singh and Ordoñez, 2016; Charter, 2018; Garmulewicz, 2018).

*Waste to Energy*

The notion of WTE has emerged and become popular in recent years and is gaining momentum lately (Kothari et al., 2010; Xin-gan et al.,2016; Pandey et al., 2016; Nizami et al., 2017).WTE is a potential alternative source of energy due to its being economically viable and environmentally sustainable (Kumar & Samadder, 2017). It is crucial in achieving sustainable development (Kothari et al., 2010). Kothari et al. (2010) argue that energy is a key consideration and what is required is a sustainable supply of clean, affordable, and renewable energy sources that do not cause negative societal impacts. Likewise, Sadef et al. (2016) looked into WTE and the recycling value of municipal solid waste (MSW) for developing an integrated solid waste management in Lahore. They found that WTE can significantly reduce the final volume of waste reaching landfills.

MSW comprises the biomass material, such as food, paper, wood waste, clothes rags, rubber, plastics and other daily used and discarded materials (Pandey et al., 2016). In their study of Malaysian WTE, Xin Gan et al. (2016) discovered that incineration is a superior technology choice when the production of electricity and heat were considered. Nizami et al. (2017) investigated generation of renewable energy using waste bio refinery, and found that this technique would be able to treat around 87.8% of the total municipal solid waste and lead to great savings. AD is one such WTE process, which could have several environmental benefits (Pham et al. 2015; Astrup et al.,2015). Although, AD plants have potential and their use has been advocated, they are still under used (Jingura and Matengaifa, 2009; Raheem et al., 2016; Grando et al., 2017; Hadidi et al., 2017). For example, only about 46 plants out of 400 municipal wastewater treatment plants in China had sludge anaerobic digestion (Wu et al. 2017).

*Anaerobic Digestion*

AD is "a process of controlled decomposition of biodegradable materials under managed conditions where free oxygen is absent…that convert[s] the inputs to biogas and whole digestate" (BSI, 2010: 3.2). It can be classified as a renewable energy source which could replace fossil fuels and be utilised for energy production (Curry and Pillay, 2012). Over the past two decades the evolution of the AD treatment capacity in Europe has been influenced mainly by EU policies, especially aimed at managing and preventing waste, including the disposal of biodegradable matter. In line with the EU Directives (2015), the UK has introduced several policy initiatives and strategies that are informed on the EU concept of waste hierarchy to divert biomaterials from landfill and produce renewable energy. This aims to contribute to mitigate climate change and enrich degraded soil (Gregson et al., 2015). A lot of AD plants adopt thickening/mesophilic anaerobic digestion/dewatering process. Some anaerobic digestion systems are based on a one-stage system whilst some have two-stages. There are some problems that can occur with the sludge AD. The low biogas yield and utilisation rate counteract some advantages of the sludge AD. Thus, there is a need for further technological innovation in AD.

Náthia-Neves et al. (2018) believe that AD is an economically viable and environmentally friendly process, as it generates clean energy at low cost without generating greenhouse gases. Although there have been many existing technologies, incineration and landfilling methods are mostly preferred all over the world today due to their high energy production potentials (Stamatelatou and Tsagarakis, 2015; Tozlu et al., 2016) AD is seen as a useful technology in MSW management (Jain et al., 2015). However, currently there is a particular need to study critically the operating parameters and also the pre-treatment technologies (including mechanical, thermal, chemical and biological methods) available for treating the substrate so that one can get the maximum output to improve the effectiveness of AD of MSW. Furthermore. literature highlights the role of SMEs in generating energy, and thus the value of using AD (Halila, 2007), despite SMEs lacking resources and innovative know how (Zorpas, 2010).

*Technological Innovation in SMEs*

CE focuses on resource efficiency and helps towards the international sustainability agenda (Charter, 2018). CE aims to maximise the material use to its highest value over time using relevant biological and technical innovations to create more circular product-service solutions. More disruptive innovations will occur from new technologies in response to societal change, such as the right to repair approach (ibid). Moreover, innovative technologies could help to "speed up" efficiencies (Qi et al., 2016). Schroeder et al. (2019) note that it is inherently important to achieve higher levels of economic productivity. Ranta et al. (2018) consider technological innovation and socio-technical systems, as both are complementary to one another, as institutional drivers and barriers of the CE.

Even over a decade ago, Hui-yue (2006) held that the technological innovation in CE was crucial and required a change in social values, given that it led to a new technological paradigm – ecotype. This strives towards ecological approach and new sustainable policy. Technical innovation is a way of achieving success in circular economy (Jun-sheng, 2018; McIntyre and Ortiz, 2016; Hagelüken et al., 2016; Linder and Williander, 2017) .Therefore, technological innovation is crucial to CE and has been recognised as a pertinent necessity in modern times.

