

Table S1: PESTEL Analysis - Political Parameters

Political parameters	Ranking relevance	Ranking uncertainty	Justification	Source documents
Renewable Energy and Climate Policy	H	L	<p>The ranking for the Renewable Energy and Climate Policy parameter is denoted as of high relevance to the case study selected because of the UK Government’s commitment to increase the energy from waste treated via AD. This is because energy security is high on UK’s political agenda, and as such biogas production via AD is highly regarded as a valuable contribution to this agenda. In view of this the UK government has departed from the waste hierarchy to support the uptake of AD in the case of unavoidable food waste generation (and where prevention measures are put in place, e.g. Courtland Agreement) over composting, a decision reinforced by the fact that AD generates greater environmental benefit than composting; hence focusing its policies to fully support food waste treatment via Anaerobic Digestion (AD). AD is incentivised through renewable energy subsidies and the Government has also adopted an Anaerobic Digestion Strategy and Action Plan to overcome barriers to the uptake of the technology.</p> <p>The uncertainty of this parameter is low as energy security will continue to be a priority in UK government’ agenda. Plans (such as the UK Action Plan) are underway to promote and increase energy from waste through anaerobic digestion.</p>	<ul style="list-style-type: none"> Defra (2013a) Anaerobic Digestion Strategy and Action Plan Annual Report 2012-13, Annual Report. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/229432/pb14019-anaerobic-digestion-annual-report-2012-13.pdf Morton, C. (2015) Anaerobic Digestion in the UK – 2015 Update, BioCycle, 56(4), 43. Available at: https://www.biocycle.net/2015/05/13/anaerobic-digestion-in-the-uk-2015-update/ Defra (2013b) Waste Management Plan for England. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/265810/pb14100-waste-management-plan-20131213.pdf
Environmental Permitting Regulation (AD planning)	H	L	<p>The ranking for the EPR is denoted as of high relevance to the case study selected. For any AD facility that is to be installed there is a set of standard rules that must be followed which is effective from the date the Industrial Emissions Directive enabling legislation comes into force, i.e. 7 January 2013.</p> <p>Other reasons for which this parameter is of high relevance is because it informs on the environmental soundness of the process and location of the facility and conveys useful information in regards to the capacity of the AD facility (<100 tonnes per day), and the permitted use of biogas in gas engines, gas turbines, boilers, fuel cells and treatment and/or upgrading the biogas to biomethane. In addition, in these permits there are provisions for AD facilities treating food waste which need approval</p>	<ul style="list-style-type: none"> EA (2017) SR2012No12 - Anaerobic digestion facility including use of the resultant biogas, on Standard permits for waste operations. Available at: http://webarchive.nationalarchives.gov.uk/20140328084622/http://www.environment-agency.gov.uk/business/topics/permitting/145249.aspx DECC and Defra (2011) Anaerobic Digestion Strategy and Action Plan - A commitment to

			<p>from the Animal Health Veterinary Lab Agency (AHVLA) under Animal By-Products legislation. Regulation (EC) 1069/2009 on the handling and use of animal by-products permits the use in AD of low-risk animal by-products which are essentially material passed fit for purpose, but no longer intended for human consumption.</p> <p>The uncertainty of this parameter is low as the environmental permitting regulations are key requirements for the installation and operation of AD in order to prevent harm to human health and the environment; these are obtained, controlled and monitored by the UK Environment Agency (EA).</p>	<p>increasing energy from waste through Anaerobic Digestion.</p>
Job Creation	H	H	<p>The ranking of this parameter is of high relevance to the sustainability assessment of food waste management via AD, due to the direct social benefits accruing from it. It is reported that AD can offer 35,000 new employment opportunities in the UK in terms of both the operation of plants and also the manufacture, construction and delivery of AD equipment.</p> <p>The uncertainty of this parameter is high because of the lack of evidence to support job creation via the AD. In a WRAP report it was stated that the total UK employment in the AD sector was estimated at 482 full-time equivalents in 2013 compared to 354 in 2012 i.e. a 36% increase. In the 2015 ADBA report it was reported that there will be 4,500 jobs in the sector, which increase is expected to be continued in the coming years (with fewer in the construction sector, but more in the ongoing maintenance sector). Yet, these figures are not specific to food waste management via AD, but general to the AD sector and it is thus unclear of how many jobs the AD of food waste can actually create. New data are needed in view of the potential uptake of the AD for food waste management in recent years.</p>	<ul style="list-style-type: none"> • DECC and Defra (2011) Anaerobic Digestion Strategy and Action Plan - A commitment to increasing energy from waste through Anaerobic Digestion. • WRAP (2014) Survey of the UK Anaerobic Digestion industry in 2013, Prepared by LRS Consultancy for WRAP, Banbury, UK. Available at: http://www.wrap.org.uk/sites/files/wrap/A_survey_of_the_UK_Anaerobic_Digestion_industry_in_2013.pdf • Anaerobic Digestion and Biogas Association, ADBA (2015) Anaerobic Digestion Market Report. Available at: http://adbioresources.org/docs/July_2015_Market_Report.pdf
Taxation policies	M	H	<p>The ranking of this parameter is of high relevance because it becomes far more economic to treat food waste that is separately collected by AD and turn it into useable, saleable products, rather than sending it to landfill and paying landfill tax. Landfill tax policy has been a key driver for the uptake of AD for the treatment of food waste.</p> <p>It had been estimated that in 2017 more than 4 million tonnes of food waste are disposed of to landfill based on UK data. Increases in landfill tax from £84.40/tonne in 2016 to £88.95/tonne in 2018, could increase the</p>	<ul style="list-style-type: none"> • HMR&C (2016) Landfill Tax: Increase in rates, Policy paper, Published 16 March 2016. Available at: https://www.gov.uk/government/publications/landfill-tax-increase-in-rates/landfill-tax-increase-in-rates

