Final report

Assessing the Costs and Benefits for Production and Beneficial Application of Anaerobic Digestate to Agricultural Land in Wales

This report is the result of a project using Cost-benefit Analysis techniques to determine the least cost option for management of digestate from anaerobic digestion (AD) of food waste, both in terms of financial and environmental costs.

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Front cover photography: Applying digestate with trailing hose equipment

Executive summary

Eunomia Research & Consulting Ltd ('Eunomia') in partnership with sub-contractor, Aqua Enviro Ltd ('Aqua Enviro'), is pleased to present this study undertaken on behalf of the Waste and Resources Action Programme (WRAP) Cymru.

The Welsh Government is currently providing significant financial support to new food waste treatment infrastructure via a network of anaerobic digestion (AD) hubs, which involve the majority of local authorities across Wales. The issue of digestate management is therefore of huge importance as this network of new facilities comes into operation in the coming months and years. The vast majority of existing and planned food waste AD facilities in Wales (and the wider UK) currently produce a 'whole' low dry solids digestate, which is subsequently applied to land. The application of whole digestate to land, however, is *perceived* by some within the waste industry to not only result in high transport costs but also to result in significant storage capacity (and related operating costs) being required if the necessary landbank is not available on a regular basis throughout the year. WRAP is keen to consider, therefore, whether de-watering of digestate, i.e. producing separate liquid and solid fractions for onward management where only the solid fraction is intended for application to land, might be able to offer a lower cost solution via reduction in transport and storage requirements. At the same time, however, WRAP is keen to consider the environmental impacts of dewatering, compared with the application of whole digestate to land.

The primary aim of this project, therefore, is to determine the *least cost* option for management of digestate from anaerobic digestion (AD) of food waste, both in terms of financial and environmental costs. Our approach to considering the impacts of different digestate management scenarios is set within a framework of Cost-benefit Analysis (CBA), with the monetisation of environmental impacts via the application of 'damage costs' to life-cycle assessment (LCA) data. The CBA model developed for this study combines 'mass flow' data with unit cost factors to calculate the environmental and financial costs for each scenario. The results are expressed by a common metric; 'per tonne of feedstock arriving at the plant before digestion'.

The dewaterability of food waste digestate is not well characterised with only a very small number of commercial sites in the United Kingdom (UK) currently carrying out any kind of dewatering. In some instances this has led to issues of liquor treatment plants failing to achieve the required level of performance and much of the data surrounding digestate dewaterability is therefore deemed by operators to be *highly commercially sensitive*. As a result, we have needed to draw on a wide variety of data and methods for accessing this data including different forms of both primary and secondary research. Even with this approach it has been necessary to eliminate some options where quantitative data was not of sufficient quality to develop a meaningful 'per tonne' cost. This has led to the selection of a single dewatering technology (centrifugation) for the purposes of modelling cost scenarios. Not only is there a stronger evidence base relating to centrifugation, it is the only technology which is being widely used in the commercial environment.

Liquor purification by membrane treatment is not considered within our scenario modelling, but we recognise that this is a potential area for future research and development for sites that wish to consider closed-loop recycling and water reuse. Furthermore, whilst composting of digestate has been excluded from these scenarios due to a lack of both robust financial and environmental data, we feel that the potential benefits of this option merit further, more detailed analysis, in a separate study.

The technologies and digestate management processes selected for inclusion in our scenario modelling can be summarised as follows:

- Centrifugation - in this process, liquid and solid phases of the conditioned whole digestate are separated by rotation at high speeds which creates centrifugal force in a horizontal, cylindrical bowl equipped with a screw conveyor;
- Biological oxidation – this process converts ammonium-nitrogen into nitrate by the process of nitrification and, if required, nitrate can be removed from the liquor through denitrification. The treated liquor can, under licence, then be discharged to watercourse or sewer, with a proportion potentially returned to the feedstock to act as dilution water;
- Nutrient recovery - soluble forms of ammonia and phosphorus can be partially precipitated from the liquor by the addition of magnesium chloride and sodium hydroxide to produce struvite or crystalline nutrient rich pellets ('prills'). Struvite can be transported relatively easily and used either directly as a fertiliser or as a base feedstock for fertiliser production;
- Disposal to sewer - liquor from the dewatering process may be discharged to sewer where permitted by the receiving water authority (Dwr Cymru), which will issue a trade effluent discharge consent following a successful application. A proportion might also be potentially returned to the feedstock to act as dilution water;
- Disposal to watercourse - the appropriately treated liquor can, under licence, be discharged to watercourse, with a proportion potentially returned to the feedstock to act as dilution water;
- Land application – the application of the fibre fraction or whole digestate directly to agricultural or grasslands as a soil improver and/or substitute fertiliser.

We then used these technologies and management processes to form overall digestate dewatering and onward management scenarios towards achievement of the following objectives:

- Maximising the dry solid content of the fibre fraction (via dewatering);
- Recovering nutrients as a separate fraction; and
- Preparing the liquor for safe disposal.

On the basis these objectives, and a range of other considerations, including commercial status, cost, data availability and recommended guidelines within PAS110, a total of eight digestate management scenarios (including the Baseline) were included within our cost-benefit analysis CBA model, as summarised in Table 1.

Table 1 List of Scenarios included within the CBA Model

Scenario	**Description**
Baseline	Whole digestate is applied directly to agricultural land
1	Dewatering of the digestate using centrifugation
	The liquor is put through a nutrient recovery (ammonia stripping, struvite precipitation) process, with the output phosphorus used as fertiliser. The residual liquor is then subjected to biological oxidation using SBR, before being discharged to sewer
	The fibre is applied directly to land
2	Dewatering of the digestate using centrifugation
	The liquor is put through a nutrient recovery (ammonia stripping, struvite precipitation) process, with the output phosphorus used as fertiliser. The residual liquor is then subjected to biological oxidation using SBR, before being discharged to watercourse
	The fibre is applied directly to land
3	Dewatering of the digestate using centrifugation
	The liquor is put through a nutrient recovery (ammonia stripping, struvite precipitation) process, with the output phosphorus used as fertiliser. The residual liquor is then discharged to sewer
	The fibre is applied directly to land
4	Dewatering of the digestate using centrifugation.
	The liquor is subjected to biological oxidation using SBR, before being discharged to sewer
	The fibre is applied directly to land
5	Dewatering of the digestate using centrifugation
	The liquor is subjected to biological oxidation using SBR, before being discharged to watercourse
	The fibre is applied directly to land
6	Dewatering of the digestate using centrifugation
	The liquor is discharged directly to sewer
	The fibre is applied directly to land
7	Dewatering of the digestate using centrifugation
	The liquor applied directly to land as a separate fraction to the fibre
	The fibre is applied directly to land as a separate fraction to the liquor

The level of dilution of the feedstock to the digester has a significant impact on the performance of different digestate management scenarios. The data-points which we have been able to access for AD plant treating food waste in the UK suggest these usually operate at a range of between 10% and 20% dry solids content. As this is such a critical assumption for this study, we have modelled two 'Central Cases', both of which start with food waste at 25.95% dry solids, and both of which assume the same starting volume of food waste. In Central Case 1, it is assumed that this is diluted to 20% dry solids. In Central Case 2, it is assumed that this is diluted to 10% dry solids.

Based on the information presented in Figure 1and Figure 2, the key findings from the study can be summarised as follows:

- Under Central Case 1 (dilution to 20% dry solids), as presented in Figure 1, at a net cost of £8.76 per tonne of feedstock, the Baseline scenario (direct application of the whole digestate to land) offers the solution with lowest net financial and environmental cost. Although transport costs are significantly higher than for other scenarios, the lack of requirement for additional processing and the assumed potential for the material to function as a substitute for the use of synthetic fertilisers, result in far lower costs than all other scenarios;

- Under our Central Case 2 (dilution to 10% dry solids) as presented in Figure 2, however, at a net cost of £13.18 per tonne of feedstock, Scenario 5 (in which liquor undergoes biological oxidation prior to being discharged to watercourse) offers the solution with lowest net financial and environmental cost. At this level of dry solids content, the high transport and spreading costs associated with the Baseline scenario are such that it performs below all dewatering scenarios aside from Scenario 7, in which both fibre and liquor are separately applied directly to land;
- Our analysis therefore demonstrates that the attractiveness of digestate dewatering to plant developers and operators is highly dependent upon the level of dilution of the feedstock to the digester. This suggests that at plant design stage, any decision relating to dewatering of digestate cannot be taken in isolation from consideration of upstream costs relating to mixing and removal of contaminants and retention time within the digester, all which also depend on the level of dilution;
- Under both Central Cases, the bulk of the costs are financial, with a relatively small impact from environmental damage costs or benefits. For this reason, we have undertaken sensitivity analysis on the value of damage costs, using damage cost data developed for the EEA, which uses higher values than under our Central Cases.[1] Whilst the performance of the Baseline scenario improves relatively better than when our central damage cost assumptions are used, under both Central Cases, the effective ranking of scenarios does not change.

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[1] *European Environment Agency (2011) Revealing the Costs of Air Pollution from Industrial Facilities in Europe, EEA Technical Report No 15/2011*

Figure 1 Summary of Results (Central Case 1 – dilution of food waste to 20% Dry Solids) – Net Costs

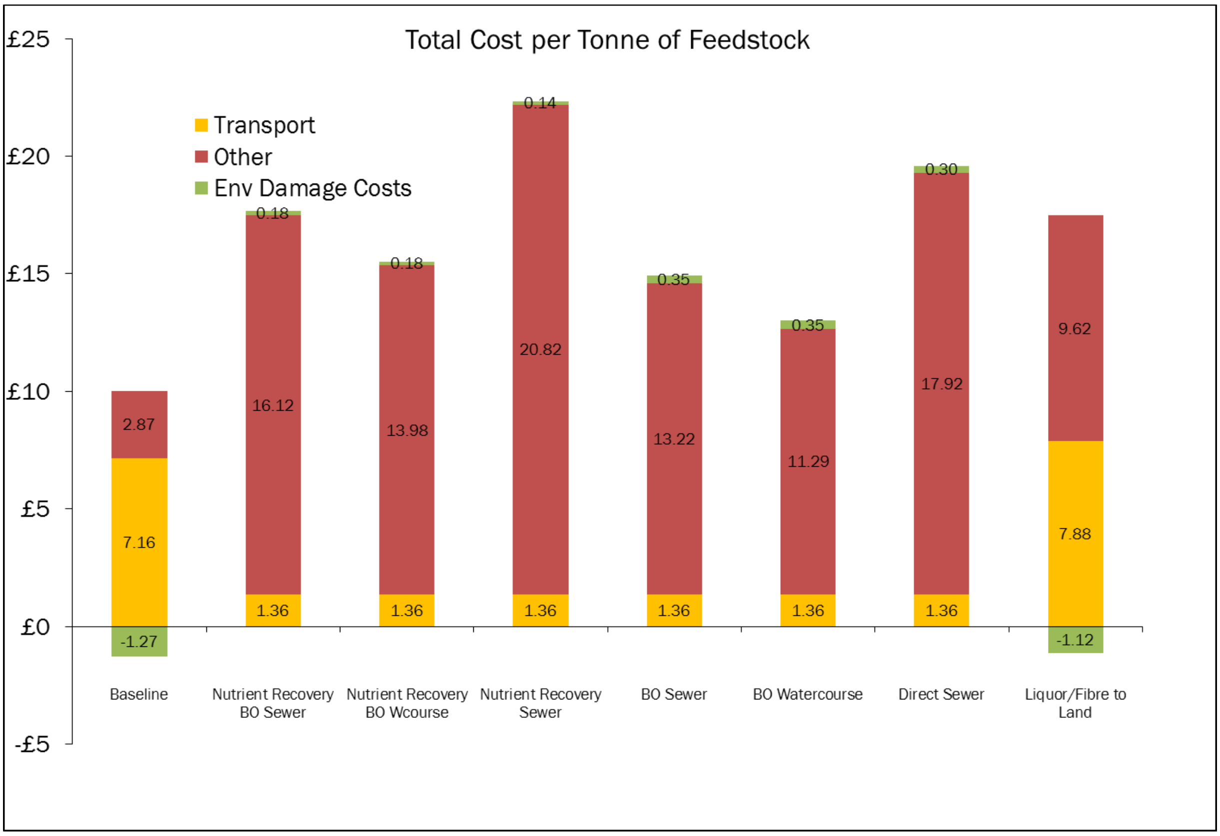
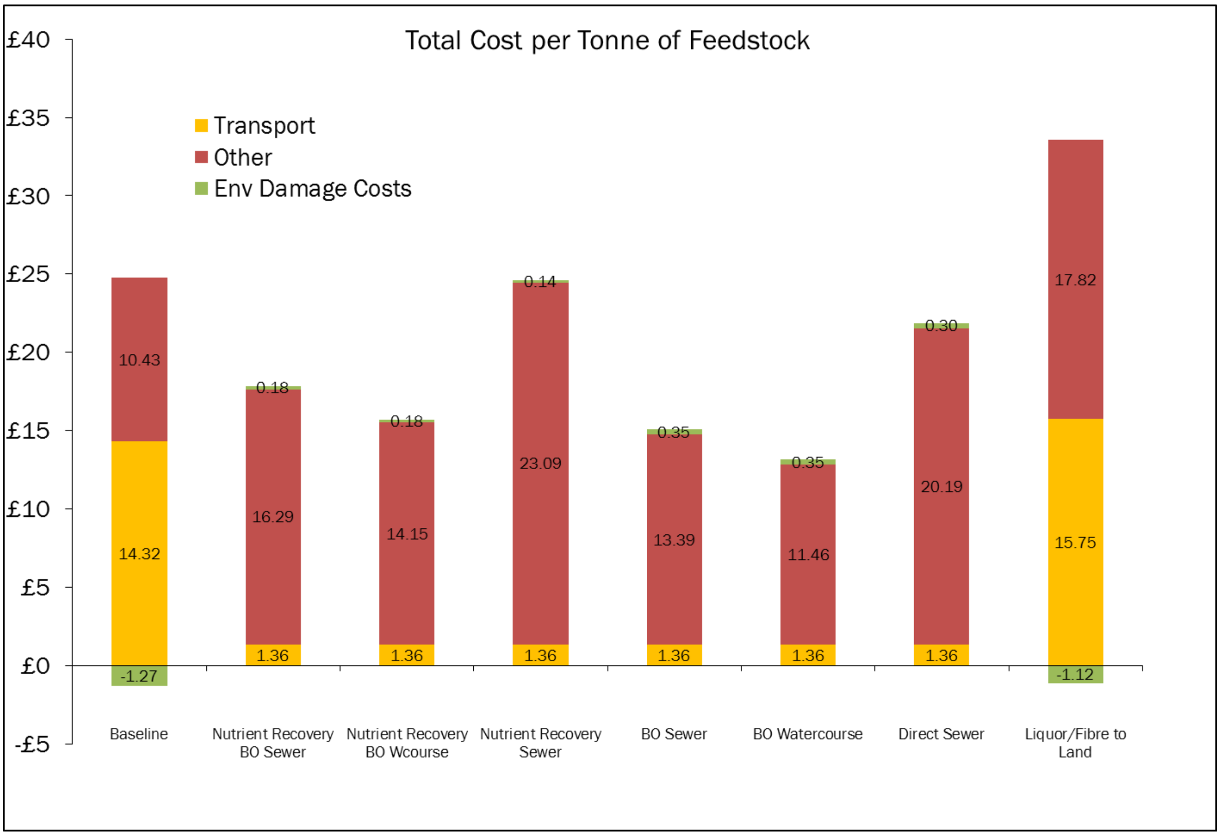


Figure 2 Summary of Results (Central Case 2 – dilution of food waste to 10% Dry Solids) - Net Costs



We have undertaken further sensitivity analysis on three other key variables, the outcomes from which can be summarised as follows:

- The impact on the results of either increasing plant size from under both Central Cases of 25 ktpa to 50 ktpa or decreasing it to 10 ktpa is not significant. The effect of doubling plant capacity is such that, under Central Case 1, the dewatering scenarios are slightly closer to, albeit still outperformed by, the Baseline scenario. Unsurprisingly, reducing plant capacity to 10 ktpa has the opposite effect, but it is important to note that neither extremes change the relative performance of the scenarios under both Central Cases;
- The transport distance required to move digestate (either whole, fibre or liquor) to the land available has a significant bearing on costs. The round-trip distance under both Central Cases is 80km, but we have tested the sensitivity of the results to increasing this distance of 280km.[2] This longer distance has a significant impact on net costs, such that under Central Case 1, five of the six dewatering scenarios, which also involve some form of liquor treatment, become preferable to the Baseline. This increases to all six such scenarios outperforming the Baseline under Central Case 2;
- The impact of raising the assumed weighted average cost of capital (WACC) to 10% or reducing this to 7% (from 8.5% under our central assumptions) is fairly minimal. These changes result in net cost variation of just £1-2 across the different scenarios and do not result in a change in relative performance under either sensitivity run;
- The impact of reducing or raising 'spreading costs' (i.e. the amount paid to a farmer or landowner to take the material for land application) has a significant impact on the performance of the different scenarios. Under both Central Cases, increasing the cost of spreading from £5 to £7.50 per tonne (net) is such that the performance of the Baseline scenario was worse relative to the other scenarios. Conversely, when spreading costs are reduced to £2.50 per tonne (net) the Baseline's relative performance improves relative to all other scenarios. Ultimately, however, these levels of change in spreading costs do not significantly alter the ranking of the different scenarios.