In practice, many researchers have investigated the importance of technological innovation in CE, for instance, Jawahir and Bradley (2016) look at the aspects of 6R-based closed-loop material flow for sustainable manufacturing. They presented the sustainable manufacturing principles in creating economic growth, environmental protection and societal benefits. Singh and Ordoñez (2016) analysed over 50 examples of products developed from discarded materials and found that resources could be recirculated to make different types of products.

Several examples of types of innovation for CE exists in the literature. For example, Garmulewicz et al. (2018) found that disruptive technology such as three-dimensional (3D) printing could enable the CE and enhance the value chain through prolonged use of materials. The author looks at economic, technological, social, organizational, and regulatory barriers to mainstream implementation to assess 3D printing's viability as an enabler of a circular economy at the local level. Kaur et al. (2018) looks at green and sustainable chemistry and waste valorisation as contributing towards the use of technologies to achieve a more CE. They make the case for its transformation into a circular plastics economy. They also look at the use if bioconversion in a food waste as biorefinery to produce fructose, as a value-added product.

Potting et al. (2017) look into 'product chains and tracks' concerned with the extraction of natural resources to waste treatment after they have been discarded. They look at the recovery of materials once they have been discarded resulting in pollution. They found that the mixing of wasted materials leads to a reduced quality and concluded that such materials cannot be used to make a same quality of product. Often these materials result in lower quality products. They advocate new technology as it leads to creation of many new products, albeit that radically new technology is often expensive and suffers from technical imperfections. New technology also challenges socio-institutional rules and norms. Finally, establishing a technological innovation system is time consuming and risky, and possibly slow and uncertain progress of technological transitions.

Given the benefits, there has been a push towards adoption of technological innovation for SMEs as their success is linked to their ability to innovate and develop valid inter-organisational relations (Nassimbeni, 2001). SMEs performance is likely to improve as they 'mirror' large manufacturing firms with respect to formal strategy and structure, and as they recognise that innovation culture and strategy are closely aligned throughout the innovation process (Terziovski, 2010). Sarkis and Zhu (2017) highlight that research in technological innovation is not well represented and is comparatively less than that of strategy and process.

There are different types of innovations ranging from product, service and process. The first type is concerned with creation of new products that differ from the already established products (Norman and Verganti, 2014). It could also be an existing product but made from newer materials. Such a product could include enhanced quality and performance. Innovation can emerge incrementally or radically as discontinuous. Product innovation offers many benefits, such as growth, expansion and gaining a competitive advantage. New products determine the overall success or failure of a business (Cooper, 2013). Innovation is the lifeblood of economies and helps business to survive and thrive (Slater et al., 2014). Kleinschmidt and Cooper (1991) look at the impact of product innovativeness on business performance. The authors have found a connection between product innovativeness and commercial success.

Innovation could bring about many opportunities for SMEs (Rizos et al., 2015; Wu, 2017). Zamfir et al. (2017) investigated SME decision models for adopting CE practices and discovered a link between characteristics of European SMEs and their CE orientation/decisions. Hence researchers like Hallstedt et al. (2013) highlight key elements needed to successfully implement a sustainability perspective in the early phases of the product innovation process. They found eight elements, which are divided into four categories: organisation, internal processes, roles, and tools. They believe that incorporating these key elements into product innovation will encourage strategic sustainability and will help the organisation in the long run.

De Medeiros et al. (2014) focus on the success of environmentally sustainable product innovation through reviewing secondary research. They found four critical success factors for environmentally sustainable product innovation: market, law and regulation knowledge; inter-functional collaboration; innovation-oriented learning; and R&D investments. SMEs can re/innovate organizational structure, organizational processes, and organisational culture based on the circular economy to ensure their survival and sustainability. Hence CE is the way forward for organisations (Zamfir et al., 2017). For AD, Prajapati et al. (2013) discuss the use of a wide range of wastewaters for algae cultivation and using wet algal biomass, resulting in reduced processing cost. They write that the biogas produced from AD is a versatile and environmentally friendly fuel which traditionally utilises cattle dung as the substrate.

*Literature Gap*

Research on CE related to operations and production is mostly concentrated around remanufacturing for OEMs, especially for large companies. There are limited number of studies in CE and SMEs, despite the fact that in the EU a majority of companies are SMEs. However, a majority of research investigating CE in WTE is for large companies. Sarkis and Zhou (2017) noted a lack of research in technological innovation, especially for SMEs. Thus only a limited amount of research has investigated how SMEs operating on a CE business model could leverage benefit from technological innovation. In this research, we aim to fill this gap. The focus is on biogas production from biological organic materials. Leakages in a bio cycle mean value loss and the inability to return the nutrients back into the soil due to contamination (EMF, 2012).