			<p>uptake of AD of food waste even more. However, this is highly uncertain and depends on the willingness of LAs and waste contractors to collect food waste separately and treat it via AD, despite of any governmental support that favours the AD treatment. This is evidenced by the fact that Waste and Resources Action Programme (WRAP) statistics showed that household food waste in the UK increased 4.4 per cent between 2012 and 2015 (despite a target to cut household waste 5 per cent by 2015) generating around 7.3 million tonnes, 4.7 Mt of which is not separated from other fractions collected by the local authorities and becomes disposed of either via sewer or landfill, costing UK families around £700 per year. In 2015, a market report from the Anaerobic Digestion and Biogas Association (ADBA) called for action to the stagnation of separate waste collection in England, which can hinder the development of the British AD industry.</p>	<ul style="list-style-type: none"> • WRAP (2017) Estimates of Food Surplus and Waste Arisings in the UK. Available at: http://www.wrap.org.uk/sites/files/wrap/Estimates_%20in_the_UK_Jan17.pdf • Sheffield H. (2017) How the UK's household problem is getting worse. The Independent. Article published online on 10th January 2017. Available at: http://www.independent.co.uk/news/uk/politics/how-the-uks-household-food-waste-problem-is-getting-worse-a7520171.html#commentsDiv • Anaerobic Digestion and Biogas Association, ADBA (2015) Anaerobic Digestion Market Report. Available at: http://adbioresources.org/docs/July_2015_Market_Report.pdf
Infrastructure investment	H	M	<p>This ranking is denoted as of high relevance because it will drive the growth of the AD process, and will demonstrate that there is interest in this industry and that it works really well for recovering resources from food waste.</p> <p>However, this parameter can be associated with high uncertainty because AD is still considered to be an immature industry when it comes to food waste management, and any investments made are based on past performance and the promise of future performance so the structure of most deals reflects the current status of the market. In Green Investment Bank's report on AD, it is reported that whilst the absence of a specific household food waste policy, the results regarding anaerobic digestion of food waste in England have been relatively mixed.</p>	<ul style="list-style-type: none"> • GIB (2015) The UK Anaerobic Digestion Market. Available at: http://www.greeninvestmentbank.com/media/44758/gib-anaerobic-digestion-report-march-2015-final.pdf
Government support for AD industry	M	H	<p>This ranking is of medium relevance to the uptake of AD for food waste management, as evidenced from the decision of the UK Government to depart from the Waste Hierarchy proposed in the WFD based on the premise that AD is more environmentally friendly than composting (according to LCA). Moreover a joint Government and Industry Anaerobic Digestion Strategy and Action Plan for England has been put in place to promote the uptake of AD in general and specifically to the treatment of food waste. In addition, the UK government is committed to moving to a low-carbon economy and meeting its carbon reduction and</p>	<ul style="list-style-type: none"> • DECC and Defra (2011) Anaerobic Digestion Strategy and Action Plan - A commitment to increasing energy from waste through Anaerobic Digestion. • Defra (2013a) Anaerobic Digestion Strategy and Action Plan Annual Report 2012-13, Annual Report. Available at: https://www.gov.uk/government/uploads/system/

			<p>renewable energy targets, and AD is sought to be a route to achieving these targets. The sustained effort to identify market for digestate and promote its use as a fertiliser, or even as a resource for landscaping and regeneration, also indicates the commitment of the government to support AD. However, government rhetoric has not been matched by investment or policies to support AD plant development, which are therefore more important.</p> <p>The uncertainty of this parameter is high, as government although it keeps promoting the uptake of AD as the optimal food waste management option, its financial support is uncertain while policies need to change. Therefore, the UK AD industry will be faced with very big challenges around feedstock supply, financial incentives and sustainability criteria. The availability of food waste is a key determinant of potential growth in AD. Improved source-segregated food waste collections would enable the UK AD market to grow due to improved access to food waste, but political changes are needed to promote that.</p>	<ul style="list-style-type: none"> • uploads/attachment_data/file/229432/pb14019-anaerobic-digestion-annual-report-2012-13.pdf • Defra (2013b) Waste Management Plan for England. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/265810/pb14100-waste-management-plan-20131213.pdf • Bioenergy Insight (2016) ADBA exclusive: UK's anaerobic digestion industry will focus on boosting performance. Available at: http://www.bioenergy-news.com/display_news/10723/adba_exclusive_uk_anaerobic_digestion_industry_will_focus_on_boosting_performance/
Stability of political framework	H	H	<p>This ranking is of high relevance due to Brexit negotiations with the EU, which is likely to pose threats to the stability of the political framework; which in turn will cause changes in the AD industry. UK's AD sector may lose support from the EU's renewable energy target and the EU's Waste Directive targets. Fiscal weakness may also limit the capacity to fund the UK's renewable heat incentive (RHI).</p> <p>The uncertainty of this parameter is also high due to the uncertainty of the political landscape over the coming years.</p>	<ul style="list-style-type: none"> • Bioenergy Insight (2016) ADBA exclusive: UK's anaerobic digestion industry will focus on boosting performance. Available at: http://www.bioenergy-news.com/display_news/10723/adba_exclusive_uk_anaerobic_digestion_industry_will_focus_on_boosting_performance/