Our analysis shows that the proposed methodology to determine how management of digestate contributes to local authority recycling targets, on which the Welsh Government is currently consulting, hugely favours solutions that involve the high capture of Nitrogen and high dry solids content.[3] Ultimately, only the Baseline Scenario and Scenario 7 (in which both liquor and fibre are applied directly to land after dewatering) are able to offer a high performance under the proposed methodology; and
It is clear that this methodology proposed by Welsh Government will function as a huge disincentive to dewatering scenarios that do not result in direct application of the separated liquor to land. This might seem appropriate in terms of direct land application being potentially the best option from a LCA (or 'environmental') perspective, which is borne out in one part of the results from this study.[4] Our scenario modelling, however, shows that when the dry solids content of the feedstock to the digester is reduced to 10% (as under Central Case 2), when considered within the framework of CBA, other dewatering and digestate management scenarios appear to be preferable.

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[2] *This reflects the worst case scenario from a previous preferred bidder for one the Welsh Food Waste Hubs*

[3] *Welsh Government (2012) Consultation Document – Draft Guidance in support of The Recycling, Preparation for Re-use and Composting Targets (Definitions) (Wales) Order 2011, Regulations 4 and 5 of The Recycling, Preparation for Re-use and Composting Targets (Monitoring and Penalties) (Wales) Regulations 2011 Made under the Waste (Wales) Measure 2010 and Consultation on issues affecting de-watering, apportionment of recycling rates from anaerobic digestion, composting and the recycling of incinerator bottom ash (IBA), 2012*

[4] *For reasons set out in Section 2.4.5 , it should be noted, however, that the impact of emissions to air from transport has been excluded from the analysis of environmental impacts. Should this impact have been included, the environmental impacts from the management of whole digestate would have been higher than has been presented*

Contents

Glossary

Term	Description
ABPR	Animal By-Products Regulation
AD	Anaerobic Digestion
ADQP	Anaerobic Digestate Quality Protocol
AMTREAT	System to remove ammonium and total nitrogen before sending waste water to the watercourse
BAT	Best Available Technique
BO	Biological oxidation
BOD	Biochemical oxygen demand
BTA	Patented method for the pretreatment of biowastes using hydro-mechanical pulping
Capex	Capital expenditure
CBA	Cost Benefit Analysis
CCC	Committee on Climate Change
CHP	Combined heat and power
DECC	Department of Energy and Climate Change
DEMON	Treatment system for recovering nitrogen from waste water (Grontmij)
DWR Cymru	Company providing water and sewage services to most of Wales
EEA	European Environment Agency
ETS	EU Emissions Trading System
EUAs	EU Emissions Allowances
GHG	Greenhouse Gas
Ktpa	Kilotonnes per annum
LCA	Life Cycle Assessment
MAC	Marginal abatement cost
methanogenic	Methane-producing (via bacteria)
Mogden	Formula for calculating the charges for trade effluent
MSW	Municipal solid waste
NOx	Nitrous oxide

Term	Description
NuReSys	Company specialising in the recovery of phosphate and nitrogen
Opex	Operational expenditure
PAS110	Publicly Available Specification (110 - Anaerobic Digestate)
Pearl	A proprietary nutrient recovery process
PM	Particulate matter
SBR	Sequencing batch reactor
SHARON	Treatment system for recovering nitrogen from waste water (Grontmij)
SOx	Sulphur oxide
Struvite	Magnesium ammonium phosphate
VFAs	Volatile fatty acids
WACC	Weighted average cost of capital
WwTW	Wastewater treatment works

1.0 Introduction, Scope and Objectives

Eunomia Research & Consulting Ltd ('Eunomia') in partnership with sub-contractor, Aqua Enviro Ltd ('Aqua Enviro'), is pleased to present this study undertaken on behalf of the Waste and Resources Action Programme (WRAP) Cymru.

The Welsh Government is currently providing significant financial support to new food waste treatment infrastructure via a network of anaerobic digestion (AD) hubs, which involve the majority of local authorities across Wales. The issue of digestate management is therefore of huge importance as this network of new facilities comes into operation in the coming months and years. Further information on these AD hubs is provided in Section 1.2.

The vast majority of existing and planned food waste AD facilities in Wales (and the wider UK) currently produce a 'whole' low dry solids digestate, which is subsequently applied to land. The application of whole digestate to land, however, is *perceived* by some within the waste industry to not only result in high transport costs, but the need for significant storage capacity (and related operating costs) is required if the necessary landbank is not available on a regular basis throughout the year. WRAP is therefore keen to consider whether de-watering of digestate, - that is, producing separate liquid and solid fractions for onward management where only the solid fraction is intended for application to land – might be able to offer a lower cost solution via reduction in transport and storage requirements. At the same time, however, WRAP is keen to consider the environmental impacts of dewatering, compared with the application of whole digestate to land.

The primary aim of this project, therefore, is to determine the *least cost* option for management of digestate from anaerobic digestion (AD) of food waste, both in terms of financial costs and 'monetised' environmental damage costs.

As discussed in more detail in Section 1.1, the Welsh Government is currently consulting on criteria relating to how different options for management of digestate will contribute to local authority recycling performance. This study, therefore, comes at a critical time, and may function as an enabler to future policy decisions on food waste digestate management in Wales.

Numerous options are currently available for post-digestion treatment of whole digestates. The most widely-applied option is dewatering, during which a proportion of the dry solids in the digestate is separated from the liquor. A range of further options are then available to treat or market the separated fractions. Given the aspirations of Welsh Government that nutrients in digestate should be (beneficially) applied to agricultural land, consideration of the *wider* impacts that may result from dewatering is essential. These include potential implications of sending liquor to sewers or watercourses near to the operating AD plant. This will help to avoid a situation whereby the pursuit of financial and environmental benefits in one sector (recycling of food waste) leads to larger overall costs in another sector, namely wastewater treatment.

Dewatering of sewage sludge digestate (more commonly known as biosolids) is an established practice with many decades of operational experience for a range of technologies. Dewatering of farm yard manures is also relatively well understood with technologies such as screw presses being employed to generate a dewatered fibre fraction. The dewatering of digestate from food waste AD facilities, however, varies greatly from that of sewage sludge or farm manures, with many factors such as the feedstock type and digestate stability affecting the dewatering properties.

The AD Quality Protocol (ADQP) defines the 'end-of–waste' criterion for digestate, which if achieved, permits the end user to accept this material without the need for an environmental permit or exemption from environmental permitting. It also places restrictions and controls on the source of feedstocks and describes acceptable end-product outlets. Compliance with Publicly Available Specification 110 (PAS110) meanwhile, provides a guarantee of the end-product digestate quality and is intended to provide confidence for the end user. It provides a number of defined and quantitative criterion with which a digestate must comply in order to allow it to be marketed as a quality assured product. At the time of writing, the ADQP and PAS110 are intimately linked - it not being possible to certify digestate as ADQP compliant without it also being PAS110 compliant. Our approach to modelling the costs and impacts of digestate management scenarios takes into consideration both of these 'standards', as described in more detail in Section 2.1.

In line with the Welsh Government's goals for recycling of nutrients to agricultural land, the focus of the study is upon options for application of digestate to agricultural land only. Where relevant, however, we provide commentary on other related markets such as horticulture or land remediation projects, although it should be acknowledged that full consideration of such markets is outside the scope of this study. Furthermore, the ADQP restricts the use of 'end of waste' digestates to a small number of markets – and, amongst other controls, specifically excludes the use of whole digestates for land restoration, and separated fibre digestates for domestic horticulture.

As described in Section 2.4, our approach to considering the impacts of different digestate management scenarios is set within a framework of Cost-benefit Analysis (CBA), with the monetisation of environmental impacts via the application of 'damage costs' to life-cycle assessment (LCA) data. This is an approach Eunomia has used widely in a range of studies on behalf of public sector bodies across the United Kingdom (UK) and beyond.[5] It is an approach recognised by Government, which for valuation of carbon dioxide (CO_2) impacts draws upon information published by the Department of Energy and Climate Change and HM Treasury.[6]

It is important to acknowledge that the focus of the CBA is upon the management of digestate only. Whilst the implementation of some technologies 'at the back end' of the AD facility may affect costs further upstream in the process, for example, how the digester itself is operated, consideration of such additional costs is outside the scope of the model developed for this study. Where such wider costs may be either significantly reduced or increased, however, we have provided relevant commentary, which may be helpful for those considering installation of dewatering technologies.

It is also important to note that whilst the goal of our analysis is to present the most accurate picture of cost data possible, it is the *comparative analysis* of scenarios which is important, rather than the *absolute* values. In this context, it should be noted that any costs that arise for the baseline and which can be equally applied to all of the other options, have not been considered. It is therefore very likely that costs from actual projects, particularly those for management of whole digestate, might vary from those presented in this study.

Whilst whole digestate can be characterised in terms of the dry and volatile solids content reasonably well (see Appendix 2), estimating the likely dry solids content of digestate for a

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[5] *For example, see WRAP (2011) Kerbside Collections Options: Wales, Eunomia on behalf of WRAP, January 2011*

[6] *DECC and HM Treasury (2012) Valuation of Energy Use and Greenhouse Gas Emissions for Appraisal and Evaluation, October 2012*

specific plant is challenging. Whilst an AD facility handling predominantly source separated local authority food waste will have common properties, the nature of the resultant digestate will be influenced by the configuration and operation of the plant. Thus two sites treating similar feedstocks, but operating under different process conditions such as organic loading rate and hydraulic retention time will produce whole digestates that behave very differently when dewatered to produce fibre and liquor fractions (see Appendix 1). Due to this variable nature of whole digestate, the evaluation of the approaches to dewatering technologies, and assessment of the most appropriate technologies to manage the liquor and fibre fractions would, in reality, be best undertaken once a facility is fully commissioned. In most cases, however, retrofit of dewatering technologies is considered unlikely, and therefore this study provides important information for developers of AD infrastructure.

1.1 Welsh Nutrient Guidance

In January 2012 the Welsh Government published draft guidance on a number of policies relating to the waste hierarchy.[7] This includes a statement that any PAS110–compliant digestate minus any contaminants should be considered as 'recycled'. Any requirement as to the final destination of the digestate, however, does not form part of the definition.

The guidance also includes a Consultation Document that proposes a recycling calculation for digestate that has been dewatered. In this case the destination *has* been defined: the output must be used for agriculture, hydroponics, or algal culture. Furthermore, the calculation is based on two properties of the output material; dry solids content, and total Nitrogen (N) content, assuming these are applied beneficially to agricultural land.

The recovery rate for dry solids and Nitrogen is calculated based on the proportion of each remaining in the fibre and liquor fractions after dewatering, with the lower rate being counted as the final recycling rate. For example:

1. One tonne of whole digestate has 10kg Nitrogen. After dewatering, 1kg of the Nitrogen is retained in the fibre, which is considered recycled (applied to land), whilst the Nitrogen in the liquor fraction (9kg) is not considered recycled (disposed to sewer). The recycling rate can therefore be calculated as (1kg + 0kg) / 10kg * 100 = 10%;
2. The same tonne of whole digestate has 250kg of dry solids. After dewatering, the liquor has 10kg dry solids, and the fibre has 220kg dry solids. As stated above, the fibre is applied to land, whilst the liquor is disposed to sewer. The recycling rate can therefore be calculated as (220kg + 0kg) / 250kg * 100 = 88%; and
3. The Consultation document states that the lesser of the two rates should be used, and thus the recycling rate of this example facility would be 10%.

Adopting this methodology, in Section 4.3 we have modelled the recycling rates which relate to the different scenarios included within the scope of the study.

1.2 Existing AD Facilities and Food Waste Hubs in Wales

At the time of writing there were only two food waste digestion facilities operating in Wales, neither which currently dewater their digestate.

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[7] *Welsh Government (2012) Consultation Document – Draft Guidance in support of The Recycling, Preparation for Re-use and Composting Targets (Definitions) (Wales) Order 2011, Regulations 4 and 5 of The Recycling, Preparation for Re-use and Composting Targets (Monitoring and Penalties) (Wales) Regulations 2011 Made under the Waste (Wales) Measure 2010 and Consultation on issues affecting de-watering, apportionment of recycling rates from anaerobic digestion, composting and the recycling of incinerator bottom ash (IBA)*

As mentioned above, the food waste ‘hub’ projects (and proposed projects) are likely to bring about significant new AD capacity in Wales. The existing and proposed facilities are summarised, along with their related procurement and development status, in Table 1-1. The nature of these facilities forms the basis of determining what we regard as a ‘typical’ AD plant within our CBA model, as discussed further in Section 2.12.1.

It is important to note that at present, none of the projects has been designed (primarily) to dewater digestate prior to land application. As explored in detail in Section 1.1 and in 4.2.5, this is possibly due to the implications of the current draft of the aforementioned guidance from Welsh Government within the wider consultation.[8] In this context, however, it should be noted that each of the final or proposed food waste treatment contracts between the relevant Local Authority and the contractor permit either party to propose changes to service delivery which could include retrofit of dewatering equipment, should this be demonstrated to provide better value for money and/or enhanced environmental or other benefits.[9]

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[8] *Ibid.*

[9] *Personal communication, Hazel Nickless, Local Partnerships (procurement advisor to Welsh Government), January 2013*

Table 1-1 Welsh Government Hub Projects

Hubs	Participating Authorities	Specified Capacity Requirement (ktpa)	Project Status[3]	Proposed Location(s)[3]	Actual (or proposed) Plant Size (ktpa)
North East	Conwy	20	Contract signed with Biogen in November 2012	Waen, Denbighshire	22.5
	Denbighshire				
	Flintshire				
Central Wales	Ceredigion	10	Contract signed with Agrivert in May 2012	Cassington, Oxford	N/A[1]
	Powys				
Heads of the Valleys	Blaenau Gwent	22	Procurement down to final two bidders	New Inn, Pontypool (Shanks)	60-90[2]
	Caerphilly			Taunton (Viridor)	N/A[1]
	Torfaen				
South West	Bridgend	70	Shanks appointed Preferred Bidder in November 2012	New Inn, Pontypool	60-90[2]
	Carmarthenshire				
	Neath Port Talbot				
	Pembrokeshire				
	Swansea				
Gwynedd	Gwynedd	10	Biogen began construction in October 2012	Llwyn Isaf, Caernarfon	11
Cardiff	Cardiff	30	Four remaining bidders in procurement	Shanks - New Inn, Pontypool	60-90[2]
				Geneco – Avonmouth, Bristol	N/A[1]
				Agrivert & Atlantic Recycling – Rumney, Cardiff	Unknown
				Kelda Biogen Renewables Cymru -	Unknown

Hubs	Participating Authorities	Specified Capacity Requirement (ktpa)	Project Status[3]	Proposed Location(s)[3]	Actual (or proposed) Plant Size (ktpa)
				Unknown	
Tomorrows Valley	Rhondda Cynon Taf	20	Biogen appointed Preferred Bidder in December 2012	Bryn Pica	22.5
	Merthyr Tydfil				
	Newport City Council				

Notes:

1. Capacity at existing facility to be used
2. Only a proportion of this capacity will be used
3. Correct at the time of writing (May 2013)

2.0 Approach and Methodology

Sections 2.1 to 2.5 set out the core assumptions used within our CBA model, along with those which form part of the related sensitivity analysis. All assumptions underpinning the mass balance, cost and environmental sub-elements of the model are provided in detail in Appendices **Error! Reference source not found.** to **Error! Reference source not found.**.

2.1 Definition of a 'Typical' AD Plant and resulting Digestate

To determine the nature of the whole digestate which can subsequently be modelled as being dewatered, it is important to consider a range of parameters. In the case of this study, the food waste 'hub' projects (and proposed projects) developed as part of the Welsh Government's Food Waste Treatment Programme have been used to characterise a 'typical' plant to act as a reference point for comparing the impacts of dewatering technologies. The key features of these projects, which drive a range of assumptions within our CBA model, can be summarised as follows:

- The use of 'wet',mesophilic AD processes (as defined in Table 2-1);
- A feedstock (Appendix 2) which is almost wholly local authority collected (LAC) food waste. Consequently, the composition (and ultimate analysis) of the feedstock modelled for this study is taken from the WRAP Cymru food waste survey.[10] This information has been cross-checked with feedstock data from 'real-world' operating AD projects provided by Aqua Enviro;
- The digester is compliant with both the Animal By-products Regulation (ABPR) and ADQP; and
- Plant capacity / throughput is based on a broad median of the current and proposed Welsh food waste hub projects, i.e. 25,000 tonnes per annum.

Furthermore, we have also assumed that the reference plant is:

- Operating at full capacity and according to its design objectives, and;
- The primary goal of the reference plant, as agreed with WRAP, is to produce a PAS110-compliant digestate (and subsequent liquor and fibre) rather than to maximise throughput or biogas generation (which would be the goal if the facility was aiming to maximising gate fee revenue or energy generation).[11] This issue is explored in detail in Section 2.1.1.

2.1.1 Plant Operation to Produce a PAS110 Digestate

2.1.1.1 Overview

Within AD processes, the biodegradable organic fraction (volatile solids) of the feedstock (which comprises around 90% of the dry solids content) is partially converted into biogas, which is principally composed of methane and carbon dioxide. The digestion process destroys between 50% and 80% volatile solids, thus 20-50% of volatile solids remain. Only a small proportion of this fraction, however, is considered to be biodegradable.[12] Although only a relatively small proportion of the biodegradable organic waste fraction remains at the end of the degradation process, the inert fraction and non-digestible organics (e.g. lignocellulose) of the feedstock are conserved during digestion. In this way a whole digestate is produced which has a considerably reduced dry and volatile solids concentration in comparison to the un-digested feedstock. A feature of AD processes (in contrast to aerobic degradation processes) is that the bacteria involved in digestion require relatively small

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[10] *WRAP (2010) Food Waste Chemical Analysis, 2010*

[11] *In this context, however, we have also considered non-PAS110 material where this comes from innovative processes, which deliver other benefits.*

[12] *Donald M.D. Gray (Gabb) (2008) Anaerobic Digestion of Food Waste, March 2008*

quantities of macro-nutrients for cell synthesis, thus total nitrogen and total phosphorus levels are also largely conserved.