## Methodology

In this research, we use a case study approach to gain a deeper insight into the use and purpose of AD by an SME, as an intensive study of a single unit (Gerring, 2004). A case study approach is correctly understood as a particular way of defining cases, not a way of analysing cases or a way of modelling causal relations (Tellis, 1997; Hancock and Algozzine, 2016; Yin, 2017).

*Case Company*

Company X is an SME that operates the only WTE AD plant in the UK and has an explicit aim of becoming circular. It was set up in 2012 and has less than 25 employees. It is located in a designated waste/recycling treatment zone. It is located in the Midlands, near the centre of England. It is surrounded by key stakeholders, including waste companies and food processing plants.

Company X holds a legal permit to convert up to 50,000 tonnes of food waste per annum into energy in the form of biogas and digestate. In terms of production inputs, Company X deals with waste from expired food from retail and hospitality sectors and waste from food processing plants. Incoming inputs include bio-liquids from waste, as they supplement the liquid content that food waste (containing 30% "dry matter") must reach for optimising the AD process (15% DM). In terms of outputs, the 2.5MWh CHP plant produces biogas that generates 22,238 MWh electricity annually, which is the equivalent of the energy required to power approximately 2,000 dwellings.

*Data Collection Approach*

The interviewees were identified on the basis of their involvement in AD design and operation. The company's founders, a technology expert, its staff, and a business consultant were approached to gain comprehensive information and perspectives. An overview of the research premise with the research questions was emailed to the company's founders, staff and technology expert prior to interviews. This was corroborated by a telephone conversation that further clarified the research aims. The data was collected over a period of 4 months, involving ten face-to-face interviews with business consultants, lasting about 1.5 hours on average, seven interviews with the technology experts, and three with the company's founders and two with the company's staff. The key questions asked are provided in Appendix A. The nature of questions was a mixture of semi-structured and open-ended; most questions were semi-structured to keep the interviews focused, with some open-ended questions to facilitate the expression of more in-depth viewpoints and feelings. The aim was to capture the views fully to learn about the actual running of AD processes and their effectiveness.

*Data Analysis Approach*

The analysis involves listing of codes and categories linked to key topics to interpret the data. This approach is advantageous as it allows codes and categories to be updated and amended during the collection of additional data (Tellis, 1997; Hancock, D.R. and Algozzine, 2016; Saunders et al., 2016; Yin, 2017). Consequently, it helps to investigate key themes and highlight new ones. Codes were developed based on the theoretical framework built on the concepts of CE and WTE. This involved interpreting the statements containing particular words and phrases and matching them to theoretical aspects.

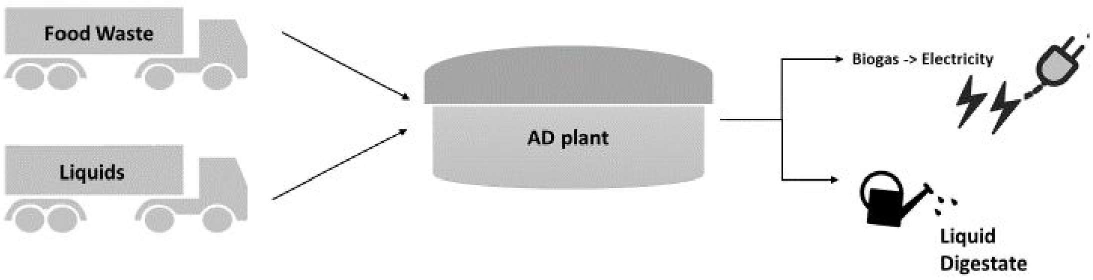
## Findings

Company X has a strategic aim of being circular and has created a relevant culture. It has also developed close working relationships with the key industrial stakeholders who can aid its mission, especially with the nearby waste management companies as well as one major electricity client (Figure 1). This has resulted in gaining mutual financial and operational benefits, as well as building trustworthy working relationships and a linked value chain. Benefits are also environmental as the proximity of the key stakeholders helps reduce their carbon footprint and is therefore beneficial for the local area and the quality of life in it.

Company X is a SME that operates the only WTE AD plant in a major UK city. It was set up in 2012 and currently has 12 employees. It is located in a designated waste/recycling treatment zone on the site of a major industrial estate. It is strategically surrounded by several stakeholders, including waste companies. It holds a legal permit to convert up to 50,000 tonnes of food waste per annum into energy in the form of biogas and digestate (See Figure 1). In terms of production inputs, it typically deals with waste from expired food from the retail and hospitality sectors and with waste from food processing plants. Incoming inputs include bio-liquids from waste, as they supplement the liquid content that food waste (containing 30% "dry matter") must reach for optimising the AD process (15%DM). In terms of outputs, the 2.5MWh CHP plant produces biogas that generates 22,238 MWh of electricity on an annual basis, which is the equivalent of the energy required to power approximately 2,000 dwellings.