Table S2: PESTEL Analysis - Economic Parameters

Economic parameters	Ranking relevance	Ranking uncertainty	Justification	Source documents
Cost savings from FW reduction	L	M	There is a trade-off between the cost savings from FW reduction/storage and the benefits from downstream pre-treatment and electricity/biogas production from AD. Rebound effects, where cost savings from reduced waste are used to purchase higher quality food, have been demonstrated and reduce economic impacts.	<ul style="list-style-type: none"> Solomie A. Gebrezgabher, Miranda P.M. Meuwissen, Bram A.M. Prins, Alfons G.J.M. Oude Lansink, Economic analysis of anaerobic digestion—A case of Green power biogas plant in The Netherlands, NJAS - Wageningen Journal of Life Sciences, Volume 57, Issue 2, June 2010, Pages 109-115, ISSN 1573-5214, https://doi.org/10.1016/j.njas.2009.07.006.
Cost savings from FW storage efficiency	L	M	These parameters have a low level of uncertainty and only dependent on the quantity of FW within the catchment area.	
Collection and transport costs	M	M	The collection and transport costs are associated with the distance from the points of collection to AD plant. There is a trade-off between the costs and the scale of the AD facilities within the catchment area. These parameters have a medium level of uncertainty and is dependent on the quantity of FW within the catchment area and the distance to the AD plant.	<ul style="list-style-type: none"> M. Walker, H. Theaker, R. Yaman, D. Poggio, W. Nimmo, A. Bywater, G. Blanch, M. Pourkashanian, Assessment of micro-scale anaerobic digestion for management of urban organic waste: A case study in London, UK, Waste Management, Volume 61, March 2017, Pages 258-268, ISSN 0956-053X, https://doi.org/10.1016/j.wasman.2017.01.036.
Pre-treatment costs	H	M	Pretreatment, depending on the type and efficiency of technology, are important factors to the overall capital, operating and maintenance costs. Better pretreatment would also result in lower costs for post-treatment. This parameter has a moderate level of uncertainty as explained above.	<ul style="list-style-type: none"> Javkhlan Ariunbaatar, Antonio Panico, Giovanni Esposito, Francesco Pirozzi, Piet N.L. Lens, Pretreatment methods to enhance anaerobic digestion of organic solid waste, Applied Energy, Volume 123, 15 June 2014, Pages 143-156, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2014.02.035.
AD costs	H	M	The supply of food wastes and size and location of the AD plant is a key factor in determining the feasibility of the AD project. The AD cost varies considerable depending on size and location as well as the design, but there is considerable experience so costs are relatively easy to ascertain	<ul style="list-style-type: none"> M. Walker, H. Theaker, R. Yaman, D. Poggio, W. Nimmo, A. Bywater, G. Blanch, M. Pourkashanian, Assessment of micro-scale anaerobic digestion for management of urban organic waste: A case study in London, UK, Waste Management, Volume 61, March 2017, Pages 258-268, ISSN 0956-053X, https://doi.org/10.1016/j.wasman.2017.01.036.

Maintenance costs	H	M	Maintenance contracts are usually available that would specify frequency and types of works. The maintenance costs are also affected by H ₂ S level in the biogas. This parameter has a moderate level of uncertainty as explained above.	<ul style="list-style-type: none"> • Lukehurst, C., Bywater, A., 2015. Exploring the viability of small scale anaerobic digesters in livestock farming. IEA Bioenergy. https://www.iea-biogas.net/files/daten-redaktion/download/Technical%20Brochures/Small_Scale_RZ_web2.pdf (accessed 30 May 2017)
Post-treatment costs	H	M	Post-treatment is an important step in AD plant which serves to stabilise the digestate so that it can be used as fertiliser or sent to landfills. The cost of post-treatment depends on the type and quality of wastes being treated in AD, end use of digestate and also type of digester. This parameter has a moderate level of uncertainty as explained above.	<ul style="list-style-type: none"> • Monson, K.D., Esteves, S.R., Guwy, A.J., Dinsdale, R.M., 2007. Anaerobic digestion of biodegradable municipal solid wastes: A review. Sustainable Environment Research Centre. http://www.walesadcentre.org.uk/Controls/Document/Docs/Anaerobic%20Digestion%20of%20BMW%20_compressed_%20-%20Part1.pdf (accessed 30 May 2017)
Revenue from digestate	H	L	Digestate which conforms to PAS110 standards can be sold as fertiliser and create additional revenue to AD plant, otherwise it will be treated as waste and would incur in disposal costs. The revenue and offset costs from digestate and its costs of disposal are standardised and the variation is considered low throughout the country and thus the parameters have a low level of uncertainty.	<ul style="list-style-type: none"> • Friends of the Earth Guildford and Waverly, 2012. Anaerobic Digestion: a technical briefing for local group campaigners. http://www.gwfoe.org.uk/wp-content/uploads/2012/11/GW-Friends-of-the-Earth-AD-technical-briefing-Nov-2012.pdf (accessed 30 May 2017) • Friends of the Earth Guildford and Waverly, 2012. Anaerobic Digestion: a technical briefing for local group campaigners. http://www.gwfoe.org.uk/wp-content/uploads/2012/11/GW-Friends-of-the-Earth-AD-technical-briefing-Nov-2012.pdf (accessed 30 May 2017)
Offset costs from digestate	H	L		
Revenue from biogas	H	M	Biogas can be converted into heat and electricity and hence an important revenue for the plant and would be able to offset the high operating costs of AD plant.	<ul style="list-style-type: none"> • Monson, K.D., Esteves, S.R., Guwy, A.J., Dinsdale, R.M., 2007. Anaerobic digestion of biodegradable municipal solid wastes: A review. Sustainable Environment Research Centre. http://www.walesadcentre.org.uk/Controls/Document/Docs/Anaerobic%20Digestion%20of%20BMW%20_compressed_%20-%20Part1.pdf (accessed 30 May 2017)
Offset cost from biogas	H	M	Alternatively, biogas can be upgraded to bio-methane after removing the pollutants such as CO ₂ , H ₂ S and NH ₃ . The revenue and offset cost from biogas has a moderate degree of uncertainty since it depends on the end use of it and also the overall capital and operating costs of the AD plant. The final selling price is governed by the grid and fuel suppliers.	