Digester operation affects the composition and stability of the whole digestate and is therefore a significant influencing factor in achieving PAS110. A feature of the UK waste digestion market is a considerable variability in plant design, with similar technologies treating the same feedstocks and tonnages, but with hydraulic retention times ranging from 20 days to more than 100 days. Such variations in plant design will result in a considerable variation in capital cost – the size of the digester will vary considerably as the retention time changes, as will the size of the storage tanks used to store digestate – and this, in turn, is likely to affect operating costs. For these reasons, only costs incurred once the whole digestate is produced are included within our model for this study.

As stated above, for the purposes of this study, plant operating practices that increase the likelihood of achieving PAS110 form the basis of the development of our model, which includes mass balance information, along with capital and operating cost data.

2.1.1.2 Assumed Level of Dilution

A key consideration with regard to operating practices relates to the level of dilution of the feedstock. Dilution influences the process in a number of ways:

- Dilution (adding liquid) is used to facilitate digester mixing and the removal of 'settleable' inorganic material (e.g. egg shells) and contaminants, such as plastics;
- Dilution generally increases the volume of whole digestate, which can increase the subsequent costs of digestate management;
- The dilution process may use either mains water or water from boreholes. In some cases the whole digestate (or separated liquor digestate) is re-circulated through the process such that this is then used to dilute the incoming feedstock. Such practices, however, can reduce the likelihood of the plant achieving PAS110 as the re-circulation process results in elevated levels of ammonium-nitrogen in the digester.[13] This partially inhibits methanogenic bacteria and results in heightened levels of volatile fatty acids (VFAs) in the whole digestate, the levels of which are controlled by the specification.[14] Previous work on behalf of WRAP suggests, at bench scale, that this can be alleviated through the addition of trace elements, where they are deficient.[15] This practice, however, is not yet widely adopted at commercial scale AD facilities; and
- Similarly, a closed loop system recycling treated liquor for dilution could lead to the accumulation of salts (in particular sodium chloride and potassium chloride) to inhibitory levels, unless the salts were specifically removed.[16] [17]

As a consequence of these issues (and others), there is a high level of variability in terms of dry solids content of feedstock across different facilities. Based on Aqua Enviro's knowledge of working closely with plant operators and developers, we have therefore included *two central cases* within our model, both based on a feedstock dry solids content of 25.95%.

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[13] *Yeniguin & Demirel (2013) Ammonia Inhibition in AD, Process Biochemistry, June 2013*

[14] *The likelihood of ammonia inhibition is also increased at higher dry solids feed concentrations (as the concentration in the digester is proportional to total nitrogen in the feedstock, which is turn is proportional to dry solids concentration), although this form of sensitivity analysis has not been considered in the modelling for this study*

[15] *WRAP (2011) Trace element supplementation for stable food waste digestion, March 2011*

[16] *Based upon food waste composition data provided in: WRAP (2010) Food Waste Chemical Analysis, March 2010*

[17] *Also refer to Gerardi (2003), The Microbiologyof Anaerobic Digesters, September 2003*

The first central case models dilution of this feedstock to a dry solids concentration of 10% and the second at 20%.[18] This approach is discussed further in Section 2.4.2.1.

2.1.1.3 Summary of Digester Operating Conditions

In addition to the operating practises outlined above, process criteria can be broadly defined which deliver 'stable' digester conditions and consequently a whole digestate that is more likely to satisfy the requirements of PAS110. In-house testing by Aqua Enviro has shown that the financial costs of dewatering and liquor treatment are minimised when the conditions in Table 2-1 are achieved during plant operation.[19] These criteria have therefore been used to define the operation of the AD plant producing the digestate in this study.

Table 2-1: Digester Operating Conditions

Parameter	**Units**	**Value/range**
Digester temperature (top and bottom)	°C	35-42
pH	n/a	6.8-8.0
VFA: Alkalinity	n/a	0.2-0.4
Total VFAs	mg/l	1000-3000
Trace nutrients[1]	mg/l	Selenium >0.16, not to exceed 1.5 Cobalt >0.22
Ammonium-N	mg/l	<3,000
Hydraulic retention time	Days	>40
Organic loading rate	Kg VS/m^3/d	<4.0
Volatile solids destruction (mass balance method)	%	>80
Toxic compounds in feedstock or recirculated liquor for dilution	n/a	absent

Notes:

1. WRAP (2011), *Trace element supplementation for stable food waste digestion,* March 2011
2. Well designed and managed digesters operating within these ranges should achieve PAS110 compliance

2.2 Options for Scenario Modelling

To determine the most relevant technologies and approaches to dewatering and subsequent liquor and fibre management, an investigation was carried out by Eunomia and Aqua Enviro into the various techniques available for treating digestate. These technologies, many of which are outlined in a recent WRAP study, were assessed in terms of their commercial and technical viability.[20] This assessment was undertaken with consideration to the risk-based capital investment decisions which Welsh local authorities and developers are required to make in the short-to-medium term as part of the ongoing AD hub projects. Following discussion with industry contacts and analysis of the current and planned implementation of treatment methods in the hubs and elsewhere in the UK, a range of scenarios was determined. Whilst it is acknowledged that this approach may have resulted in the deselection of technologies which are *theoretically* feasible, the consideration of *both* commercial realities and technical attributes is in line the objective of this report to offer practical decision-making guidance.

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[18] *In neither case do we assume that either digestate or liquor is recirculated into the AD process*

[19] *This information is not available in the public domain, but we have provided a summary in Appendix 1*

[20] *WRAP (2012), Enhancement and treatment of digestates from anaerobic digestion, November 2012*

Table 2-2 shows the initial technology options which were considered against a baseline of spreading whole digestate to land. The options are described in detail in Section 3.0, along with the rationale for their inclusion or exclusion within the model. The final selected options, arranged in sequence as end-to-end processes, are detailed in Section 3.6.

Table 2-2: Initial Technology and Management Options Considered

Fraction	**Technology / Management Route**	
Whole Digestate	Direct land application	
	Dewatering	Belt press
		Belt thickener
		Belt drier
		Bucher press
		Centrifuge
	Evaporation	Thermal
		Solar
Liquor	Direct land application	
	Purification (ultrafiltration and reverse osmosis) followed by disposal to sewer or watercourse	
	Nutrient recovery (ammonia stripping, struvite precipitation) followed by disposal to sewer or watercourse	
	Biological oxidation (sequencing batch reactor) followed by disposal to sewer or watercourse	
	Recirculation to digester	
	Direct disposal to sewer	
	Direct disposal to watercourse	
Fibre	Direct land application	
	Lime stabilisation	
	Composting	
	Drying and pelletisation followed by energy recovery	
	Direct energy recovery	

2.3 Approach to Collection of Financial, Mass Balance and Environmental Data

The dewaterability of food waste digestate is not well characterised, with only a very small number of commercial sites in the UK currently carrying out any kind of dewatering. In some instances this has led to issues of liquor treatment plants failing to achieve the required level of performance and much of the data surrounding digestate dewaterability is therefore deemed by operators to be highly commercially sensitive.

As a result, we have needed to draw on a wide variety of data and methods for accessing this data, which can be summarised as follows:

- Review of the data held internally (by Aqua Enviro) on:
  - Digestate dewaterability;
  - Most appropriate conditioning agents;
  - Fibre quality; and
  - Liquor composition.

- Review of previous WRAP study findings on technology selection and nutrient content of whole digestate;
- Sampling and analysis from existing operational plants to corroborate findings, for example, the split in nutrient content between fibre and liquor fractions;
- Telephone discussions and meetings with key suppliers of dewatering and liquor treatment technologies to acquire data on performance and maintenance requirements; and
- Liaison with AD plant operators and contacts at the Sustainable Organic Resources Partnership (SORP) to review how the equipment design specifications compare to practical operational experiences.

Where it has been identified that particular technologies have performed very poorly on food waste digestate or there are insufficient data to make an assessment, these have been excluded from the CBA modelling.

In some cases, it should also be noted that where data on dewatering technologies have not been available from food waste AD plant, it has been necessary to draw upon Aqua Enviro's experience of AD in the waste water industry.

2.4 Cost-benefit Analysis

2.4.1 Model Design

The CBA model developed for this study combines 'mass flow' data with unit cost factors to calculate the environmental and financial costs for each scenario. The results are expressed by a common metric; 'per tonne of feedstock arriving at the plant before digestion'. This allows for sensible comparison as the mass and composition of the feedstock is assumed to be consistent for all options. The design of the model itself is structured into four elements:

1. Inputs, which include:
    a) Greenhouse gas (GHG) and air quality damage cost factors;
    b) Capital expenditure;
    c) Operational (per unit) costs for process chemicals;
    d) Electricity;
    e) Haulage; and
    f) Fertiliser costs.

   Mass and composition data for feedstock, digestate, liquor and fibre are also included.

2. Unit values (environmental):

   By combining mass figures with environmental impact factors, each significant aspect of the process is given a damage cost per tonne of feedstock coming into the AD plant.[21]

3. Unit values (financial):

   The capital and operational costs of each aspect of the process are divided by the throughput to arrive at a 'per tonne of feedstock' value.

4. Summary cost analysis:

   Overall financial and environmental damage cost analysis for each option.

2.4.2 Development of the Baseline Scenario and Comparison with Alternatives

An important first step in undertaking any CBA is to establish a baseline against which alternatives must be assessed. In this case, we have assumed that the baseline is the direct

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[21] *This involves developing a pollution inventory that calculates a monetary impact value for each kilogramme of pollutant, based on damage cost factors. Please refer to Section 2.4.5 for further explanation*

application of digestate to land, with no intermediate dewatering step. Inherent in this baseline are the benefits associated with the avoided requirement to use synthetic fertilisers, both in terms of direct emissions to air, and the avoided GHG emissions associated with the energy required by the fertiliser manufacturing process.

As mentioned above, the baseline, along with the alternative options, is calculated on a unit basis ('per tonne of feedstock presented to the AD plant'). As there are insufficient data to build a full logistical model for the transport of digestate to land, we have assumed that an average transport distance can be applied in both the baseline and alternative processes.

The impacts of each of the alternative processes are compared against the baseline to identify a net impact for each. On a per tonne basis, given the assumptions applied, this identifies the net cost or benefit of a given alternative approach relative to the baseline. As stated above, the baseline cost per tonne is a comparator only and does not constitute an absolute cost to the plant operator. Indeed, any costs that arise for the baseline but can be equally applied to all of the other options have not been considered.

2.4.2.1 Assumed Dry Solids Content of Baseline and Alternative Scenarios

As discussed in Section 2.1.1.2 with regard to dilution of feedstock, at the plant design stage, the estimated feed dry solids concentration to the digester has a critical influence both on the size of the digester and upon the volume of whole digestate to be managed.

Dilution liquid will be required for sites handling local authority food waste, which we have assumed to be around 26% dry solids, based on anecdotal evidence and discussion with industry.[22] In practice, dilution might be achieved by importing low strength co-substrates, the addition of dilution water, re-circulation of whole digestate or a combination of all three.

There are a number of competing factors for the optimum solids content of the feedstock to the digester. On the one hand, higher water content allows for easier filtration of contaminants and a better consistency for digestion. On the other, this increases volume and mass and therefore storage and transport costs are higher. A higher solid content also has potential 'upstream' effects, such as a potentially longer retention period during digestion, which also adds to costs. Whilst the impact of such costs on the wider AD process is outside the scope of this study, it is worth noting here for any future consideration and analysis of such impacts.

Sites employing, for example, the BTA process (for pulping feedstock and removing contaminants) operate in the range of 10-12% dry solids and usually require only relatively small digesters.[23] Although pumping technology is relatively efficient, there remain difficulties, in particular removing plastics and grits, which can cause serious mixing problems thus adversely affecting subsequent digester performance. A value of 10% dry solids is therefore considered to represent a sensible value, albeit those sites where this is practised will in reality seek to bring in other wastes with a lower dry solids content (e.g. farm yard manures) to bring down the overall dry solids concentration, rather than relying solely on dilution water.[24]

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[22] *We have also based these assumptions upon food waste composition data, for local authority collected waste, developed by WRAP. See WRAP (2010) Food Waste Chemical Analysis, March 2010*

[23] *For processes with longer retention times, this may go up to an absolute maximum of 20% dry solids.*

[24] *Based on information provided by operators and suppliers of equipment, on the most common approaches currently being adopted*

In summary, a large section of the data provided by operators suggests that a dry solids content of 10-20% might be appropriate. We have therefore modelled dilution of the 26% dry solids feedstock to either 10% or 20% as our two central cases. This takes into consideration all data-points, and the potential benefits of a more liquid feedstock within the digester, as described above. The model assumes that the dilution is achieved through the addition of water, rather than through the re-circulation of digestate liquor or use of low strength co-substrates.

2.4.3 Modeling Operating Costs

Operating costs (and any revenues) of the scenarios are analysed relative to the baseline, taking account of impacts associated with:

- The use of energy (electricity);
- Labour, maintenance, testing and ancillary operations; and
- The financial cost of process chemicals.

The following costs, which are usually embedded within contract fees, have also been used within the model:

- Disposal of liquor to sewer:

The Mogden Formula for calculating financial costs for disposal to sewer has been used. Two options exist to discharge both untreated and treated liquor:

  - For untreated liquor, which is rich in nitrogen and phosphorus, it is unlikely that any DWR Cymru wastewater treatment works will provide a trade discharge consent under the standard charging mechanism (Mogden formula), as it does not incorporate these components. For the purposes of the modelling undertaken for this study, however, and in the absence of an alternative, we have assumed that it would be possible to discharge untreated liquor and have therefore applied the standard Mogden formula; and
  - Where liquor treatment is included within the model it has been assumed this incorporates nitrogen and phosphorus removal by biological and chemical means. The likelihood of DWR Cymru granting a trade effluent discharge licence is greatly increased in this scenario and a standard Mogden charge is applied for all scenarios (see Appendix 3).

- Haulage and spreading of whole digestate, fibre and liquor to land:
  - A contract fee (per tonne) has been used in the model, which encompasses transport costs and those associated with spreading, minus any 'revenues' associated with the value of the material in displacing synthetic fertiliser. No distinction is made between haulage and spreading costs for different digestate fractions (for example: tanker or trailer).

2.4.4 Modeling of Capital Costs

To account for expenditure on equipment and commissioning required for dewatering facilities, we have sought to calculate an annualised cost of capital.

There is no guidance for the derivation of a suitable figure for the Weighted Average Cost of Capital (WACC) in the waste sector. The Committee on Climate Change (CCC), in commissioning a report requiring the development of marginal abatement cost curves for the waste sector, originally proposed the use of a default figure of 10%.[25] Subsequently, a further report from the CCC emerged which cited a figure estimated by Oxera of 4.7-5.3%.[26] [27] It should be emphasised that these are intended to represent the WACC in real terms. As such, the implied nominal rates would be higher owing to the effects of inflation.

The waste sector's WACC is affected by the risk associated with the investment being made. As the waste sector shifts away from 'traditional ways' of doing things, and to the extent that contract structures seek to ensure risk is borne, where appropriate, by the private sector, so the cost of capital appears to have increased. It seems possible that the average cost of capital may be lower in 'merchant' transactions where the transfer of risk is not explicitly priced into the cost of capital. Obtaining financial support for a given project, however, may be more difficult owing to the issues associated with securing supply of waste into the project.

In our modelling, we have therefore taken the following approach:

- Capital expenditure for the commissioning of additional equipment required for dewatering and associated processes is presented on an annualised basis, using a WACC (taking into consideration the likely debt and equity split) of 8.5% over a 20 year term under the 'central' case; and
- We assume that the equipment is installed as part of a 'new build' project, rather than retrofitted to an existing plant.

These assumptions have been used to calculate total 'per tonne' figures for CAPEX as set out in Table A3-. It is worth stating that the current environment is one in which the availability of credit is constrained, leading to a worsening in the terms upon which credit is made available. This would be expected to increase the cost of capital. However, the analysis here is forward looking, and extends beyond the short-term so we consider the above figures to be reasonable in the medium to long term.

2.4.5 Damage Cost Data used to Evaluate Pollution Impacts

Environmental impacts are given a monetary value in the model through the use of damage cost data which are used to evaluate the impact of emissions to air. Other pollution impacts, such as emissions to watercourses, are not included in the model, as the data surrounding the valuation of these impacts are not sufficiently robust. The damage cost data are applied to both:

- The emissions directly linked to the treatment process – such as emissions of methane (CH_4) occurring during digestate storage; and
- The indirect impacts associated with the manufacture of chemicals used within specific treatment processes, and those associated with the displacement of the use of synthetic fertiliser resulting from the application of digestate to land.