Strengthening a dedicated, exclusive and long-term collaboration with key stakeholders, such as the waste management companies, would increase efficiency (e.g. UK Waste Solutions to create value (Table 1) by optimising efficiencies (Table 2). This is done through knowledge sharing, joint R&D activities, ad-hoc investments in the value chain (e.g. in the packaging issue) and special financial transaction agreements which could help extract and distribute untapped value along the value chain (Figure 2). Indeed, according to one of the Directors: "*Collaboration and continuous dialogue with all the stakeholders in your industry is the only way to ensure that there are some gains at all levels of society*".

Figure 1. Electricity Production Process




From the interviews, it emerged that there are two main types of operational issues that Company X could face.

1. The control and maintenance quality of the collected waste is of paramount importance. If, for instance, hazardous waste or contaminated waste get into the plant then this can disrupt the operations. The plant has had to deal with such situations and suspended the operations for a few months while decontaminating the site. This obviously has caused loss of income and extra costs.

2. The removal of the digestate can be difficult to estimate accurately and therefore costs may end up higher than expected.

Based on the data collection from Company X's Directors, the former Technical Director, the main Business Consultant and staff, it has emerged that there is a certain level of awareness of the CE principles within the company. The interviewees gave an overall score of 2 out of 5 corresponding to a level of awareness of the basic principles of the CE. It is worth noting that staff showed a lower level of CE awareness compared to the other interviewees: "*I have heard of this concept of circular economy*". "*I think it relates to waste management*" said an administrative staff; whereas the Business Consultant stated that "*CE is about resource efficiency and better material flows that can be achieved through a different business logic*".

From the conversations, it has also become apparent that the company aims to increase awareness of CE in order to translate the principles at an operational level to overcome barriers and risks. These have then been illustrated clearly in Table 3. In fact, the former Technical Director and the company's main Business Consultant have worked on a project to improve some aspects of production resources (liquids cycle) and output (digestate) with the view of increasing the efficiency of the whole production process and attempting to "close some materials loops". "*The business should be more value driven, meaning that the focus should be on introducing new technology and new other end-products*", stated the former Technical Director.

In terms of value distribution, Company X has developed a close relationship with the key stakeholders, especially with the nearby waste management companies. This has resulted in gaining mutual financial and operational benefits as well as building trustworthy working relationships. Benefits are also environmental, as the proximity of the key stakeholders helps reduce their carbon footprint and is, therefore, beneficial for the local area and the quality of life of the community.

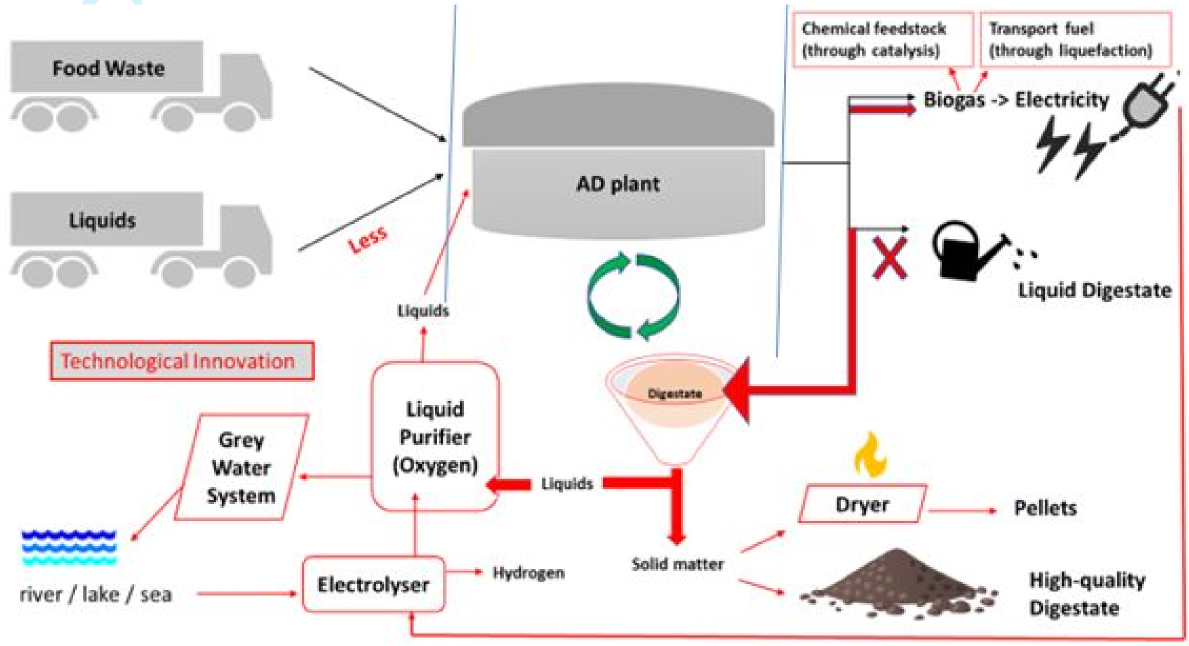
Perhaps strengthening a dedicated, exclusive and long-term collaboration with key stakeholders, such as the waste management companies, through knowledge sharing, joint R&D activities, ad-hoc investments in the value chain (e.g. in the packaging issue) and special financial transaction agreements could help extract and distribute untapped value along the value chain.