Labour costs	M	L	<p>Labour time is associated with feedstock preparation and AD plant operation.</p> <p>There is a low level of uncertainty in labour cost as this is determined by government and organisations.</p>	<ul style="list-style-type: none"> • Lukehurst, C., Bywater, A., 2015. Exploring the viability of small scale anaerobic digesters in livestock farming. IEA Bioenergy. https://www.iea-biogas.net/files/daten-redaktion/download/Technical%20Brochures/Small_Scale_RZ_web2.pdf (accessed 30 May 2017)
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Table S3: PESTEL Analysis - Social Parameters

Social parameters	Ranking relevance	Ranking uncertainty	Justification	Source documents
Household welfare improvement from behaviour change	M	H	Evidence from WRAP research shows that a reduction in household food waste results in households ‘trading up’ to higher standard food items using about half the money they save. This offers circumstantial evidence for improved diet resulting from food waste reduction. Trials of separated food waste collection in the UK by WRAP in 2009 found that only 4-8% of participants reported changing their attitudes or habits relating to food purchasing. This implies little direct impact on eating habits, but does not necessarily contradict the indirect impacts through higher purchasing power. Evidence for this impact mechanism is at best circumstantial and incomplete and therefore highly uncertain.	<ul style="list-style-type: none"> • WRAP, 2009. Evaluation of the WRAP Separate Food Waste Collection Trials. Banbury, UK. • WRAP. (2015). Strategies to achieve economic and environmental gains by reducing food waste, (February), 61. http://doi.org/978-1-84405-473-2
Distribution to poor households	M	H	Schemes to redistribute food waste to poor households, particularly waste from supermarkets to food banks, have grown in recent years (FareShare 2015). This has the potential to reduce the occurrence of malnutrition, but there is no direct empirical evidence of this, hence leaving this parameter highly uncertain.	<ul style="list-style-type: none"> • FareShare Food Efficiency Framework, 2015. FareShare Food Efficiency Framework. London, UK.
Vermin and malodour reduction	H	M	Issues of malodour and vermin are significant in the waste management sector. These are highlighted in Lehman et al. (2011) where a stakeholder consultation process to identify social impact categories to use for waste packaging management identified Odour as a subcategory to include that is not on the list compiled in the SLCA guidelines. The UK government AD strategy and action plan cites bioaerosols and odours from AD facilities as a regulatory issue requiring further investigation. Lukehurst and Al Seadi (2010) cite the reduction of odours that can be achieved by digestion prior to use as fertiliser as a positive environmental impact.	<ul style="list-style-type: none"> • Lehmann, A., Russi, D., Bala, A., Finkbeiner, M., & Fullana-i-Palmer, P. (2011). Integration of Social Aspects in Decision Support, Based on Life Cycle Thinking. <i>Sustainability</i>, 3(12), 562–577. http://doi.org/10.3390/su3040562 • DECC, Defra, 2011. Anaerobic digestion strategy and action plan, Department of Energy & Climate Change. London, UK. • Lukehurst, C. T., Frost, P., & Al Seadi, T. (2010). Utilisation of digestate from biogas plants as biofertiliser. <i>IEA Bioenergy</i>.

			The impact of malodours and vermin are widely considered as important social factors to consider in waste management assessments. Their importance is certain, but there is little empirical evidence of its impact.	
Job opportunities	H	H	<p>Employment opportunities, skilled work, and equality (both sex and disability) in employment are important impact subcategories included in SLCA guidance. Total employment opportunities are widely referenced in AD literature both government and industry; 35,000 new jobs in plant operation, as well as manufacturing, construction and delivery, is cited by DECC and Defra. WRAP reported a 36% increase in UK employment in the AD sector between 2012 and 2013. ADBA reported 4,500 jobs in the AD sector in 2015.</p> <p>Vinyes et al. report significant differences in employment opportunities and equality of access to employment between different waste management systems for used cooking oil in Spain. There is evidence that job opportunities is a highly relevant parameter for AD treatment of food waste, but little recent or specific data leaves any conclusions highly uncertain. Past reports of employment numbers take an AD industry total and do not detail employment specifically related to food waste management.</p>	<ul style="list-style-type: none"> • DECC and Defra (2011) Anaerobic Digestion Strategy and Action Plan - A commitment to increasing energy from waste through Anaerobic Digestion. • WRAP (2014) Survey of the UK Anaerobic Digestion industry in 2013, Prepared by LRS Consultancy for WRAP, Banbury, UK. Available at: http://www.wrap.org.uk/sites/files/wrap/A_survey_of_the_UK_Anaerobic_Digestion_in_industry_in_2013.pdf • Anaerobic Digestion and Biogas Association, ADBA (2015) Anaerobic Digestion Market Report. Available at: http://adbioresources.org/docs/July_2015_Market_Report.pdf • Vinyes, E., Oliver-Solà, J., Ugaya, C., Rieradevall, J., & Gasol, C. M. (2013). Application of LCSA to used cooking oil waste management. <i>The International Journal of Life Cycle Assessment</i>, 18(2), 445–455. http://doi.org/10.1007/s11367-012-0482-z
Improved working conditions for waste sector workers	H	H	<p>Trials of separated food waste collection carried out in the UK by WRAP in 2009 highlighted the benefits of collection crew having “ownership and pride” in the service. Vinyes et al. (2013) report significant differences in the level of education of workers and in equal opportunities for the disabled between different waste collection and treatment options for cooking oil waste. This parameter can therefore be considered highly relevant, but limited evidence also renders it highly uncertain.</p>	<ul style="list-style-type: none"> • WRAP. (2009). Evaluation of the WRAP Separate Food Waste Collection Trials (pp. 1–83). Banbury, UK. • Vinyes, E., Oliver-Solà, J., Ugaya, C., Rieradevall, J., & Gasol, C. M. (2013). Application of LCSA to used cooking oil waste management. <i>The International Journal of Life Cycle Assessment</i>, 18(2), 445–455. http://doi.org/10.1007/s11367-012-0482-z