In the central case, our approach to valuing the climate change impacts in monetary terms is based on that outlined in the latest guidance from DECC on the valuation of carbon in policy

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[25] *CCC (2008) The Committee on Climate Change's Methodology And Approach To Using Marginal Abatement Cost Curves To Derive Domestic Carbon Budgets, Internal Draft.*

[26] *CCC Shadow Secretariat (2008) Capital Costs, Discount Rates, and MAC Curves, Internal paper*

[27] *Oxera Consulting (2007) Economic Analysis for the Water Framework Directive: Estimating the Cost of Capital for the Cost-Effectiveness Analysis, Financial Viability Assessment and Disproportionate Costs Assessment—Phase II, Report for Defra, DfT and the Collaborative Research Programme, June 2007*

appraisal.[28] Under this approach, the precise valuation methodology differs according to the specific policy question being addressed:

- For appraising policies that reduce/increase emissions in sectors covered by the EU Emissions Trading System (ETS), and in the future other trading schemes, a 'traded' price of carbon is used. This is based on estimates of the future price of EU Allowances (EUAs) and, in the longer term, estimates of future global carbon market prices; and
- For appraising policies that reduce/increase emissions in sectors not covered by the EU ETS (the 'non-Traded Sector'), the 'non-traded' price of carbon is used. This is based on estimates of the marginal abatement cost (MAC) required to meet a specific emission reduction target.

The traded cost is applied to impacts resulting from electricity use and the manufacture of synthetic fertiliser (as both are included within the ETS), whilst the non-traded cost is applied to emissions resulting directly from the AD facility.

Our approach to valuing the other air pollutants having an impact on human health – which, in the case of digestate management, relates principally to emissions of nitrous oxides (NOx) and ammonia - is based on a dataset developed by Eunomia on behalf of the Environment Agency which sought to provide guidance on the use of damage cost data in BAT appraisals.[29,30] This, in turn, is based on modelling previously undertaken by the Interdepartmental Group on Costs and Benefits (IGCB), a group of analysts led by Defra who provided advice to government on the quantification and valuation of local environmental impacts.

It should be noted that the impact of emissions to air from transport has been excluded from the analysis of the environmental impacts. This is because fuel duty – which is included in the modeling of the financial costs of transport - is assumed to 'internalize' the environmental impacts of transport. As such, the separate inclusion of transport-related emissions within the environmental analysis would effectively result in a double-counting of these impacts.

Assumptions in respect of the damage cost data used within our CBA model are presented in Table 2-3. With regard to the climate change impacts, this data confirms there is a significant differential between the values applied to 'traded' emissions from facilities within the EU-ETS and those 'non-traded' emissions that fall outside this scheme. For this reason, as described in Section 2.5.4, we have undertaken sensitivity analysis on this approach via the use of an alternative dataset for valuing the emissions impacts, which was recently published by the European Environment Agency.

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[28] DECC and HM Treasury (2012) *Valuation of Energy Use and Greenhouse Gas Emissions for Appraisal and Evaluation*, October 2012

[29] *Eunomia (2011) Options for the Segregation and Collection of Welsh I&C Waste, Final Report, November 2011*

[30] *Eunomia / M Holland (2011) Use of Damage Cost Data for BAT Decision Making, Final Report for the Environment Agency, April 2011*

Table 2-3: Damage Cost Assumptions used within CBA Model

Nature of Impacts	Sector/Pollutant	Damage cost per tonne of pollutant emitted
Climate change impacts	'Traded'	£6
	'Non-traded'	£58
Air quality impacts	Ammonia	£3,812
	NOx	£2,819
	SOx	£3,598
	PM	£38,465

Sources: DECC and HM Treasury (2012) *Valuation of Energy Use and Greenhouse Gas Emissions for Appraisal and Evaluation, October 2012; Eunomia / M Holland (2011) Use of Damage Cost Data for BAT Decision Making, Final Report for the Environment Agency, April 2011*

2.5 Approach to Sensitivity Analysis

The assumptions set out in Sections 2.5.1 to 2.5.4 reflect the main areas of uncertainty within the model. It is therefore important to test the impact of variations in each of these assumptions upon the model results, as reported in Section 4.1.1.

As highlighted in Section 2.4.2.1, it should be noted that a key area of sensitivity relates to the assumed dry solids content of the feedstock. As this is such a critical variable and because there is no established 'norm' across different AD plant processing food waste in the UK, we have chosen to present two Central Cases in this regard (rather than to assume a central case and run the other as a sensitivity). One of these cases assumes dilution to 20% dry solids, the other dilution to 10% dry solids.

2.5.1 Scale of Plant

The assumed capacity of the AD facility (and related digestate management equipment and processes) will have an impact on costs on a per tonne basis, mainly through reduced per tonne capital expenditure for larger plants. Having reviewed the likely configurations of the AD Hubs in Wales, as set out in Section 1.2, our central case is based on a plant with 25 ktpa capacity. It should be noted that this capacity is based on the tonnage of feedstock presented to the plant prior to any pre-treatment or dilution that might affect the overall tonnage input to the digester.

To reflect the range in scale of all plants which may be constructed as a result of the hub funding, to test the sensitivity of this assumption, we have also modelled the following two cases:

- High case - 50ktpa; and
- Low case – 10ktpa.

For both of these sensitivity 'runs' it should be noted that we have assumed that there is no variation (per tonne of feedstock input) in the environmental damage costs, which might arise due to the installation of different abatement equipment.

2.5.2 Distance to Landbank

The distance between the AD plant and the location of land application of the digestate has a significant impact on the model results, due to the high cost (relative to other aspects of the model) of loading, haulage and actual spreading to land, along with the environmental impacts associated with fuel use.

There are a number of variables when calculating an average distance for use in our model. These include availability of grassland and arable land, road accessibility, competition from other AD plants, and the proximity of the AD plant to rural areas.

The WRAP Cymru 'Landbank' study undertaken in 2011 does not address these factors and simply assumes that all 'agricultural land' in Wales can be used for application of digestate.[31]Consideration of all such issues is beyond the scope of our analysis, but we have attempted to use the most sensible data point from the WRAP Cymru study.

Under our central case, therefore, we have assumed an 'average' travelling distance of 40km (25 miles) which represents the 'high' option within the WRAP Cymru study. This distance is only 'one way', however, and therefore, we have used a value of 80 km to reflect the full 'return trip' via road.

As a result, as part of our sensitivity analysis, discussed in detail in Section 4.2.2, we have also modelled each scenario assuming a far higher 'return trip' distance of around 280 km (175 miles). This is intended to reflect a potential 'worst case' scenario and is based on the proposition from TEG, which *was* preferred bidder for the North East Wales Food Waste Hub contract. TEG proposed to send digestate to Todmorden in England as a back-up option should local markets not be secured.

2.5.3 Weighted Average Cost of Capital

Please see section 2.4 for an explanation of the rationale for cost of capital rates. Those used under our central case and as part of the sensitivity analysis can be summarised as follows:

- Central case - 8.5%;
- 'High' case - 10%; and
- 'Low' case - 7%.

2.5.4 Damage Costs

Methodologies used in CBA apply a monetary cost to environmental impacts such that these impacts can then be compared with the financial cost associated with the same option. Our previous experience of undertaking this type of analysis has confirmed that the financial costs typically dominate the outcome. It was therefore felt that an exploration of sensitivities in the results with regard to the potential variation in feedstock and digestate composition would add relatively little value to the analysis. This is because only a minor change in the environmental impacts would be likely if such variability were considered. We have, however, considered the potential change in the impacts resulting from the variation associated with changing assumptions with regard to the damage cost data applied to the pollutants.

Section 2.4.5 highlights that under the central case, we have applied the damage cost dataset developed for policy appraisal by DECC to the climate change emissions, whilst the impact of other pollutants to air is considered through a dataset developed for England's Environment Agency. Our sensitivity analysis considers the results where the pollution is valued using data from analysis undertaken on behalf of the European Environment Agency

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[31] *WRAP (2011) An evaluation of land availability for application of food waste derived digestate at regional Hub locations across Wales, 2011*

(EEA).[32] The damage cost data used for this sensitivity analysis is presented in Table 2-4. These datasets apply a relatively low impact to the pollution in comparison to other sources.

Table 2-4: Damage Cost Data used in Sensitivity Analysis

Impacts		**Damage cost per tonne of pollutant emitted**[1]
Climate change impacts	CO_2 equivalent	£30
Air quality impacts	Ammonia	£14,313
	NOx	£4,892
	SOx	£7,378
	PM	£23,258

Notes:
1. The original dataset provided damage costs in 2005 prices. These have been inflated to give prices for 2012

Source: European Environment Agency (2011) *Revealing the Costs of Air Pollution from Industrial Facilities in Europe,* EEA Technical Report No 15/2011

The EEA dataset applies the same cost to all climate change impacts (i.e. it does not split them into 'traded' and 'non-traded' as per the DECC approach), whilst impacts for the other air pollutants are (for the most part) attributed a relatively high value in comparison to that associated with assumptions used in the central case.[33] It is therefore anticipated that the modified assumptions used in the results from this sensitivity analysis, presented in Section 4.2.4, will result in a relative increase in the contribution from the environmental impacts in comparison to that seen in the central case.

2.5.5 Costs of Spreading Digestate to Land

Our estimates for the net cost to the AD plant operator of spreading digestate to land have been based on the premise that, *in general*, the operator tends to pay the farmer or landowner and that any value of the digestate is outweighed by the need for the operator to remove the material from their site. The data-points we have gathered relating to this cost vary significantly depending upon local geography, whilst the prospect of dewatering also brings into play a number of further potential variables; for example, it is possible that fibre, which can have a lower nutrient content than whole digestate, will be of less value as a fertiliser replacement. On the other hand, some farmers may prefer a drier product, depending on seasonal and soil conditions. For this reason we have included the following relatively wide sensitivity band within the model for all types of material, whether whole digestate, fibre, or liquor:

- Low spreading costs – £2.50 (net), per tonne of material received by the farmer;
- Central case – net £5.00 (net), per tonne of material received by the farmer; and
- High spreading costs – net £7.50 (net), per tonne of material received by the farmer.

These estimates are based on aggregated information gained from personal communications with AD operators across the UK during the course of this study.[34] We acknowledge that in

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[32] *European Environment Agency (2011) Revealing the Costs of Air Pollution from Industrial Facilities in Europe, EEA Technical Report No 15/2011*

[33] *Although PM emissions are attributed a relatively high value in the central case in comparison to the values used within the sensitivity analysis, emissions of PM make only relatively minor contribution to the total environmental impact associated with the management of digestate*

[34] *Due to commercial confidentiality, we are not able to name either the plant operators or recipients of the digestate*

some cases, operators may receive a payment for digestate from farmers, but our research indicated that in most cases, this represents a cost. It should also be noted that we believe these assumptions to be accurate at the time of writing, but that the market is not static, and there are a range of influences which might subsequently raise or lower these estimates.

3.0 Description and Rationale for Selection of Digestate Management Scenarios

3.1 Analysis of Experience and Best Practice in Europe

As Europe represents the World's most advanced AD market, operational and technological experience in other EU Member States was considered as an initial guiding factor for scenario selection.

Germany has the most potential to provide supporting evidence; it has the most mature AD industry in Europe, which accounted for over 60% of European biogas production in 2010 (including that generated from landfill gas), with some plant having been operated for over a decade.[35] The industry is considerably less mature in other Member States, although it is anticipated that growth over the next four years will come from other countries such as Italy and the Netherlands where the industry is rapidly becoming more established.[36]

The German biogas industry has developed along very different lines to that of the UK. As a result of subsidies offered at various points to plant operators over the past decade, the sector is heavily dominated by small plant typically treating agricultural wastes and, more recently, purpose grown energy crops.[37] In contrast to the situation in the UK, Germany's AD facilities which treat food waste, where they do exist, tend to accept a mixture of both food and garden wastes.[38] The characteristics of the digestate produced by these facilities are therefore very different to those of digestate generated by UK plant, where the feedstock is typically solely food waste. Furthermore, whilst these German AD plant typically use 'dry' digestion technologies (to better manage the inclusion of garden wastes), the UK industry is dominated by 'wet' digestion facilities, which reflects both the goal of solely treating food wastes and the influence of the waste water treatment industry.

As such, although a considerable body of information on the performance and operation of German plant exists in the literature, given the differences in the nature of plant operating in Germany and the UK, there is not significant data which is appropriate for use within this study. We have therefore concentrated our attention on data from currently operating UK facilities.

3.2 Key Criteria for Selection of Scenarios

For a study of this nature, it would be ideal to produce a fully transparent framework for scoring each potential technology or management route to determine whether it should be included within the analysis. When faced with a range of options for which in most cases data-points are either very limited or in some cases, non-existent, however, a degree of subjectivity is required in this regard.

The basis for development of the different digestate management scenarios (in addition to the Baseline scenario of application of whole digestate to land), within the modelling undertaken for this study is related to the following four key considerations:

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[35] *Oxford Institute for Energy Studies (2012) Perspectives for Biogas In Europe, University of Oxford, December 2012*

[36] *Ecoprog / Fraunhofer Institute (2013) Biogas to Energy 2012/3 – the World Market for Biogas Plants*

[37] *Wilkinson, K (2011) A Comparison of the Drivers Influencing Adoption of On-farm Anaerobic Digestion in Germany and Australia, Biomass and Bioenergy, 35, pp1613-1622*

[38] *Prognos (2010) Bio-Waste Potential for Energy Production and GHG-Reduction in Germany and Europe*

1. Commercial status and/or perceived technical risk

   If a technology is not yet proven on food wastes, then derivation of realistic commercial-scale costs is not usually possible, and therefore in some cases, the technology has been excluded.

2. Level of capital and operating costs

   Where we know some technologies are prohibitively expensive, they have sometimes been excluded from the analysis.

3. Availability of sufficiently robust data

   Where there is simply not sufficient available data of the required quality, we have also excluded some approaches.

4. Ability to meet the requirements of and guidelines recommended within PAS110

   As set out in Section 2.1.1, this was agreed with WRAP as being the key goal of our 'reference' AD facility, and therefore technologies which are unlikely to meet the requirements have been excluded.

These considerations have been applied in a *qualitative sense* to select our digestate management scenarios. They are explored in detail in Sections 3.3 to 3.5 with regard to technologies used in the initial treatment of whole digestate (dewatering), and in the management of subsequent liquor and fibre fractions.

3.3 Dewatering of Whole Digestate

There is a paucity of data in the public domain regarding the dewaterability of whole digestate from food waste digestion facilities. The factors influencing whether or not a given material can be effectively dewatered are, however, well understood based on operational experience in other sectors. Such factors include, *inter alia*:

- The age or freshness of the material;
- The type and dose rate of conditioning agents (e.g. polymer, ferric chloride, alum) used;
- Particle size;
- Fibre content;
- pH;
- Dry and volatile solids content; and
- Charge (measured in terms of millivolts).

In order to select modelling scenarios, an understanding of the impact of some of these factors upon the dry solids content of the fibre generated and the liquor quality is required. In contrast to digestate originating from principally food waste there is a wealth of information regarding the dewaterability of sewage sludge which can be used to benchmark operating practises and costs to deliver quality outputs.

It should be noted that in the vast majority of cases, the dewatering process comprises the addition of polymer and/or metal salts to the whole digestate to assist the separation of free and capillary water from the solids fraction, which is subsequently removed by filtration, pressing or centrifugation, as described in Section 3.3.1.

3.3.1 Mechanical Separation

Whole digestate can be dewatered using a range of technologies. Whilst the performance, costs and application of each of these technologies is well understood when applied to the treatment of sewage sludge, there is much less operational experience of using the same techniques for the digestate produced from food waste digestion.

Traditional techniques for dewatering digestate from the stabilisation of sewage sludge are based upon either filtration or centrifugation techniques.

The following *filtration* technologies are currently available on the market:

- Belt thickener
  The whole digestate is mixed with a polymer and fed onto a PVC belt. The dry solids are retained on the belt and free water drains by gravity filtration through the belt. The thickened sludge is discharged into a collection trough at a dry solids concentration of up to 7.5%.
- Belt press
  The filtration section of the belt press operates in the same way as the belt thickener but in this case the thickened sludge is subsequently compressed by a series of rollers to deliver a whole fibre.
- Belt drier
  The whole fibre (produced by filtration) is exposed to conditioned, dried air to increase the percent dry solids of the thickened sludge/fibre fraction.
- Bucher press
  In contrast to the belt press, the Bucher press operates as a batch system. Conditioned whole digestate is dewatered under pressure by filtration.

Centrifugation is the other main approach to dewatering. In this process, liquid and solid phases of the conditioned whole digestate are separated by rotation at high speeds which creates centrifugal force in a horizontal, cylindrical bowl equipped with a screw conveyor.

As stated above, there are relatively few data-points available with regard to the use of dewatering techniques on food waste digestate. In-house tests by Aqua Enviro aimed at understanding the performance of the dewatering process on food waste digestate, however, have shown that it is much more difficult to dewater this material in comparison to sewage sludge digestate, as is discussed in more detail in Appendix 1. In particular, this testing has shown that it is extremely challenging to effectively filter food waste digestate, which significantly limits the throughput of filtration technologies. This, in turn, is likely to considerably increase the operating cost associated with using any of the filtration options.

shows the differential in performance between a belt press and centrifuge when used to dewater either sewage sludge or food waste digestate. These data are based on operational performance information from the water industry and on trial data from Aqua Enviro. The data in

show that dry solids capture by the belt press – a typical filtration-based separation technology - is likely to be lower than is the case with the centrifuge. This poorer capture rate will be particularly problematic where plants are aiming to deliver a material that is capable of being stacked in a 'heap', for which a guideline dry solids content of at least 23% is recommended within PAS110.

In this regard, it is important to also acknowledge that we are not aware of any project developer in the UK market which is currently aiming to use filtration methods for digestate dewatering. As such, all dewatering technologies that incorporate filtration (including the belt thickener, belt press, belt drier and Bucher press) have been excluded from the scenarios modelled for this study. Use of a centrifuge, however, consistently exceeds the level of dry solids required to deliver a separated fibre that is 'stackable' and provides a reasonable guarantee to operators in terms of dry solids concentration. As a result, this represents the core method we have modelled for the dewatering element of all scenarios.