Table 1: Value Creation

| ***COMPANY X*'S VALUE CREATION ANALYSIS** |
| --- |
| 1. The screening for apparent *value leakage* suggests that the liquids cycle is not optimised as liquids are recovered at the end of the AD process, as a system output. |
| 2. Screening for improving *value creation for customers* by extracting the residual value from the digestate that could be improved and sold. |

3. Screening for *productivity improvements of the capital stock*; the plant could increase waste food intake if the digestate/liquids cycles were improved through technology innovation.

Figure 2: Circular AD Process




*Key*:
Dark line= original AD process
Red Line=New process enabled by technological innovation

Table 2: Optimising Efficiencies

| **Optimising operating expenses** | **How?** | **Implications** |
|---|---|---|
| Reducing disposal costs for digestate | Recover more value from digestate using newer technological innovations | Reduced operating expenses |
| Reduce the need to purchase liquids | Technological innovation | Increase intake of waste food |
| **Optimising capital employed** | | |
| Increasing capital productivity | Technical innovation | Increase incoming food waste |
| | | Obtaining a higher quality digestate that could become a revenue stream instead of a cost |
| | | Packaging recycling would lower the cost of disposal. |
| **Higher revenue** | | |
| Economies of scale | More incoming food waste | Higher revenue |
| Economies of scope | More products | Digestate, biogas and plastic materials |
| Higher margins | From optimised production and diversification as a market leader | From increased income from traditional and new sources. |

Table 3: Barriers and Risks

| Barriers/Risks | B=Barriers<br>R=Risks | I=Internal<br>E=External |
|---|---|---|
| Lack of company culture in CE | B | I |
| Lack of technical know-how | B | I |
| Lack of capital | B | I & E |
| Lack of effective Government support or legislation | B | E |
| Administrative burden perception | B | I |
| Lack of support from supply chain | B & R | E |
| Technology not yielding expected positive results (AD) | R | I |

## Research Synthesis

Firstly, it was found that an increased communication and collaboration with UK waste producers on how to treat the food waste (and therefore its "quality") would lower operational issues whilst strengthening key partner relationships. It would help, for example, in achieving trust and resource use efficiency (Monlau et al., 2016). A good relationship between different stakeholders involved with WTE and AD is crucial, especially in this early era of exploiting such WTE technologies. Stakeholders create a very important network to provide materials, resources, advice and information and so to facilitate smooth operations (Curry and Pillay, 2012). The collaboration requires the development of trust between partners, who then provide a degree of certainty, predictability and management (Terziovski, 2010; Sarkis and Zhu, 2017). Our research clearly shows the existence of a strong network of stakeholders, even more, essential for SMEs, given their limited resources and a high degree of vulnerability in the area of CE and WTE.

Secondly, the flow of liquid into the process could be reused by retreating the digestate. This was an apparent loss in the value chain because the liquid digestate could not be used for any other purpose and instead was going to the landfill (Pham et al., 2015; Astrup et al., 2015). Focusing on the composition of the liquid digestate, it was found that it could be converted into value through reprocessing and feeding it back into the system after some remix. This led to the need for further innovative alterations to the current AD system using new technology. This would enable recovering of extra calorific content left in the digestate (currently an end-product that is disposed at a cost) and extracting the liquid content from it (Wu et al. 2017). This feedback could return to the beginning of the AD process, resulting in a reduced need for the purchase of liquids and the possibility to increase the intake of feedstock (see Figure 2). This would also lower costs involving purchase extra liquids (Tozlu et al., 2016; Gottardo et al., 2017).

Table 2 highlights ways to increase efficiencies by optimising the operating costs, increasing productivity and yield, and using bulk buying power. In the first two aspects, heavy use of technologies can be made to optimise the processes in production and to reuse the waste from the output stage of AD. However, this innovative process would entail a certain amount of water to be discharged off-site (Kleinschmidt and Cooper, 1991). If further technological innovation was introduced to treat the liquids and turn them back to water, then this could be discharged back into the nearby river so that the water cycle could be truly circular and restorative (Náthia-Neves et al. (2018).