Reduced transport disruption with urban AD plants	M	H	<p>Appropriately sized AD Plants can be located closer to the city centres where food waste arises, reducing the need for large vehicles through urban areas. This benefit was identified in the Reull AD Plant case study in DECC and Defra 2011.</p> <p>This parameter has a high level of uncertainty as it is supported by evidence from only a single case study. It is also likely to be highly site specific.</p>	<ul style="list-style-type: none"> DECC and Defra, 2011. Anaerobic digestion strategy and action plan, Department of Energy & Climate Change. London, UK.
Health impacts from bio-hazardous materials	M	L	<p>The health impacts from bio-hazardous materials are highly regulated due to their potentially serious public health consequences. This issue has been widely studied as part of environmental impact assessments and is therefore well understood. As a social parameter, this is therefore not of highly significant relevance as the political and environmental awareness of the issue effectively reduces its relevance in the social sphere.</p>	

Table S4: PESTEL Analysis - Technological Parameters

Technological parameters	Ranking relevance	Ranking uncertainty	Justification	Source documents
Food Packaging Design	H	L	In 2009, two anaerobic digestion plants had food waste depackaging units installed, and there were numerous food waste depackaging companies.	<ul style="list-style-type: none"> • WRAP: OFW005-001 April 2009: Review of Food Waste Depackaging Equipment http://www.wrap.org.uk/sites/files/wrap/Food%20waste%20depackaging%20equipment%20FINAL%20REPORT%20April%202009.pdf • Chen Y, Cheng JJ, Creamer KS, Inhibition of anaerobic digestion process: a review 10.1016/j.biortech.2007.01.057
Food Preservation Activities	H	L	<p>The use of biodegradable packaging would eliminate the need for these units/companies.</p> <p>Inhibitory effects such as low methane yield and low instability caused by factors including ammonia, sulphide, light metal ions, heavy metals, organics have been identified.</p> <p>These parameters have a low level of uncertainty, as the technologies are well-known.</p>	
Collection Vehicles Fuel Efficiency	M	L	<p>Fuel efficiency will be improved where AD plants are located close to the source of substrate, such as on farms.</p> <p>These parameters have a low level of uncertainty, based on the above.</p>	<ul style="list-style-type: none"> • http://clearfleau.com/lake-district-biogas-ad-plant-green-energy-from-cumbrian-cheese/
Pre-Treatment Technology Efficiency	H	M	<p>Pre-treatment methods could increase methane content in biogas. Pre-treatment techniques enhance the anaerobic digestion of organic solid waste, including mechanical, thermal, chemical and biological methods, both independently and in combination. As these parameters are still under investigation, and have many possible combinations, the level of uncertainty is moderate.</p>	<ul style="list-style-type: none"> • Javkhlan Ariunbaatar, Antonio Panico, Giovanni Esposito, Francesco Pirozzi, Piet N.L. Lens, Pretreatment methods to enhance anaerobic digestion of organic solid waste, Applied Energy, Volume 123, 15 June 2014, Pages 143-156, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2014.02.035. • Dhamodharan Kondusamy, Ajay S Kalamdhad: Pre-treatment and anaerobic digestion of food waste for high rate methane production – A review https://doi.org/10.1016/j.jece.2014.07.024

				<ul style="list-style-type: none"> • http://biogas.ifas.ufl.edu/foodwaste/documents/2009%20Soil%20and%20Water%20Science%20Department%20Forum.pdf
Pre-Treatment Technology Reliability	H	M	<p>Pre-treatment can reduce the effect of feedstock variations. Matching pre-treatment techniques to substrate characteristics remains a challenge.</p> <p>As such, these parameters have a moderate uncertainty.</p>	<ul style="list-style-type: none"> • M. Walker, H. Theaker, R. Yaman, D. Poggio, W. Nimmo, A. Bywater, G. Blanch, M. Pourkashanian, Assessment of micro-scale anaerobic digestion for management of urban organic waste: A case study in London, UK, Waste Management, Volume 61, March 2017, Pages 258-268, ISSN 0956-053X, https://doi.org/10.1016/j.wasman.2017.01.036. • The effects of substrate pre-treatment on anaerobic digestion systems: A review MyCarlsson Anders Lagerkvist, Fernando Morgan-Sagastume, https://doi.org/10.1016/j.wasman.2012.04.016
AD Technology Efficiency	H	M	<p>Maintenance contracts are usually available that would specify frequency and types of works.</p> <p>An example of a maintenance schedule for an AD plant is provided in the attached links.</p> <p>The efficiency of the process is dependent on bacteria and temperature.</p> <p>As the efficiency is dependent on a number of variables, these parameters have a moderate uncertainty.</p>	<ul style="list-style-type: none"> • Lukehurst, C., Bywater, A., 2015. Exploring the viability of small scale anaerobic digesters in livestock farming. IEA Bioenergy. https://www.iea-biogas.net/files/daten-redaktion/download/Technical%20Brochures/Small_Scale_RZ_web2.pdf (accessed 30 May 2017) • https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/526234/6_Management_and_Maintainance_Schedule_Odour_Management_Plan_and_BAT_Analysis.pdf • http://www.sswm.info/category/implementation-tools/wastewater-treatment/hardware/site-storage-and-treatments/anaerobic-di
Biogas Extraction Technology	M	M	<p>Post-treatment is an important step in AD plant which serves to stabilise the digestate so that it can be used as fertiliser or sent to landfills.</p> <p>Alkaline post-treatment has been tested to improve sludge anaerobic digestions.</p> <p>A WRAP study identifies various digestate enhancement technologies.</p> <p>These parameters have a moderate uncertainty, as the technologies are not yet well known.</p>	<ul style="list-style-type: none"> • Monson, K.D., Esteves, S.R., Guwy, A.J., Dinsdale, R.M., 2007. Anaerobic digestion of biodegradable municipal solid wastes: A review. Sustainable Environment Research Centre. http://www.walesadcentre.org.uk/Controls/Document/Docs/Anaerobic%20Digestion%20of%20BMW%20_compressed_%20-%20Part1.pdf (accessed 30 May 2017)