Table 3-1: Dewatering Characteristics of Sewage Sludge and Food Waste Digestates

Parameter	**Unit**	**Belt press**		**Centrifuge**	
		Digested sewage sludge	**Food waste digestate**	**Digested sewage sludge**	**Food waste digestate**
Dry solids (%)	%	20-25	16-25	25-32	Up to 30
Solids capture (%)	%	>98	75-95	>98	75-95
Polymer consumption	kg poly/tds	<7	>10	<10	>10

3.3.2 Evaporation

Waste heat from combined heat and power (CHP) engines, used to generate energy at AD facilities, can be recovered for use in other processes. Such heat has traditionally been employed in the sewage sludge industry to maintain digester temperature by heating the incoming feed to offset thermal losses from the digester itself. This practise is well documented and is also commonplace within designs for food waste digestion plants.

Waste heat can also potentially be used to evaporate water from the whole digestate to increase the dry solids concentration. To date, however, this practice has not been widely adopted even in the sewage sludge digestion industry, and is thus operational experience is not well documented. Based on the limited data that are available, however, it can be surmised that such processes could only deliver up to approximately 20% dry solids content, which suggests that the whole fibre produced may not be stackable.[39]

The use of such techniques for food waste digestate is likely to pose specific challenges, including but not limited to the following:

- The increase in temperature associated with evaporation is accompanied by ammonia release. This can be mitigated by reducing the pH, but this is likely to result in additional operating costs;
- Food waste digestate is typically rich in dissolved salts and hydrogen sulphide, both of which are corrosive and which may necessitate the use of high grade stainless steel when constructing the heat exchangers. The corrosion is also likely to lead to the fouling of these exchangers, incurring further additional costs in the form of additional fuel consumption, maintenance and loss of throughput, although methods to address fouling can be employed to remove the deposits caused by the corrosive activity of the digestate.

It is not possible at this stage to evaluate the true capital or operating costs for this technology or to benchmark its performance over a sustained period of operation, given the lack of operating experience even in the water industry. Furthermore, the additional challenges associated with the use of these techniques in the treatment of food waste digestate are likely to result in additional costs.

These constraints to inclusion of evaporation as an option within this study, however, should not preclude its consideration in future such studies, should new, reliable evidence become available in a commercial context.

For all of the above reasons, therefore, evaporation techniques have been excluded from the scenarios modelled for this study.

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[39] *Pell Frischmann (2012) Enhancement and Treatment of Digestates from Anaerobic Digestion, Report for WRAP, November 2012*

3.4 Management of Liquor

The liquor that arises from the dewatering process contains a range of constituents including dissolved salts, particulate, colloidal and soluble organic and inorganic material. A range of technologies can be employed to deliver liquor, that following treatment may be:

- Discharged to watercourse (provided the appropriate consents are in place);
- Discharged to sewer; or
- Re-used within site processes or for irrigation.

The following sections provide analysis of the likely performance of the treatment options under typical conditions given the design of the plant set out in Section 2.1.

It is acknowledged that we have examined the various technologies with reference to current operational experience, which has heavily influenced our selection of scenarios for modelling. It should therefore be noted that there are several other options that, without having been shown to work successfully at commercial scale, may be technically feasible, and thus could merit further investigation when considering optimal treatment technologies in the longer term.

3.4.1 Purification Techniques

Purification of the food waste digestate liquor resulting from the dewatering process can - in theory at least - be achieved through the use of membranes. These membranes are selective barriers which can be employed to purify the liquor to remove suspended dry solids, solutes of high molecular weight and even ions from the 'mother' liquid. The resultant permeate – which accounts for up to 75% of the total flow treated – may then be reused in the AD process as dilution water, or it may be discharged to a water course. The remaining 25% of the flow must be disposed of (at cost) to land, sewer or undergo further treatment.

Membranes are not widely used in the treatment of liquors arising from dewatering processes in the sewage sludge industry as alternative treatment systems are already in place. In addition the membranes themselves are susceptible to fouling. Fouling is a term used to describe the potential deposition and accumulation of constituents in the liquor on the membrane. It is an important consideration in the design and operation and affects pre-treatment needs, cleaning requirements of the membrane, operating conditions, cost, and performance.[40] The liquors resulting from sewage sludge anaerobic digestion plants may contain high levels of soluble organic and inorganic material including calcium and iron. The presence of these compounds reduces both the throughput and the life of the membranes, thereby increasing the Capex and Opex associated with liquor purification.

The separation of whole digestate from food wastes is likely to deliver liquor that contains even higher levels of organic and inorganic material than from sewage sludge digestate, and therefore Capex and Opex is likely to be accordingly even higher. It should also be recognised that there is a paucity of information in this area. For these reasons, liquor purification by membrane treatment is not considered within our scenario modelling. Treatment by membranes is nevertheless recognised as a potential area for research and development in the industry as part of a future scenario for sites that wish to consider closed loop recycling and water reuse.

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[40] *Metcalfe & Eddy (2002). Wastewater Engineering, Treatment and Reuse. McGraw Hill.*

3.4.2 Nutrient (Struvite) Recovery

Operational problems associated with scaling from the precipitation of struvite (magnesium ammonium phosphate) in AD pipework in sewage sludge plant are well documented. Where this has been experienced, water treatment companies have considered direct precipitation and the recovery of these nutrients. Furthermore, on water treatment sites that incorporate biological nutrient removal, struvite precipitation can also be adopted to offset chemical dosing costs (e.g. ferric salts). Struvite recovery is practised in the UK at both Reading and Derby wastewater treatment works.

The financial drivers for removing nitrogen and phosphorus from the liquor depend on the end application, becoming relevant where consents for discharge apply for both. This is almost certain to be the case for food waste digestion facilities discharging to river and also to sewer in the future.[41] Soluble forms of ammonia and phosphorus can be partially precipitated from the liquor by the addition of magnesium chloride and sodium hydroxide to produce struvite or crystalline nutrient rich pellets ('prills'). Where technologies such as Ostara's Pearl process or NuReSys are employed, up to 90% of phosphorus and 40% of ammonia in the dewatering liquors can be removed. As a solid material, struvite can be transported relatively easily and used either directly as a fertiliser or as a base feedstock for fertiliser production. Phosphorus is also a finite global resource and as a consequence struvite recovery is likely to become more important in the future.[42]

Although struvite recovery is not currently practised in UK waste digestion facilities, it is proven technology within the water treatment industry, and data on capital and operating costs are available. As such, this technology has been included within the scenarios modelled for this study.

3.4.3 Biological Oxidation

The liquors resulting from dewatering processes are potentially rich in BOD (biochemical oxygen demand) and ammonia-nitrogen. Biological oxidation (BO) processes convert ammonia-nitrogen into nitrate by the process of nitrification and, if required, nitrate can be removed from the liquor through denitrification. The treated liquor can, under licence, then be discharged to watercourse or sewer, with a proportion potentially returned to the feedstock to act as dilution water. The process also converts BOD into a biological sludge as a by-product which could, in theory, be returned as a feedstock to the digester.[43]

Performance levels of the biological oxidation process will fall as VFA levels in the digester increase and/or the rate of dry solids capture from dewatering processes reduce. This will result in increased operating costs. Variation in the quality of the liquor arising from the dewatering process also adds complexity and risk to the design and operation of the AD facility; as such, the development of a robust solution will require some upfront testing on the commissioned facility.

A range of processes can be used to perform biological oxidation, ammonia oxidation and denitrification including:

- Membrane bioreactors (BOD and ammonia oxidation, but not denitrification);
- Moving bed bioreactors (BOD and ammonia oxidation, but not denitrification);

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[41] *UKWIR (2012) A Review of the Effectiveness of Mogden Formula Charging when Meeting Modern Sewage Treatment Works Consent, 2012*

[42] *Driver (1998) cited in WRAP (2012) Enhancement and treatment of digestates from anaerobic digestion, November 2012*

[43] *It should be noted, however, that within the scope of this study, it has not been possible to model the impacts of returning this sludge (and its associated Nitrogen content) to the digester, either in terms of cost and environmental impacts or calculation the recycling rate under the proposed Welsh Government methodology, as described in Sections 1.1 and 0*

- Sequencing batch reactors (SBRs) (BOD, ammonia oxidation and denitrification);
- The SHARON and DEMON processes (oxidise ammonia but do not oxidise BOD); and
- The AMTREAT process. (BOD, ammonia oxidation and denitrification).

Of the above options, the most robust data on financial cost and operational performance is available for the SBR processes, as this is an option currently practised in the UK.[44] Whilst, therefore, there might be concerns over related technical 'proof of concept' on food wastes, there are both suitable data available and potential cost benefits associated with this approach, such that we have included it within our scenario modelling. This data suggests that an ammonium-N removal rate of between 90 and 99% is possible. For the purposes of modelling for this study, therefore, we have assumed that at least 90% is achieved.

3.4.4 Disposal to sewer

Liquor from the dewatering process may be discharged to sewer where permitted by the receiving water authority (Dwr Cymru), which will issue a trade effluent discharge consent following a successful application. The applicant is required to provide data on the volume and composition of the discharge. This data feeds into the Mogden formula to calculate a charge to be paid to the water company for use of the sewerage network and assets at the receiving wastewater treatment works (WwTW).

It is important to note, however, that there are two potential issues associated with this approach:

- The Mogden formula does not include a charge component for ammonia-nitrogen, nitrate, total nitrogen or phosphorus. The treatment of water containing these chemicals, however, imposes a significant financial cost on the receiving WwTW, as well as additional risks. As such, the WwTw may, at their discretion, refuse to allow the discharge, which is potentially a significant hurdle for sites wishing to discharge liquor (untreated) direct to sewer. Where the liquor treatment process includes a biological oxidation step, however, nitrogen and phosphorus levels will be reduced;[45] and
- The receiving WwTW may not have sufficient capacity to permit the trade discharge licence.

On the basis that there is sufficient data from water treatment companies available to model this approach, we believe it merits inclusion within our scenario modelling.

3.5 Management of Fibre

3.5.1 Direct Land Application

The separated fibre will have a far higher dry solids content, potentially reducing transport costs in comparison to those associated with the use of the raw digestate. A recent report produced for WRAP which considered the different digestate management options used in the UK suggested that application of the separated fibre to land was already taking place.[46] Given that the costs and benefits can be modelled using a similar approach to that used for the modelling the performance of applying the whole digestate to land, this option has been included within our scenario modelling. It is important to note, however, that all of the dewatering processes set out in Section 3.3 result in most of the available nitrogen content being found in the liquor, although most of the phosphorus will be retained in the fibre. As

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[44] *For the purposes of modelling it has been assumed that the licence agreement for water course will require at least partial reduction in phosphorus and that this will be achieved through chemical addition. It is further assumed that costs for chemical addition are avoided where nutrient (struvite) recovery is also employed and this is therefore included as an operational saving.*

[45] *Our model accounts for this potential outcome including the associated additional treatment costs.*

[46] *Pell Frischmann (2012) Enhancement and Treatment of Digestates from Anaerobic Digestion, Report for WRAP, November 2012*

such, the environmental benefits – considered in terms of avoided emissions from displaced synthetic fertiliser application – associated with fibre will be significantly reduced in comparison to those associated with applying the whole digestate to land.[47]

3.5.2 Lime Stabilisation

The addition of lime to sewage sludge was commonplace in the wastewater treatment sector prior to 2005, when it was traditionally added to the sludge 'cake' to raise the pH such that an enhanced, stable product could be produced containing relatively low levels of pathogens. This technique is, however, rarely employed today, as water companies seek to recover energy from biosolids through anaerobic digestion.

Food waste digestion incorporates a pasteurisation stage to satisfy ABPR regulations, and therefore does not require the use of lime to destroy pathogens. This approach has therefore not been included within our scenario modelling.

3.5.3 Composting

Several operators are reportedly considering the addition of the separated digestate fibre into composting processes. The composting of digestate is more commonplace elsewhere in Europe, particularly in countries where restrictions have been placed on the application of the raw digestate to land. The operational experience of this type of approach, however, largely relates to dry digestion processes used to treat a feedstock containing a mixture of food and garden waste. These processes result in far more structural material being left at the end of the digestion, such that the output may be more readily mixed into a composting process. In contrast, food waste digested alone degrades very readily in the AD process, such that relatively little structural material is left. Given the low dry solids content of digestate from food waste AD processes, it is therefore likely that separation would be required prior to the fibre being mixed with the compost.

As indicated above, following dewatering, a significant proportion of the nutrient content remains in the liquor. This limits the potential for augmenting the nutrient of compost through mixing it with digestate fibre, although there is also the potential for mixing some of the liquor into the composting process where additions of moisture are needed to optimise this process[48]

Notwithstanding the relatively modest improvement in the nutrient content of the final product, there may be additional environmental benefits associated with using compost to which digestate has been added, albeit there are little data from UK practice by which such benefits may be considered at present. It is likely, however, that for the most part such benefits will come from the compost, rather than from the digestate. Such benefits are outside the system boundaries of the study, which considers the costs and benefits associated with digestate application only.[49]

In terms of costs, although composting the fibre fraction will undoubtedly result in both additional Capex and Opex, the composting process potentially allows the resulting product to be used in other markets such as horticulture. This is the result of a likely reduction in the

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[47] *It is acknowledged that the fibre will contain more organic matter than the liquor. Although there are benefits associated with increasing the soil organic content, it is difficult to account for these benefits through the use of damage cost data which considers impacts associated with emissions to air.*

[48] *We are not aware, however, of any plant at which this approach is currently practised. As such there is little data on which to base the potential improvement in nutrient content which might result from such an approach.*

[49] *As such, benefits associated with applying the compost to land could only be considered through extending the system boundaries of the analysis to include a separate compost production system for the other options*

salinity of the digestate. Such markets offer the potential for revenues from sale of the compost, which could be attractive to operators. The horticultural market could also provide greater flexibility of options for operators, such that transport costs, which represent a major element of total digestate management costs, could be materially reduced. There is little data, however, to substantiate the financial returns from horticultural use of the fibre output, whilst such (non-agricultural) markets are also outside the scope of this study – and outside the scope of the ADQP (see Section 1.0).

The above issues suggest that it would be both extremely challenging (and therefore present significant risk to the credibility of this study) to attempt to model either the net costs or environmental benefits associated with the composting of digestate. Whilst we have therefore excluded this from our scenario modelling, we feel that its potential benefits merit further, more detailed analysis, in a separate study.

3.5.4 Drying and Pelletisation

Options exist to increase the dry solids content of the fibre either through thermal drying utilising the waste heat from the CHP unit, and/or by blending in waste wood or sawdust. The resultant product is a low ash pellet for combustion units.

To our knowledge, this process has been adopted at one site in Wales; at Burdens' demonstrator site in Llangadog, South West Wales, which processes up to 5,000 tonnes of food waste per annum. This pilot facility has thus far not generated sufficient data to enable evaluation of the potential to either scale-up the operation, or assess its effectiveness and costs.

Market demand for the resulting pellets, aside from use in dedicated combustion facilities, is so far largely untested. As such, this approach has not been considered within our scenario modelling.

3.5.5 Direct Energy Recovery

Direct energy recovery from the fibre fraction would result in the production of carbon dioxide and an ash product, with little agronomic benefit. It is anticipated that odour management is also likely to be an issue, and that the operating costs associated with drying the fibre and managing odour are therefore likely to be high, although data is not available to quantify these cost elements with any degree of certainty.

The available technologies (i.e. Incineration, gasification and pyrolysis) are unlikely to be cost effective as a treatment option for plant handling less than 100,000 tonnes per annum, making them unsuitable as an option to be considered for any of the Welsh food waste hubs. As such, this approach has not been considered within our scenario modelling.

3.6 Scenarios Selected for Inclusion within the Model

Based on the outcome of the analysis described above, seven scenarios (including the baseline) have been included in our CBA model. These scenarios are outlined in both Table 3-2 and Table 3-3.

Table 3-2 represents a matrix of options, which demonstrates the differences and similarities between scenarios. Reading from left to right each combination of treatment processes can be identified. For example, Scenario 1 includes dewatering using a centrifuge, with the liquor undergoing nutrient recovery followed by biological oxidation, followed by disposal to sewer, with the fibre fraction being applied to land. Scenario 2 is exactly the same, apart from the liquor (following nutrient recovery and biological oxidation) is discharged to watercourse.

Within these processes there may be a number of separate sub-processes and mass flow outputs. For example, there is a phosphorus-based fertiliser generated by the nutrient recovery process. For the purposes of clarity, however, this table displays the main process steps that uniquely identify the scenarios modelled.

Table 3-3 provides a straightforward list of the scenarios selected for inclusion within the model. There are 10 processes applied to either the whole digestate, fibre or liquor, depending on the scenario and the combination of these processes provide the basis for each scenario.