Thirdly, the biogas that usually goes into the CHP generator could be liquefied, used and sold as a transport fuel, perhaps to local transport companies (Figure 2), as also indicated by other researchers, but harnessing this further for the benefit of Company X (Pham et al., 2015; Astrup et al., 2015). Alternatively, innovative catalysis technology could convert biogas into a valuable chemical feedstock that could be utilised as input for many industries. An AD process can be further improved with an increased degree of innovation and use of technology (McIntyre and Ortiz, 2016; Hagelüken et al., 2016; Linder and Williander, 2017). Its output can be converted in forms suitable for generating further efficiencies in energy generation with a greater degree of ease. This would also increase the number and types of end users. This would raise the profit propositions and make it a worthwhile venture for the owners to engage in. Thus, engaging in such WTE aspects of CE would also prove to be a useful venture for other SMEs.

Any company has incentives to cut out waste and improve the efficiency of its operations and offerings. Factors such as the minimisation of leakage levels in the loops are crucial ways for companies, and specifically an AD plant, to become more circular. In order to achieve this, innovation is the inevitable step to take. Technological innovation will be fruitful not only for the SMEs (Terziovski, 2010) but also for other organisations thinking of moving towards a circular business model. This will require creative thinking and a detailed understanding of the whole system.

## Conclusion

There is a considerable role that even SMEs can play towards circularity, ranging from recycling to remanufacturing, to using the last-ditch attempt to convert waste into energy. The latter appears to be a less cumbersome activity, however, it is very difficult to generate energy from waste in an efficient and effective way. This research demonstrates that SMEs can play a significant role in helping an economy, like that of the UK, to achieve circularity and become sustainable. It requires the use of sophisticated technology and innovation. Any value proposition depends on the effective arrangement of processes and, subsequently, their monitoring and enhancement. The paper highlights the AD techniques in helping to reduce the greenhouse gas emissions of waste. Further, it is one of the cheaper methods of energy generation. According to EMF (2015a), technological advances have improved this process further. The researchers undertook an in-depth study to highlight the role played by an SME in converting waste into energy and helping to achieve circularity.

The paper looks further into how the latest innovation can be used to improve the process in question and to maximise the amount of energy generated. Hence, the use of waste by SMEs would lead to an increase in its use, leading to many environmental benefits as well as clean energy generation. It would help to reduce pollution, water acidification, and carbon emissions that eventually lead to climate change. It is useful in addressing the need for waste food producers and offers cheap raw material for waste processors for generating energy. The benefits to the public are that it reduces the need for landfill and increases recycling.

This paper sheds fresh light on the very last stage of disposal (a forgotten stage of circular economy due to its lack of perceived value) where the biological waste is rendered useless but can be used for generating much-needed energy and obtaining nutrient-rich compost for agriculture. The theoretical contribution of this paper is that it highlights how AD use for WTE helps to achieve the circular value of preservation, optimisation and effectiveness leading towards doing "the right thing" while achieving economic value and social well-being. Therefore, WTE is a very viable way of contributing to the circular economy, with SME that can help fuel exponential growth in the use of biological waste. The paper, therefore, demonstrates the important role of the AD process, which involves the decomposition of biodegradable materials. It shows that AD is an economically viable and environmentally friendly process of obtaining clean energy at lower costs.

Finally, for SMEs interested in AD for WTE, this paper introduces further innovation to the AD process to leverage further potential for reuse of waste liquid. This research looks at how the waste liquid could be reprocessed to yield greater value from the process. The reuse of liquid would help to recover the value leakage, as it was found that the wasted liquid still contained calorific content that could be put through the digestate several times. This would decrease the need to purchase liquids needed for processing, making it a more efficient process. Therefore, any SMEs entering the WTE market ought to take into consideration such design implications.

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## Appendix A

### QUESTIONNAIRE 1

Name of the company
Legal status
Location
Date of establishment
Number of employees (please attach an organigram if available)

**Is your business member of any association?**

**Value Proposition**

• What bundles of products and services are you offering to each customer segment?
• Which one of your customer's problems are you helping to solve?
• What value do you deliver to the customer (e.g. newness, performance, customisation, "getting the job done", cost reduction, risk reduction, convenience, price, accessibility, etc.)?
• Which customer needs are you satisfying?

**Who are the most important customers?**

**Customer relationship**

• What type of relationship does each of your customer segments expect you to establish and maintain with them (e.g. personal assistance, dedicated personal assistance, self-service, automated services, communities, co-creation, etc.)?
• Which ones have you established?
• How are they integrated with the rest of the business model?
• How costly they are?