				<ul style="list-style-type: none"> Alkaline post-treatment for improved sludge anaerobic digestion Huan Li, Shuxin Zou, Chenchen Li, Yiyang Jin Shenzhen Environmental Microbial Application and Risk Control Key Laboratory, Graduate School at Shenzhen, Tsinghua University, Shenzhen 518055, China 10.1016/j.biortech.2013.04.093 http://www.wrap.org.uk/sites/files/wrap/Digestates%20from%20Anaerobic%20Digestion%20A%20review%20of%20enhancement%20techniques%20and%20novel%20digestate%20products_0.pdf
Digestate Post-Treatment Technology Efficiency	H	M	<p>Dewatering of digestate may be required, including improving quality of removed water so can be re-used. This can require significant energy use to achieve. This parameter has a moderate uncertainty, as post-treatment technologies are not yet well-known.</p> <p>There are many companies online offering biogas storage solutions. As such, this parameter has a low uncertainty.</p>	<ul style="list-style-type: none"> Friends of the Earth Guildford and Waverly, 2012. Anaerobic Digestion: a technical briefing for local group campaigners. http://www.gwfoe.org.uk/wp-content/uploads/2012/11/GW-Friends-of-the-Earth-AD-technical-briefing-Nov-2012.pdf (accessed 30 May 2017) Friends of the Earth Guildford and Waverly, 2012. Anaerobic Digestion: a technical briefing for local group campaigners. http://www.gwfoe.org.uk/wp-content/uploads/2012/11/GW-Friends-of-the-Earth-AD-technical-briefing-Nov-2012.pdf (accessed 30 May 2017) http://www.walesadcentre.org.uk/Controls/Document/Docs/Digestate%20Characteristics%20and%20Processing.pdf http://www.kemira.com/en/industries-applications/biogas/digestate-treatment/pages/default.aspx
Biogas Storage Technology	M	L		
Biogas Scrubbing Technology Efficiency	H	L	<p>Biogas can be upgraded to bio-methane after removing the pollutants such as CO₂, H₂S and NH₃. Cleaning and polishing discharges can be undertaken to make removed water suitable for re-use.</p>	<ul style="list-style-type: none"> Monson, K.D., Esteves, S.R., Guwy, A.J., Dinsdale, R.M., 2007. Anaerobic digestion of biodegradable municipal solid wastes: A review. Sustainable Environment Research Centre. http://www.walesadcentre.org.uk/Controls/Document/Docs/Anaerobic%20Digestion%20of%20B
CHP Engine	H	L	<p>There is a requirement for a unified approach to scrubbing, compressing and storage for wider applications.</p>	

Technologies			<p>These parameters have been widely researched and therefore have a low uncertainty.</p>	<p>MW%20_compressed_%20-%20Part1.pdf (accessed 30 May 2017)</p> <ul style="list-style-type: none"> • http://clearfleau.com/lake-district-biogas-ad-plant-green-energy-from-cumbrian-cheese/ • Biogas scrubbing, compression and storage: perspective and prospectus in Indian context, S.S.Kapdi, V.K.Vijay, S.K.Rajesh, Rajendra Prasad, https://doi.org/10.1016/j.renene.2004.09.012 • Water Scrubbing: A Better Option for Biogas Purification for Effective Storage C. <i>Ofori-Boateng and E.M. Kwofie</i> World Applied Sciences Journal 5 (Special Issue for Environment): 122-125, 2009
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Table S5: PESTEL Analysis - Environmental Parameters

Environmental parameters	Ranking relevance	Ranking uncertainty	Justification	Source documents
Global warming potential	H	L	GHG emissions either associated with the overall AD procedure and its relevant mechanisms or saved via the use of biogas	<ul style="list-style-type: none"> Bernstad A, la Cour Jansen J., 2012. Review of comparative LCAs of food waste management systems--current status and potential improvements. <i>Waste Management</i> 32(12), 2439-2455. doi: 10.1016/j.wasman.2012.07.023. Di Maria, F., Micale, C., 2015. Life cycle analysis of incineration compared to anaerobic digestion followed by composting for managing organic waste: the influence of system components for an Italian district. <i>Int J Life Cycle Assess</i> 20, 377–388. doi:10.1007/s11367-014-0833-z
Eutrophication potential	H	L	Risk of nutrients leaching to surface and groundwater	<ul style="list-style-type: none"> Evangelisti, S., Lettieri, P., Borello, D., Clift, R., 2014. Life cycle assessment of energy from waste via anaerobic digestion: A UK case study. <i>Waste Management</i> 34, 226–237. doi:10.1016/j.wasman.2013.09.013
Ozone depletion potential	H	M	Nonetheless, this is highly dependent on the assumptions made on the energy substituted by biogas	<ul style="list-style-type: none"> Fusi, A., Bacenetti, J., Fiala, M., Azapagic, A., 2016. Life Cycle Environmental Impacts of Electricity from Biogas Produced by Anaerobic Digestion. <i>Frontiers in Bioengineering and Biotechnology</i> 4, 153. doi:10.3389/fbioe.2016.00026 Lukehurst, C.T., Frost, P., Seadi, Al, T., 2010. Utilisation of digestate from biogas plants as biofertiliser. <i>IEA Bioenergy</i>. Salemdeeb, R., zu Ermgassen, E.K.H.J., Kim, M.H., Balmford, A., Al-Tabbaa, A., 2017. Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options. <i>Journal of Cleaner Production</i> 140, 871–880. doi:10.1016/j.jclepro.2016.05.049
Human toxicity potential	H	L	Highly regulative with regards to specific concentration limits of toxic metals, and of high importance especially where animal by-products are present	<ul style="list-style-type: none"> Seo, S., Aramaki, T., Hwang, Y., Hanaki, K., 2004. Environmental impact of solid waste treatment methods in Korea. <i>Journal of Environmental Engineering</i> doi: 10.1061/(ASCE)0733-9372(2004)130:1(81)
Energy depletion	H	M	Highly relevant to the yields of biogas during AD and the energy mix substituted	<ul style="list-style-type: none"> Salemdeeb, R., zu Ermgassen, E.K.H.J., Kim, M.H., Balmford, A., Al-Tabbaa, A., 2017. Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste

				management options. <i>Journal of Cleaner Production</i> 140, 871–880. doi:10.1016/j.jclepro.2016.05.049
Photochemical oxidation	M	L	Combustion of biogas in CHP units can significantly contribute to this parameter	<ul style="list-style-type: none"> • Evangelisti, S., Lettieri, P., Borello, D., Clift, R., 2014. Life cycle assessment of energy from waste via anaerobic digestion: A UK case study. <i>Waste Management</i> 34, 226–237. doi:10.1016/j.wasman.2013.09.013 • Fusi, A., Bacenetti, J., Fiala, M., Azapagic, A., 2016. Life Cycle Environmental Impacts of Electricity from Biogas Produced by Anaerobic Digestion. <i>Frontiers in Bioengineering and Biotechnology</i> 4, 153. doi:10.3389/fbioe.2016.00026
Abiotic resource depletion	M	L	Fossil fuels used for the collection and transport of food waste and construction materials constitute important factors for this parameter	<ul style="list-style-type: none"> • Salemdeeb, R., zu Ermgassen, E.K.H.J., Kim, M.H., Balmford, A., Al-Tabbaa, A., 2017. Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options. <i>Journal of Cleaner Production</i> 140, 871–880. doi:10.1016/j.jclepro.2016.05.049
Terrestrial ecotoxicity	M	M	CHP efficiency would have to be below 25% for terrestrial ecotoxicity to be lower than the fossil fuel alternative	<ul style="list-style-type: none"> • Whiting, A., Azapagic, A., 2014. Life cycle environmental impacts of generating electricity and heat from biogas produced by anaerobic digestion. <i>Energy</i> 70, 181–193. doi:10.1016/j.energy.2014.03.103
Acidification potential	L	M	NO _x emissions, reported only from CHP plants, have been found to contribute only to a minor degree	<ul style="list-style-type: none"> • Evangelisti, S., Lettieri, P., Borello, D., Clift, R., 2014. Life cycle assessment of energy from waste via anaerobic digestion: A UK case study. <i>Waste Management</i> 34, 226–237. doi:10.1016/j.wasman.2013.09.013
Aquatic ecotoxicity	L	M	Emissions of pesticides used for maize cultivation and some metals (nickel, beryllium, cobalt, and vanadium)	<ul style="list-style-type: none"> • Fusi, A., Bacenetti, J., Fiala, M., Azapagic, A., 2016. Life Cycle Environmental Impacts of Electricity from Biogas Produced by Anaerobic Digestion. <i>Frontiers in Bioengineering and Biotechnology</i> 4, 153. doi:10.3389/fbioe.2016.00026

Table S6: PESTEL Analysis - Legal Parameters

Legal parameters	Ranking relevance	Ranking uncertainty	Justification	Source documents
<p>Waste management legislations</p>	<p>H</p>	<p>M</p>	<p>This parameter is highly significant for the success or failure of any A.D. project, it incorporates all statutory and other legislation which apply to the A.D. system</p> <p>If any relevant legislation is not complied with them the project will be subject to prosecution resulting in fines and possible closure of the operation</p> <p>The waste framework directive (WFD) which has been incorporated into UK domestic legislation and has been designed to address issues including waste minimisation and reducing waste to landfill all of which is of benefit to technologies such as A.D. This piece of legislation specifically Article 4 of the WFD framework ranks the 5 steps for dealing with waste according to their environmental impact and is known as the “waste hierarchy”</p> <p>This legislation has led to policy initiatives (see policy)</p> <p>A.D is a Permitted Activity and there are legal requirements which must be complied with</p> <p>The Industrial Emissions Directive (IED) legislation must be complied with and is of relevance to Environmental Permitting for AD plants with exceeding a capacity threshold of 100 tonnes per day.</p> <p>It is a requirement that the waste hierarchy referred to in Article 4 of the Waste Framework Directive is applied to the (a) generation of waste by the activities; and (b) any waste generated by the activities is treated in accordance with the waste hierarchy referred to in Article 4 of the Waste Framework Directive; (c) where disposal is necessary, this is undertaken in a manner which minimises its impact on the environment.</p> <p>https://www.gov.uk/guidance/waste-legislation-and-regulations</p> <p>The level of uncertainty associated with legal parameters and requirements is dependent upon other factors within the PESTEL analysis and relies upon the political climate of the time.</p>	<ul style="list-style-type: none"> • Castiglione, C., Infante, D. & Smirnova, J. 2015. Environment and Economic Growth: Is The Rule Of Law The Go-Between? The Case of High-Income Countries. <i>Energy, Sustainability and Society</i>, 5. • Cecere, G. & Corrocher, N. 2016. Stringency of Regulation And Innovation In Waste Management: An Empirical Analysis On Eu Countries. <i>Industry and Innovation</i>, 1-22. • Droste, N., Hansjürgens, B., Kuikman, P., Otter, N., Antikainen, R., Leskinen, P., Pitkänen, K., Saikku, L., Loiseau, E. & Thomsen, M. 2016. Steering Innovations Towards a Green Economy: Understanding Government Intervention. <i>Journal of Cleaner Production</i>, 135, 426-434. • Koch, N., Grosjean, G., Fuss, S. & Edenhofer, O. 2016. Politics Matters: Regulatory Events as Catalysts For Price Formation Under Cap-And-Trade. <i>Journal of Environmental Economics and Management</i>, 78, 121-139. • Ramanathan, R., He, Q., Black, A., Ghobadian, A. & Gallea, D. 2017. Environmental Regulations, Innovation and Firm Performance: A Revisit Of The Porter Hypothesis. <i>Journal of Cleaner Production</i>, 155, 79-92. • Ribeiro, F. D. M. & Kruglianskas, I. 2015. Principles of Environmental Regulatory Quality: A Synthesis from Literature Review. <i>Journal of Cleaner Production</i>, 96, 58-76. • Vardon, M., Burnett, P. & Dovers, S. 2016. The Accounting Push and The Policy Pull: Balancing