Table 3-2: Matrix of Selected Scenarios included within the CBA model

Scenario	**Dewatering process**	**Liquor Management**			**Fibre Management**
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table 3-3: List of Scenarios included within the CBA Model

Scenario	Process Ref	Description
Baseline	**1**	**Whole digestate is applied directly to agricultural land**
1	2	Dewatering of the digestate using centrifugation
	3	The liquor is put through a nutrient recovery (ammonia stripping, struvite precipitation) process, with the output phosphorus used as fertiliser. The residual liquor is then subjected to biological oxidation using SBR, before being discharged to sewer
	10	The fibre is applied directly to land
2	2	Dewatering of the digestate using centrifugation
	4	The liquor is put through a nutrient recovery (ammonia stripping, struvite precipitation) process, with the output phosphorus used as fertiliser. The residual liquor is then subjected to biological oxidation using SBR, before being discharged to watercourse
	10	The fibre is applied directly to land
3	2	Dewatering of the digestate using centrifugation
	5	The liquor is put through a nutrient recovery (ammonia stripping, struvite precipitation) process, with the output phosphorus used as fertiliser. The residual liquor is then discharged to sewer
	10	The fibre is applied directly to land
4	2	Dewatering of the digestate using centrifugation.
	6	The liquor is subjected to biological oxidation using SBR, before being discharged to sewer
	10	The fibre is applied directly to land
5	2	Dewatering of the digestate using centrifugation
	7	The liquor is subjected to biological oxidation using SBR, before being discharged to watercourse
	10	The fibre is applied directly to land
6	2	Dewatering of the digestate using centrifugation
	8	The liquor is discharged directly to sewer
	10	The fibre is applied directly to land
7	2	Dewatering of the digestate using centrifugation
	9	The liquor applied directly to land as a separate fraction to the fibre
	10	The fibre is applied directly to land as a separate fraction to the liquor

4.0 Presentation of Results

Sections 4.1 and 4.1.1 present the costs of the digestate management scenarios modelled for this study, as set out in Section 3.6, under both the central case and under various forms of sensitivity analysis. The results are expressed in '£ per tonne of feedstock presented to the AD plant', which allows for a consistent measurement indicator, as we assume the same mass and composition of feedstock is used for each scenario. As mentioned above, as this is essentially a comparative analysis, the costs presented are *relative* and should not be regarded as an absolute cost for each process. In this context, again it should be noted that certain constants (i.e. costs which are the same for any process chosen) have been excluded from the analysis, to simplify the modelling process.

4.1 Central Case

As described in Section 2.4.2.1, we have arranged the scenario modelling around two central cases:

1. Central Case 1: Feedstock (as received) diluted with water to give an input to the digester at 20% Dry Solids; and
2. Central Case 2: Feedstock (as received) diluted with water to give an input to the digester at 10%.Dry Solids.

Again, we have modelled these two cases because:

- The estimated feed dry solids concentration to the digester has a critical influence upon the volume of whole digestate to be managed, and therefore the results of the analysis; and
- Whilst a large section of the data provided by operators suggests that a dry solids content of 20% might be appropriate, taking into consideration all data-points, and the potential benefits of a more liquid feedstock within the digester, a dry solids content of 10% appears equally important.

Since the outputs of the model are presented on a 'per tonne of feedstock received' basis, diluting this feedstock to 10% Dry Solids (Central Case 2) results in around twice the volume of digestate than diluting this feedstock to 20% Dry Solids (Central Case 1), with consequent impacts on digestate management costs/benefits.

Within the scenarios modelled across these two cases the following constants have been applied:

- Cost of capital – 8.5%;
- Size of plant – 25,000 tonnes per annum;
- Damage cost calculation factors – derived from DECC;[50]
- Distance to land for spreading – 80 km (round-trip); and
- Costs of spreading digestate to land - £5 per tonne (net).

The results showing the net cost/benefit of the environmental damage costs and financial costs under our Central Case 1 are presented in Table 4-1 and Figure 4-1. Detailed results for each scenario are presented in Appendix 5. The key features of these results can be summarised as follows:

- At a net cost of £8.76 per tonne of feedstock, the Baseline scenario (direct application of the whole digestate to land) offers the solution with lowest net financial and environmental cost. Although transport costs are significantly higher than for other scenarios, the lack of requirement for additional processing and the assumed potential for

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[50] *DECC and HM Treasury (2012) Valuation of Energy Use and Greenhouse Gas Emissions for Appraisal and Evaluation, October 2012*

the material to function as a substitute for the use of synthetic fertilisers, result in far lower costs than all other scenarios;

- For similar reasons, Scenario 7 (whereby fibre and liquor are directly applied to land following dewatering) performs relatively well compared with the scenarios whereby liquor is discharged to sewer;
- Of the scenarios in which liquor is not directly applied to land, Scenario 5 (in which liquor undergoes BO prior to being discharged to watercourse) is the best performing;
- The three scenarios which involve directing liquor to sewer are the three worst performing due to the cost of this practice; and
- Scenario 3 (which involves a nutrient recovery step but no subsequent BO step) represents the highest cost of all, largely due to the additional Mogden charges levied by the water industry for such liquor.

The results showing the net cost/benefit of the environmental damage costs and financial costs under our Central Case 2 are presented in Table 4-2 and Figure 4-2. Detailed results for each scenario are presented in Appendix 6. The key features of these results can be summarised as follows:

- At a net cost of £13.18 per tonne of feedstock, Scenario 5 (in which liquor undergoes BO prior to being discharged to watercourse) offers the solution with lowest net financial and environmental cost. This is because although the BO process is relatively expensive, there are assumed to be low costs for discharge to watercourse compared with discharge to sewer, albeit Scenario 4, in which liquor is discharged to sewer following BO, has been modelled as the second best performing;
- The additional costs of the nutrient recovery process, which are not fully offset by the displacement of synthetic fertiliser, are such that Scenarios 1 and 2 perform slightly worse than Scenarios 3 and 4;
- The high transport and spreading costs associated with the Baseline scenario (direct application of the whole digestate to land) far outweigh the benefits of no processing costs. As a result, aside from Scenario 7 (whereby fibre and liquor are directly applied to land following dewatering) for the same reasons, it is the worst performing scenario; and
- Scenario 3 (which involves a nutrient recovery step but no subsequent BO step) performs similarly badly, largely due to the additional Mogden charges levied by the water industry for such liquor.

Under both Central Cases, it is clear from this analysis that the bulk of the costs are financial, with a relatively small impact from environmental damage costs or benefits. As discussed above, for this reason, we have undertaken sensitivity analysis on the value of damage costs, the results of which are presented in Section 4.2.4.

Table 4-1: Net Costs (£ per Tonne of Feedstock received) – Central Case 1: Dilution to 20% Dry Solids

Fraction	**Treatment Processes**			**Scenarios**							
				Baseline	**1**	**2**	**3**	**4**	**5**	**6**	**7**
				Whole Digestate to Land	**Nutrient Recovery, BO, Sewer**	**Nutrient Recovery, BO, Water-course**	**Nutrient Recovery, Sewer**	**BO, Sewer**	**BO, Water-course**	**Liquor Direct to Sewer**	**Liquor Direct to Land**
Whole Digestate	Direct application to land			8.76							
	Dewatering (Centrifuge)				5.66	5.66	5.66	5.66	5.66	5.66	5.66
Liquor	Nutrient recovery	Biological oxidation	Sewer		9.75						
			Water-course			7.62					
		Sewer					14.41				
	Biological oxidation	Sewer						7.02			
		Watercourse							5.10		
	Direct disposal to sewer									11.68	
	Direct application to land										8.46
Fibre	Direct application to land				2.25	2.25	2.25	2.25	2.25	2.25	2.25
	Total £ per Tonne Feedstock			**8.76**	**17.66**	**15.53**	**22.32**	**14.93**	**13.01**	**19.59**	**16.37**

Table 4-2: Net Costs (£ per Tonne of Feedstock received) – Central Case 2: Dilution to 10% Dry Solids

Fraction	**Treatment Processes**			**Scenarios**							
				Baseline	**1**	**2**	**3**	**4**	**5**	**6**	**7**
				Whole Digestate to Land	**Nutrient Recovery, BO, Sewer**	**Nutrient Recovery, BO, Water-course**	**Nutrient Recovery, Sewer**	**BO, Sewer**	**BO, Water-course**	**Liquor Direct to Sewer**	**Liquor Direct to Land**
Whole Digestate	Direct application to land			23.49							
	Dewatering (Centrifuge)				5.66	5.66	5.66	5.66	5.66	5.66	5.66
Liquor	Nutrient recovery	Biological oxidation	Sewer		9.93						
			Water-course			7.79					
		Sewer					16.69				
	Biological oxidation	Sewer						7.19			
		Watercourse							5.27		
	Direct disposal to sewer									13.96	
	Direct application to land										24.54
Fibre	Direct application to land				2.25	2.25	2.25	2.25	2.25	2.25	2.25
	Total £ per Tonne Feedstock			**23.49**	**17.83**	**15.70**	**24.60**	**15.10**	**13.18**	**21.86**	**32.45**

Figure 4-1: Summary of Results (Central Case 1) – Net Costs Dilution to 20% Dry Solids

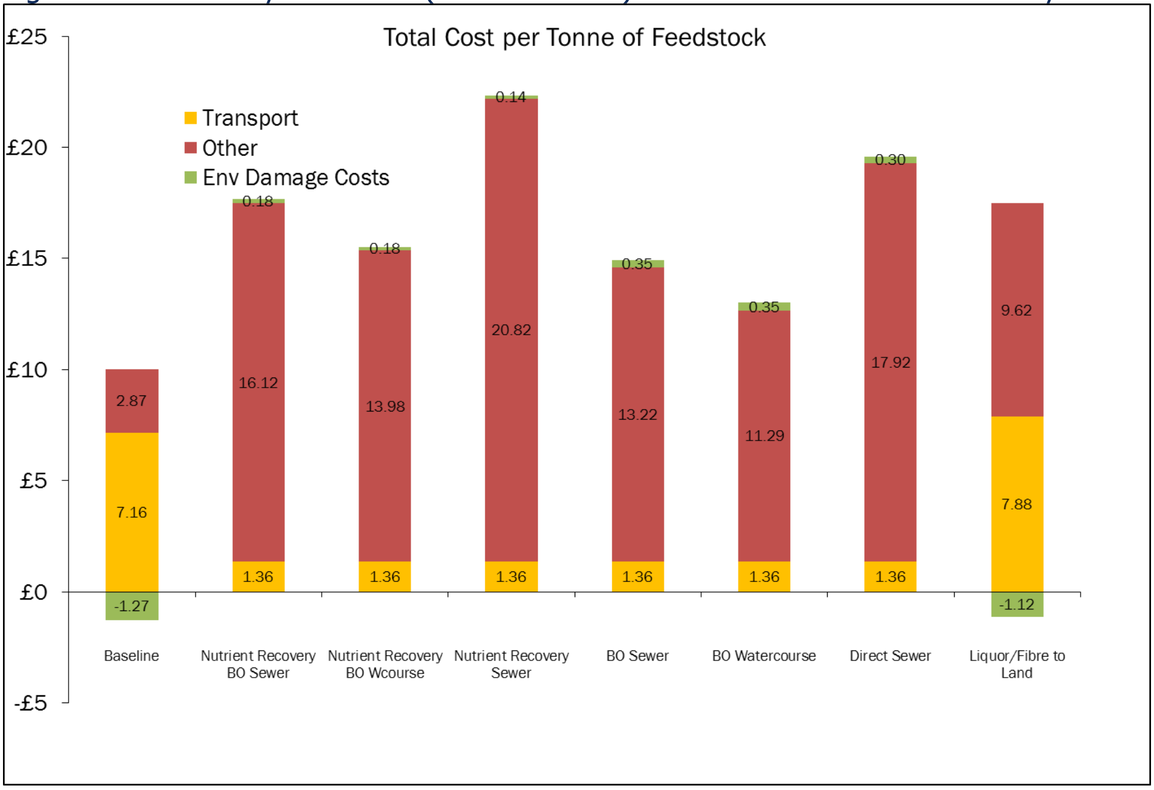
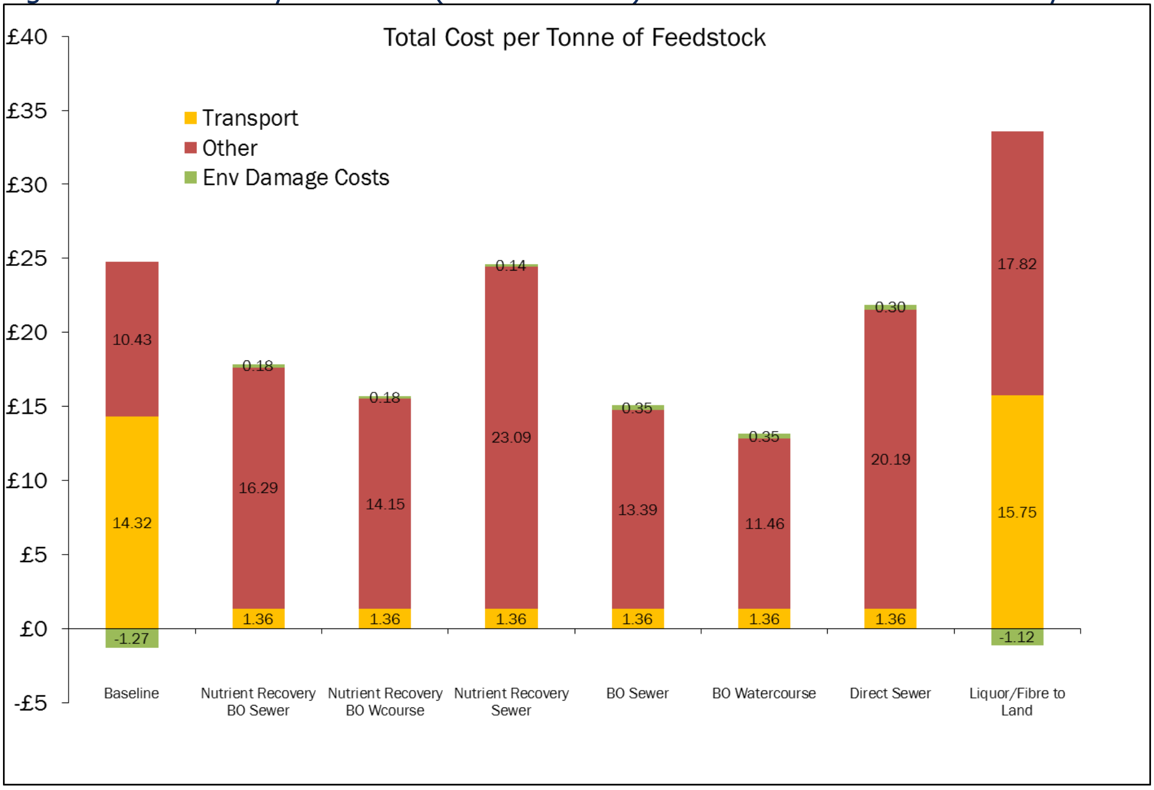


Figure 4-2: Summary of Results (Central Case 2) - Net Costs Dilution to 10% Dry Solids



4.1.1 Comparison of Results from Central Cases

All scenarios are more expensive under Central Case 2 than under Central Case 1. This is largely because dilution of the feedstock as received (Dry Solids content 25.95%) requires far more water in Central Case 2 (diluted to Dry Solids content of 10%) than in Central Case 1 (diluted to Dry Solids content of 20%), and produces far greater quantities of digestate for subsequent management. This suggests that it is the benefits in the core AD process, such as improved mixing and removal of contaminants, which will drive lower dry solids content within the feedstock, rather than any benefit within the dewatering process.

The performance of the Baseline scenario under the two Central Cases can be explained in a similar way. When significant dilution of the feedstock occurs, as under Central Case 2, the application of whole digestate to land performs far worse than under Central Case 1. In contrast, most of the scenarios whereby liquor is applied to sewer perform relatively better compared with the Baseline under Central Case 2, as they are not incurring significantly greater transport and spreading costs for the additional liquor from the dewatering process.

Our analysis therefore demonstrates that the attractiveness of dewatering to plant developers and operators is highly dependent upon the level of dilution of the feedstock to the digester. This suggests that:

- At plant design stage, any decision relating to dewatering of digestate cannot be taken in isolation from consideration of upstream costs relating to mixing and removal of contaminants and retention time within the digester, all which also depend on the level of dilution; and
- If dewatering is being considered as a retrofit to an existing plant, if this is already operating at low dry solids content, operators should consider whether the wider plant operating costs associated with reducing the dilution of the feedstock to the digester outweigh the benefits associated with lower digestate management costs following dewatering.

4.2 Sensitivity Analysis

4.2.1 Scale of Plant

As set out in Section 2.5.1, we have modelled the impact of either increasing plant size from under both Central Cases of 25 ktpa to 50 ktpa or decreasing it to 10 ktpa, as presented in

Figure 4-3 to Figure 4-6. The effect of doubling plant capacity is to reduce Capex and Opex by approximately 20% on a per tonne basis, resulting in slightly lower annualised costs for most dewatering scenarios. This is such that these become slightly closer to, albeit still outperformed by, the Baseline scenario. Unsurprisingly, reducing plant capacity to 10 ktpa has the opposite effect, but it is important to note that neither extremes change the relative performance of the scenarios under both Central Cases.