**Channels**

• Through which channels do your customer segments want to be reached?
How are you reaching them now?
• How are you channels integrated?
• Which ones work best?
• Which ones are most cost-efficient?
• How are you integrating them with customer routines?

**Key partners**

• Who are your key partners?
• Who are your key suppliers?
• Which key resources are you acquiring from partners?
• Which key activities do partners perform?

**Key activities**

• What key activities do your Value Proposition require (e.g. production, problem solving, platform/network, etc.)?
• And your distribution channels?
• And your customer relationship?
• And your revenue stream?

**Key resources**

• What key resources do your value proposition require, e.g. physical, intellectual (such as brand patents, data, etc.), human, financial?
• And your distribution channels?
• And your customer relationship?
• And your revenue stream?
• What are your energy sources (Renewables? Fossil? Etc.)?
• What are your natural resources involved in your business activity?

**Please briefly describe the technology involved in your business.**
**Cost structure**
• What are the most important costs inherent in your business model?
• Which key resources are most expensive?
• Which key activities are most expensive?
• Is your business more… ○ Cost driven (leanest cost structure, low price value proposition, maximum automation, extensive outsourcing)

OR

- Value driven (focused on value creation, premium value proposition)?7
    - Please, sample characteristics: ○ Fixed costs (salaries, rents, utilities)
- Variable costs
- Economies of scales
- Economies of scope

**Revenue streams**
• For what value are your customers really willing to pay?
• For what do they currently pay?
• How are they currently paying?
• How would they prefer to pay?
• How much does each revenue stream contribute to overall revenues?
Types: asset sale, usage fee, subscription fee, lending/renting/leasing, licensing, brokerage fees, advertising, etc.

Do you have any Environmental Management Standard in place (e.g. ISO14001, Investor in the Environment, etc.)? If yes, please briefly outline the main policies in place (e.g. waste management, energy management, sustainable transport plan, sustainable procurement, etc.).

Do you have an Energy Management System in place (e.g. ISO5001)?

Do you have any other Standards in place (e.g. Quality Management ISO9001)?
Please look at the diagram below showing the material flow and answer the following questions:

**Input in the production process**
How much input is coming from virgin and recycled materials and reused components?

**Utility during use phase**
How long and intensely is the product used compared to an industry average product of similar type? This takes into account increased durability of products, but also repair/ maintenance and shared consumption business models.

**Destination after use:**
How much material goes into landfill (or energy recovery), how much is collected for recycling, which components are collected for reuse?

**Efficiency of recycling:**
How efficient are the recycling processes used to produce recycled input and to recycle material after use?

**In a scale from 0 to 10 how would you assess the level of risk of the following:**
(0=no risk; 10=very high)
Material price variation
Material supply chain
Material scarcity
Toxicity of inputs

**Do you measure and monitor the following…?**
Energy usage
CO2 emissions

**QUESTIONNAIRE 2**

1. Details of the AD plant

2. Details on the gasification plant

3. Type of filtering/aeration system

4. Waste

5. Details of the overall intake of feedstock to foresee future developments

6. Current surplus energy produced or energy purchased (if production is lower than the demand)

7. Location of CHP and gasifier? Any adjacent building or room what could share the heat naturally produced without measures of convoy/store it? An industrial building with healthy plants all around might be more appealing.