			<p>The legislation has a high impact on the way in which A.D. operate therefore it is highly relevant and the uncertainty associated with its ranking is dependent upon the stability policy initiatives. This is dependent upon government strategy and the relative importance that they placed upon any given policy initiative and its perceived effectiveness</p> <p>Companies have identified the need for a stable legislative environment for them to make substantial investments in environmental technologies.</p>	<p>Environment and Economic Decisions. <i>Ecological Economics</i>, 124, 145-152.</p> <ul style="list-style-type: none"> • Wilts, H., Von Gries, N. & Bahn-Walkowiak, B. 2016. From Waste Management to Resource Efficiency-The Need For Policy Mixes. <i>Sustainability (Switzerland)</i>, 8, 1-16. • Defra 2015. Uk Response To European Commission Consultation Of Member States On The Circular Economy. <i>In: Department For Environment, F. A. R. A. D. (Ed.) Waste And Recycling</i>. London Uk: Uk Government. • Department For Environment Food & Rural Affairs, D. 2011. Environmental Permitting Guidance: Integrated Pollution Prevention And Control (Ippc) Directive, Part A(1) Installations And Part A(1) Mobile Plant [Online]. Ukgov. Available: https://www.gov.uk/government/publications/environmental-permitting-guidance-integrated-pollution-prevention-and-control-ippc-directive-part-a-1-installations-and-part-a-1-mobile-plant [Accessed June 2016 2016]. • Department For Environment Food & Rural Affairs, D. 2014. <i>Waste Legislation and Regulations</i> [Online]. Uk Government. Available: https://www.gov.uk/guidance/waste-legislation-and-regulations [Accessed 7th October 2016 2016]. • Environment Agency, 2016. <i>Standard Rules: Environmental Permitting</i> [Online]. Uk Government. Available: https://www.gov.uk/government/collections/standard-rules-environmental-permitting [Accessed June 2016 2016].
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End-of-Waste criteria (including Quality Protocols)	H	L	<p>Non-compliance with the end of waste criteria and protocols will limit the potential uses of the A.D. digestion produced reducing access to potential markets for this product.</p> <p>This is an ongoing government policy making it reasonably stable so has low uncertainty</p>	<ul style="list-style-type: none"> • Environment Agency and Wrap (Waste & Resources Action Programme) Quality Protocol. Anaerobic Digestate. End Of Waste Criteria For The Production And Use Of Quality Outputs From Anaerobic Digestion Of Source-Segregated Biodegradable Waste. • Kosseva, M. R. 2009. Processing Of Food Wastes. <i>Advances In Food And Nutrition Research</i>. • Department For Environment Food And Rural Affairs, D. 2015. Anaerobic Digestion Strategy And Action Plan: Annual Report 2014.
Renewable Heat Incentive	H	M	<p>Food waste meets the criteria for the renewable heat incentive thus making it highly significant.</p> <p>There is potential for competition from the combined heat and power electricity generation plants for this as a feedstock.</p> <p>The element of potential competition for the feedstock makes this category more uncertain</p> <p>Potential for change in the level and availability of R H I could contribute to the uncertainty in this category</p>	<ul style="list-style-type: none"> • Pelkmans, L., Guisson, Ruben., Elbersen, Berien., Panoutsou, Calliope. 2016. Swot Analysis of Biomass Value Chains. Strategic Initiative for Resource Efficient Biomass Policies. European Union • Fuelling And Sustainability Team Renewable Electricity, 2016. Renewables Obligation: Sustainability Criteria.
Feed-in Tariffs	H	H	<p>The feed in tariff is highly relevant for A.D. because these are associated with smaller scale electricity generation and has a significant impact on the viability of this type of technology.</p> <p>Feed in tariffs affect the economic viability of the electricity generated from this source and are subject to change thus there is a large degree of uncertainty associated with this source of revenue.</p>	<ul style="list-style-type: none"> • Fuelling and Sustainability Team Renewable Electricity 2016. Renewables Obligation: Sustainability Criteria. • OFGEM. 2017a. Environmental Programmes [Online]. Ofgem. Available: https://www.ofgem.gov.uk/environmental-programmes [Accessed 7th Januray 2017 2017]. • OFGEM. 2017b. Feed-In Tariff (FIT) rates [Online]. Available: https://www.ofgem.gov.uk/environmental-programmes/fit/fit-tariff-rates [Accessed 7th January 2017 2017].
Renewable Obligation Certification	H	H	<p>The ROC scheme will close to all new generating capacity on 31 March 2017 in the UK.</p> <p>This has a high degree of relevance due to the economic importance of complying with the legal requirement.</p>	<ul style="list-style-type: none"> • Fuelling and Sustainability Team Renewable Electricity 2016. Renewables Obligation: Sustainability Criteria. • OFGEM. 2017c. Renewable Energy Guarantees Origin (REGO) [Online]. Available:

Renewable Energy Guarantees Origin (REGO)			There is a high level of uncertainty associated with the continuation of the scheme and what types of renewables will be eligible	<p>https://www.ofgem.gov.uk/environmental-programmes/rego [Accessed 7th January 2017 2017].</p> <ul style="list-style-type: none"> • OFGEM. 2017d. Renewables Obligation (RO) [Online]. Available: https://www.ofgem.gov.uk/environmental-programmes/ro [Accessed 6th January 2017 2017].
Environmental Permitting Regulation	H	L	AD plants are subject to environmental permitting regulations that are set out in legislation. This is highly relevant to the viability of AD plant development, but of low uncertainty.	<ul style="list-style-type: none"> • Environment Agency 2015. Waste classification technical guidance.