Figure 4-3: Net Costs Central Case 1: Dilution to 20% Dry Solids, 10 ktpa Undiluted Equivalent Capacity

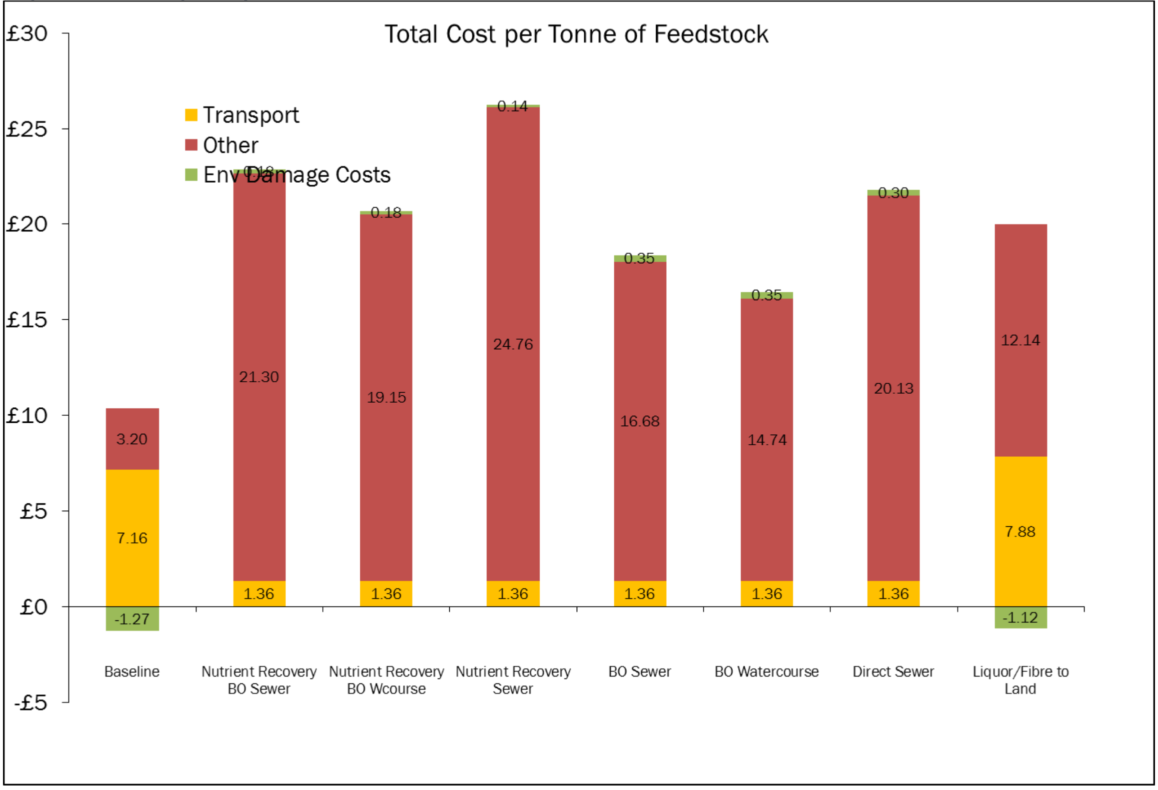


Figure 4-4: Net Costs Central Case 2: Dilution to 10% Dry Solids, 10 ktpa Undiluted Equivalent Capacity

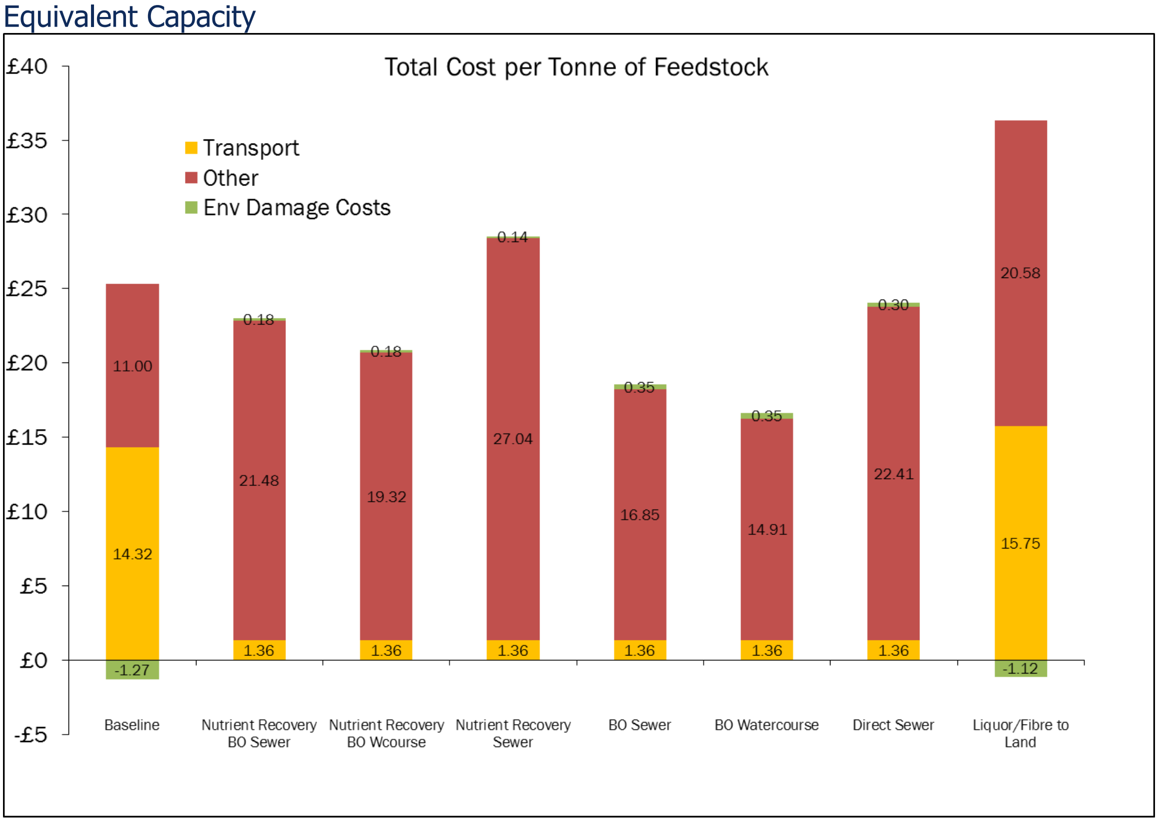


Figure 4-5: Net Costs Central Case 1: Dilution to 20% Dry Solids, 50 ktpa Undiluted Equivalent Capacity

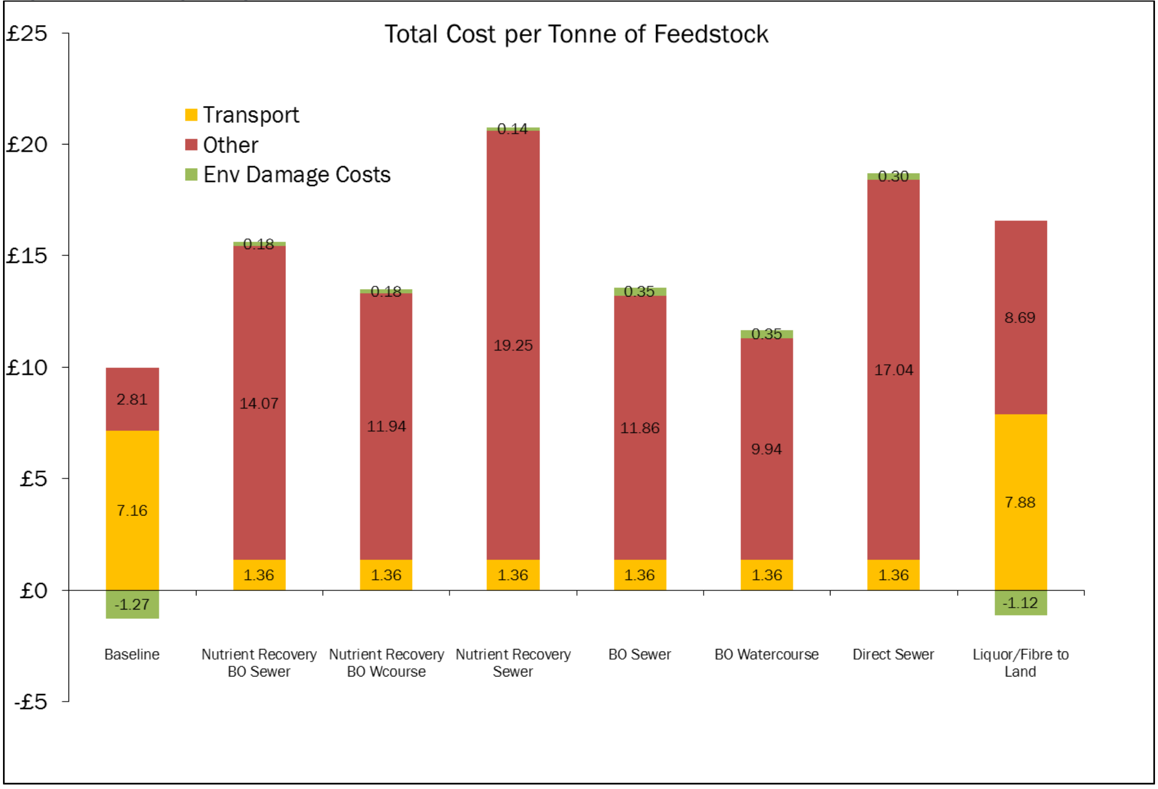
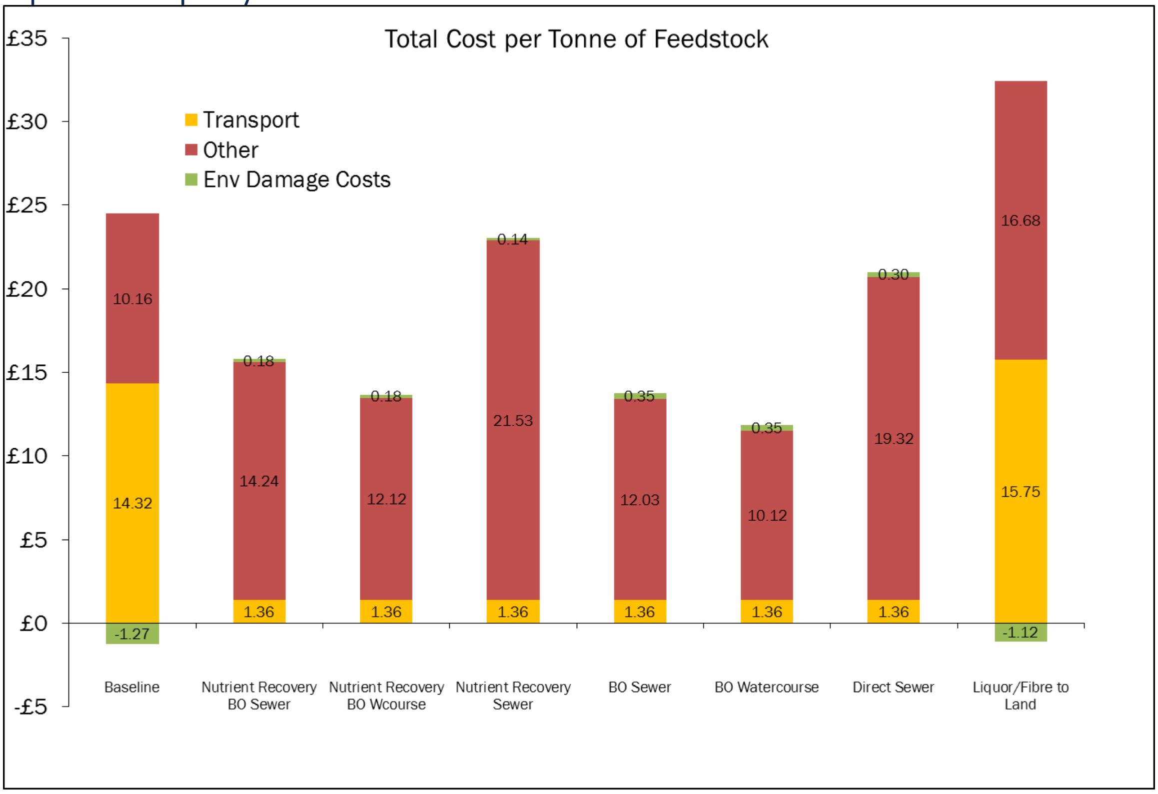


Figure 4-6: Net Costs Central Case 2: Dilution to 10% Dry Solids, 50 ktpa Undiluted Equivalent Capacity



4.2.2 Distance to Land

The transport distance required to move digestate (either whole, fibre or liquor) to the land available for spreading has a significant bearing on costs. Due to the need to avoid contamination that would breach ABPR requirements, it is assumed the vehicles are *not* carrying any other material on return journeys (i.e. 'backhauling'), and therefore a round-trip distance has been used in the model for cost calculation.

As described in Section 2.5.2, the round-trip distance under both Central Cases is 80km, whilst Figure 4-7 and Figure 4-8 represent the effect of an average round-trip distance of 280km, to reflect the worst case scenario from a previous preferred bidder for one the Welsh Food Waste Hubs. This longer distance has a significant impact on net costs, such that under Central Case 1, five of the six dewatering scenarios, which also involve some form of liquor treatment, become preferable to the Baseline. This increases to all six such scenarios outperforming the Baseline under Central Case 2.

Figure 4-7: Net Costs Central Case 1: Dilution to 20% Dry Solids, 280km Round-trip

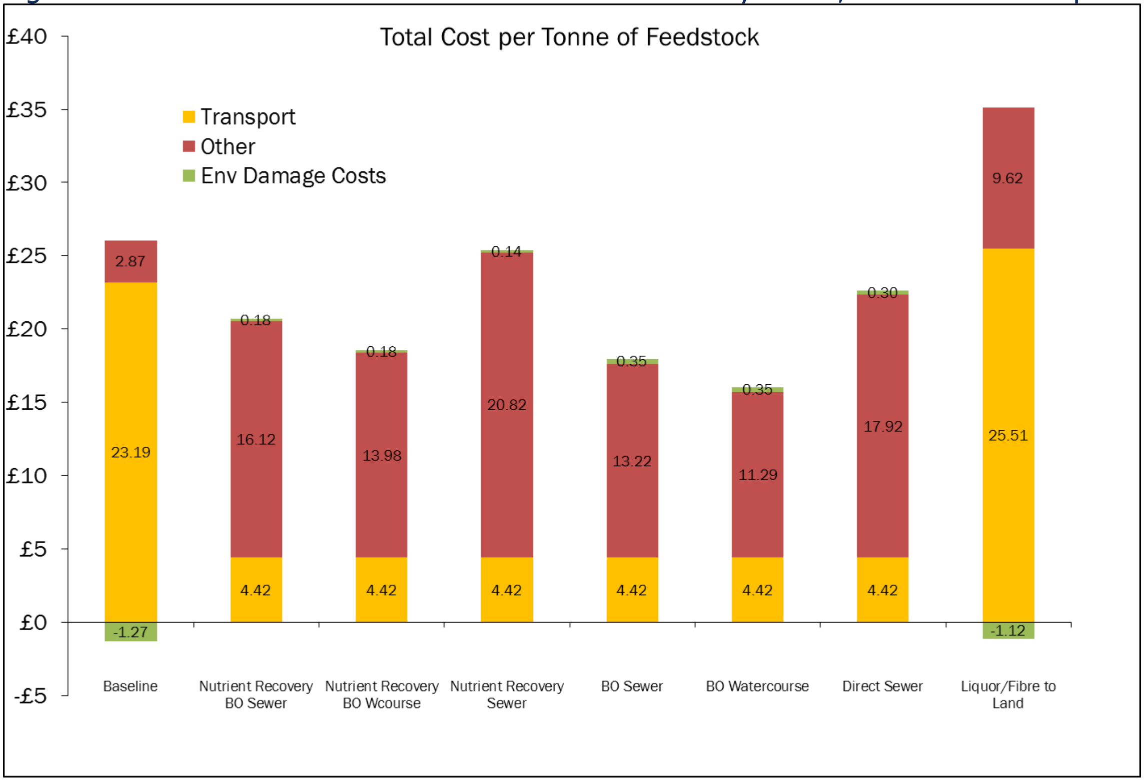
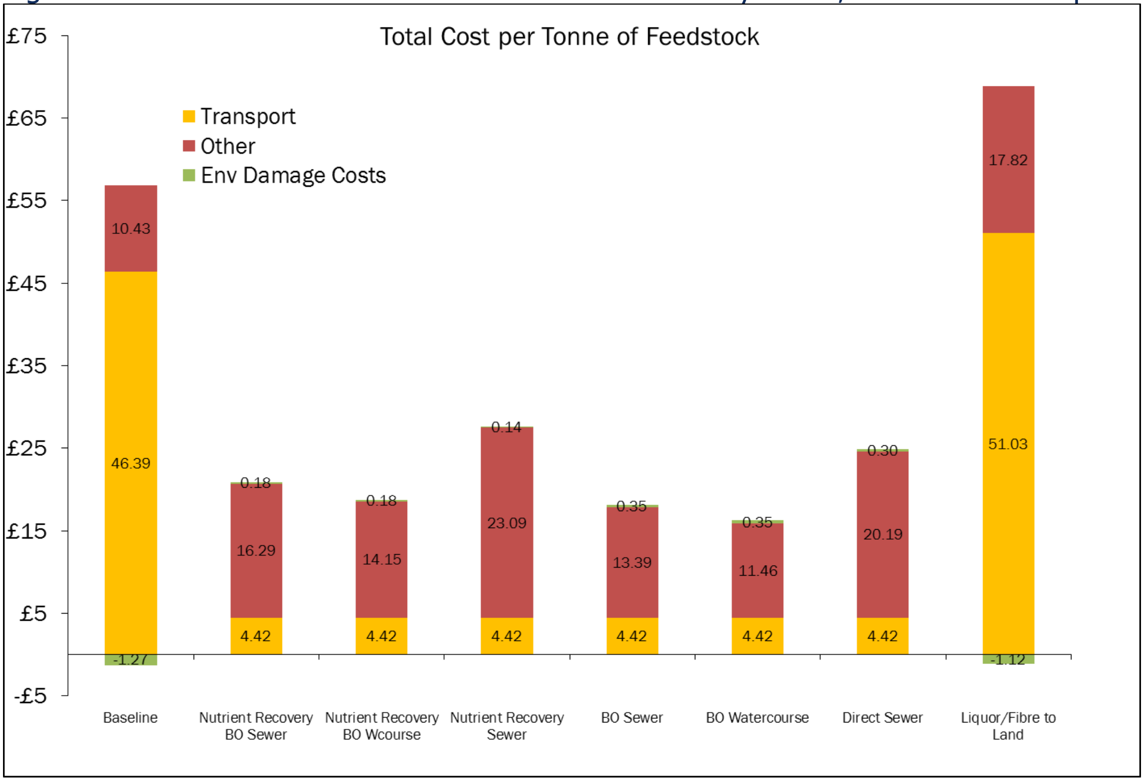


Figure 4-8: Net Costs Central Case 2: Dilution to 10% Dry Solids, 280km Round-trip



4.2.3 Weighted Average Cost of Capital

As shown in Figure 4-9 to, the impact of raising the assumed cost of capital to 10% or reducing this to 7% (from 8.5% under our central assumptions) is fairly minimal. These changes result in net cost variation of just £1-2 across the different scenarios and do not result in a change in relative performance under either sensitivity run.