8. Air purity assessment (for plant safety)

11. Any current third party that could be involved in the supply/buyer chain?

12. Land availability for future projects and expansion

# Waste to Energy and Circular Economy: The Case of Anaerobic Digestion

Figure 1. Electricity Production Process

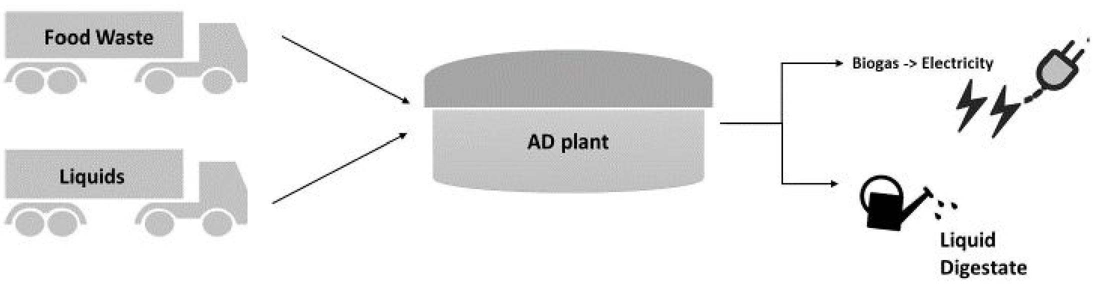
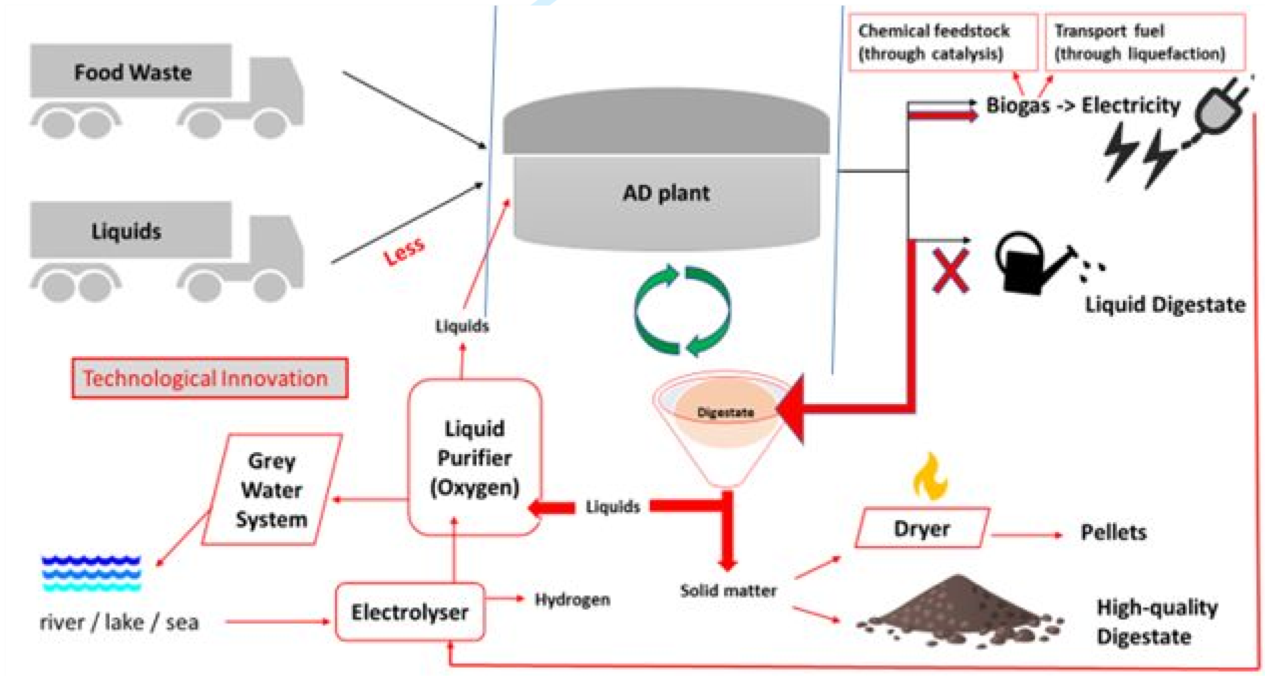



Figure 2: Circular AD Process




*Key*:
Dark line= original AD process
Red Line=New process enabled by technological innovation

Waste to Energy and Circular Economy: The Case of Anaerobic Digestion

Table 1: Value Creation

| ***COMPANY X*'S VALUE CREATION ANALYSIS** |
|---|
| 1. The screening for apparent *value leakage* suggests that the liquids cycle is not optimised as liquids are recovered during at the end of the AD process, as a system output. |
| 2. Screening for improving *value creation for customers* extract the residual value from the digestate that could be improved and sold. |
| 3. Screening for *productivity improvements of the capital stock*; the plant could increase waste food intake if the digestate/liquids cycles were improved thanks through technology innovation. |

Table 2: Optimising Efficiencies

| **Optimising operating expenses** | **How?** | **Implications** |
|---|---|---|
| Reducing disposal costs for digestate | Recover more value from digestate using newer technological innovations | Reduced operating expenses |
| Reduce the need to purchase liquids | Technological innovation | Increase the incoming waste food |
| **Optimising capital employed** | | |
| Increasing capital productivity | Technical innovation | Increase incoming food waste |
| | | Obtaining a higher quality digestate that could become a revenue stream instead of a cost |
| | | Packaging recycling would lower the cost of disposal. |
| **Higher revenue** | | |
| Economies of scale | More incoming food waste | Higher revenue |
| Economies of scope | More products | Digestate, biogas and plastic materials |
| Higher margins | From optimised production and diversification as a market leader | From increased income from traditional and new sources. |

Table 3: Barriers and Risks

| Barriers/Risks | B=Barriers<br>R=Risks | I=Internal<br>E=External |
|---|---|---|
| Lack of company culture in CE | B | I |
| Lack of technical know-how | B | I |
| Lack of capital | B | I & E |
| Lack of effective Government support or legislation | B | E |
| Administrative burden perception | B | I |
| Lack of support from supply chain | B & R | E |
| Technology not yielding expected positive results (AD) | R | I |