Figure 4-9: Cost of Capital Summary, Central Case 1: Dilution to 20% Dry Solids, at 7% WACC

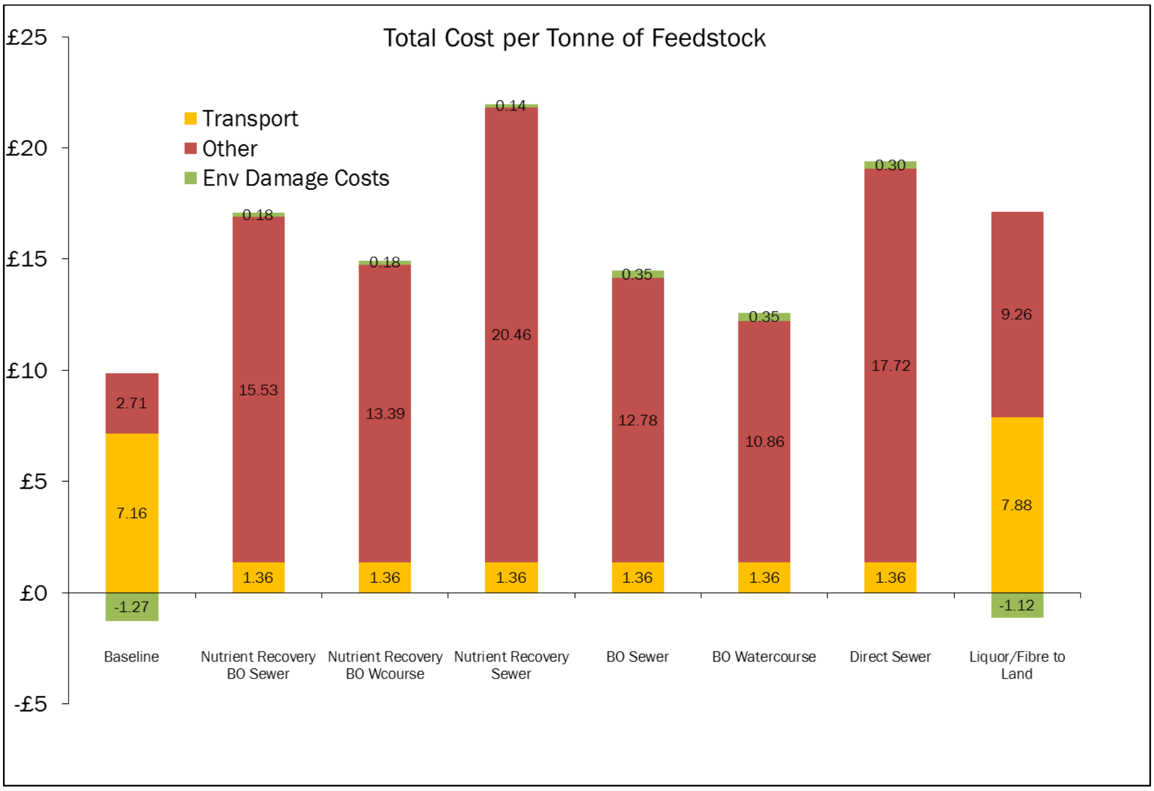


Figure 4-10: Cost of Capital Summary, Central Case 2: Dilution to 10% Dry Solids, at 7% WACC

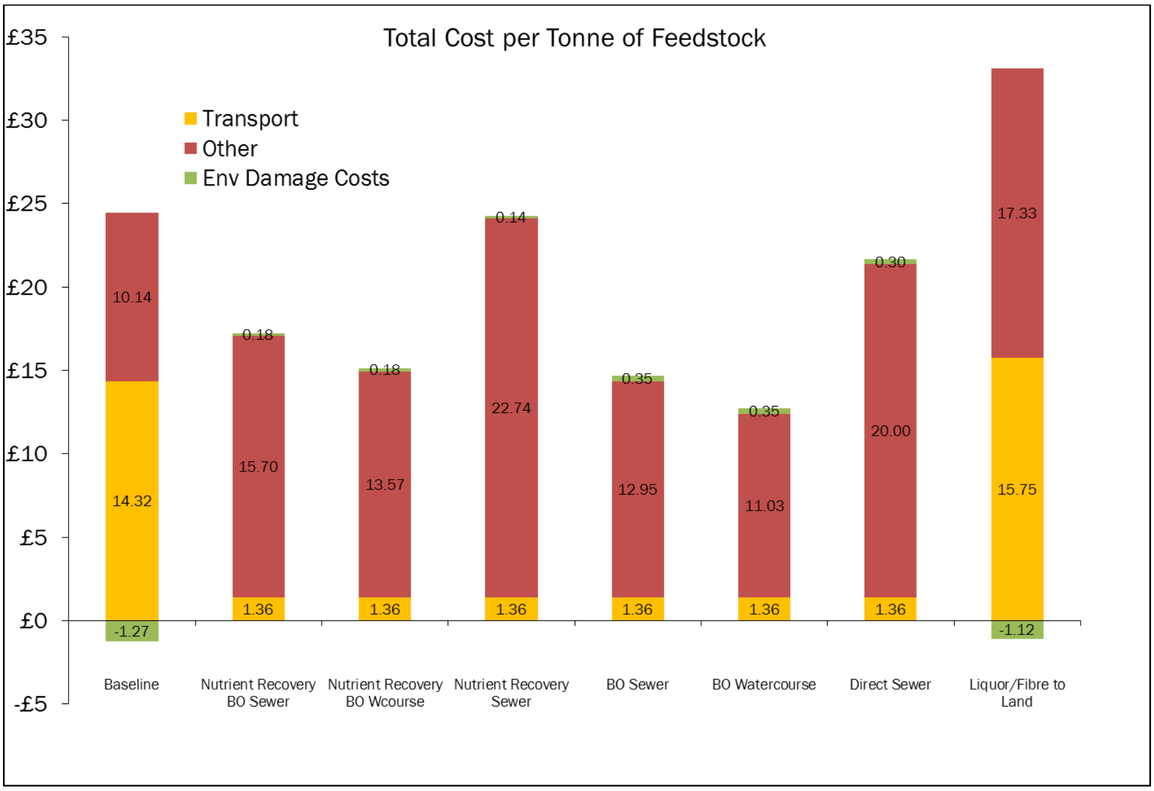


Figure 4-11: Cost of Capital Summary, Central Case 1: Dilution to 20% Dry Solids at 10% WACC

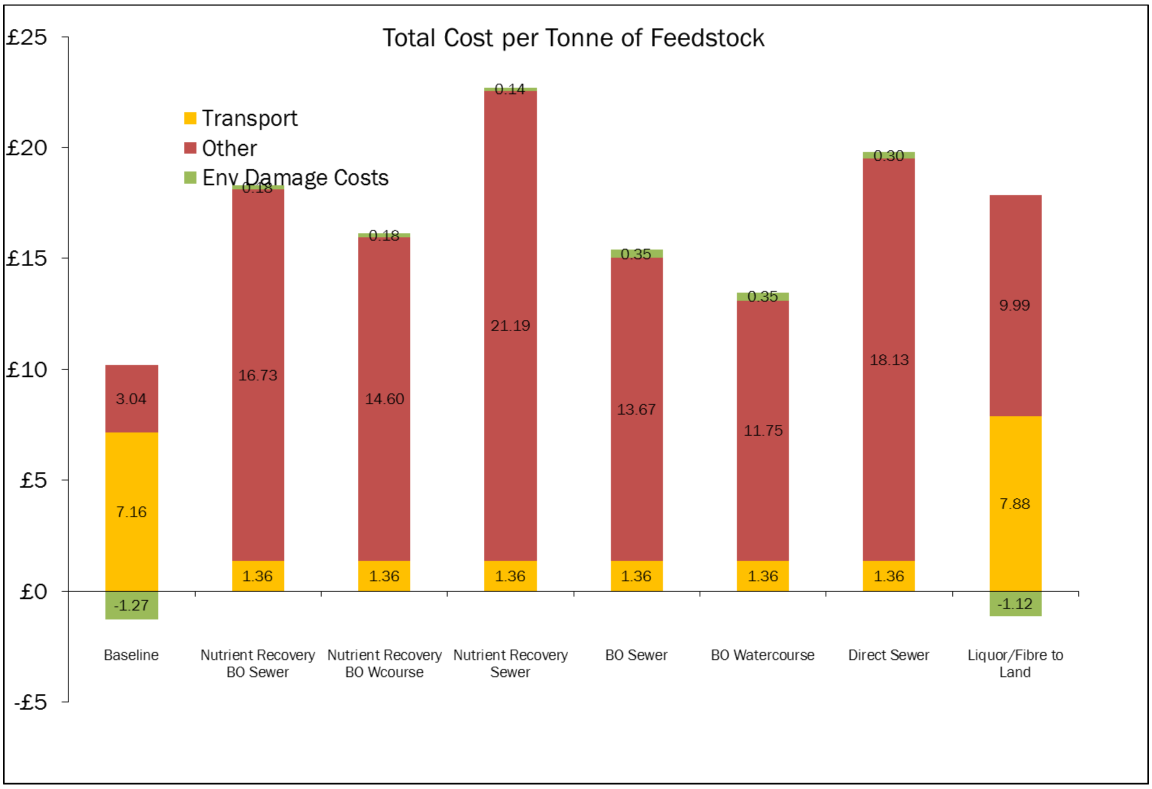
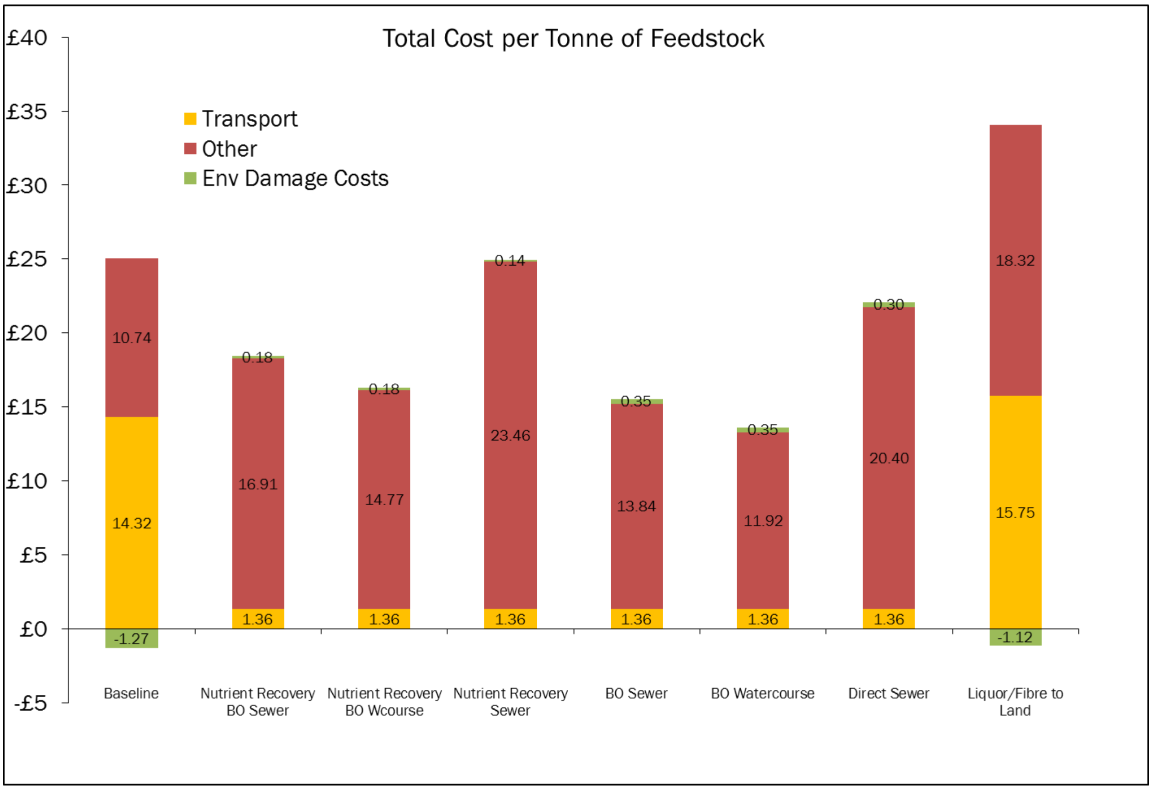


Figure 4-12: Cost of Capital Summary, Central Case 2: Dilution to 10% Dry Solids, at 10% WACC



4.2.4 Environmental Damage Costs

Figure 4-13 and

presents the results of the analysis using damage cost data developed for the EEA, which applies a greater cost to pollutant impacts than the dataset used under the Central Cases.[51]

The change in damage costs has the most profound impact on those options (the Baseline and Scenario 7) in which digestate can be used to displace a significant amount of ammonium-based fertiliser, which requires substantial energy consumption in the manufacturing process. Under Central Case 1, the Baseline scenario now performs even better than alternatives. Under Central Case 2 it also closes the gap with the best performing dewatering scenarios.

Only a very minor improvement is seen for the two nutrient recovery scenarios (Scenarios 2 and 3) as these only recover a fairly small amount of phosphorus, and the phosphorus fertiliser manufacturing process uses less energy and resources than is the case with ammonia fertilisers.

It should be acknowledged, however, that under both Central Cases, the effective ranking of scenarios does not change compared with the use of our central damage cost assumptions.

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[51] *European Environment Agency (2011) Revealing the Costs of Air Pollution from Industrial Facilities in Europe, EEA Technical Report No 15/2011*

Figure 4-13: Cost Summary, Central Case 1: Dilution to 20% Dry Solids, using EEA Damage Costs

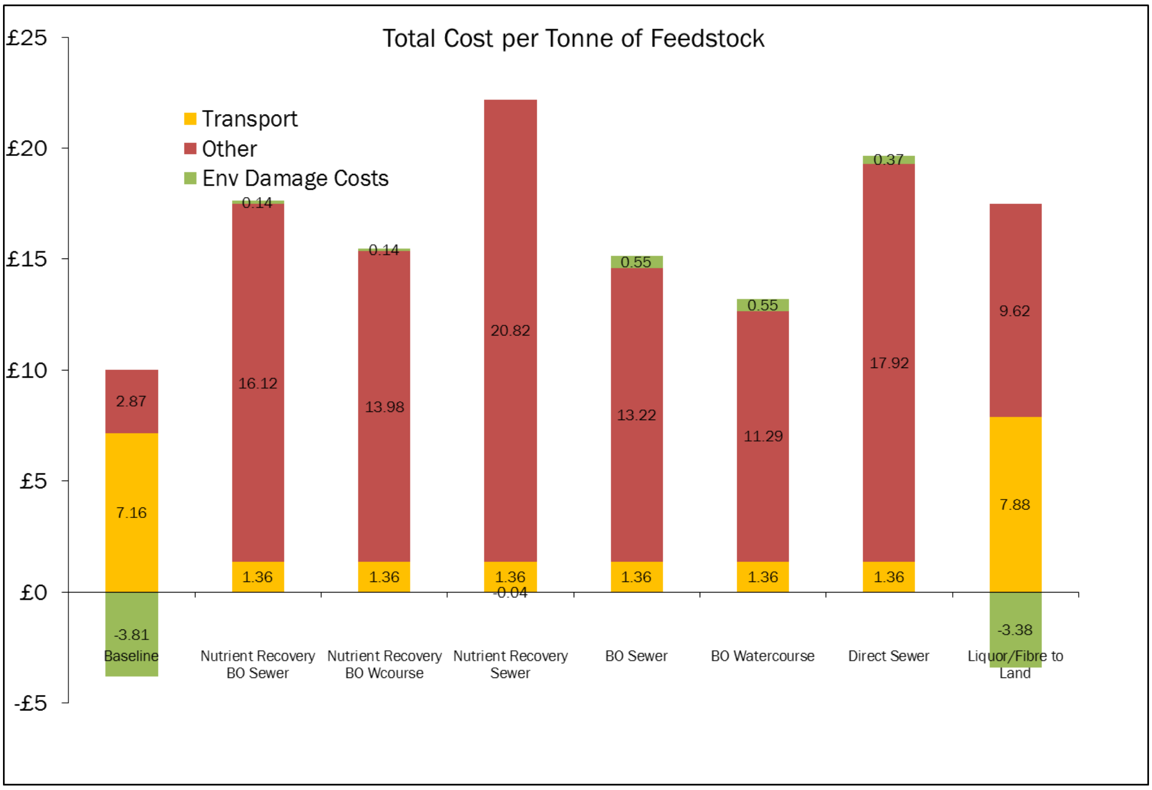
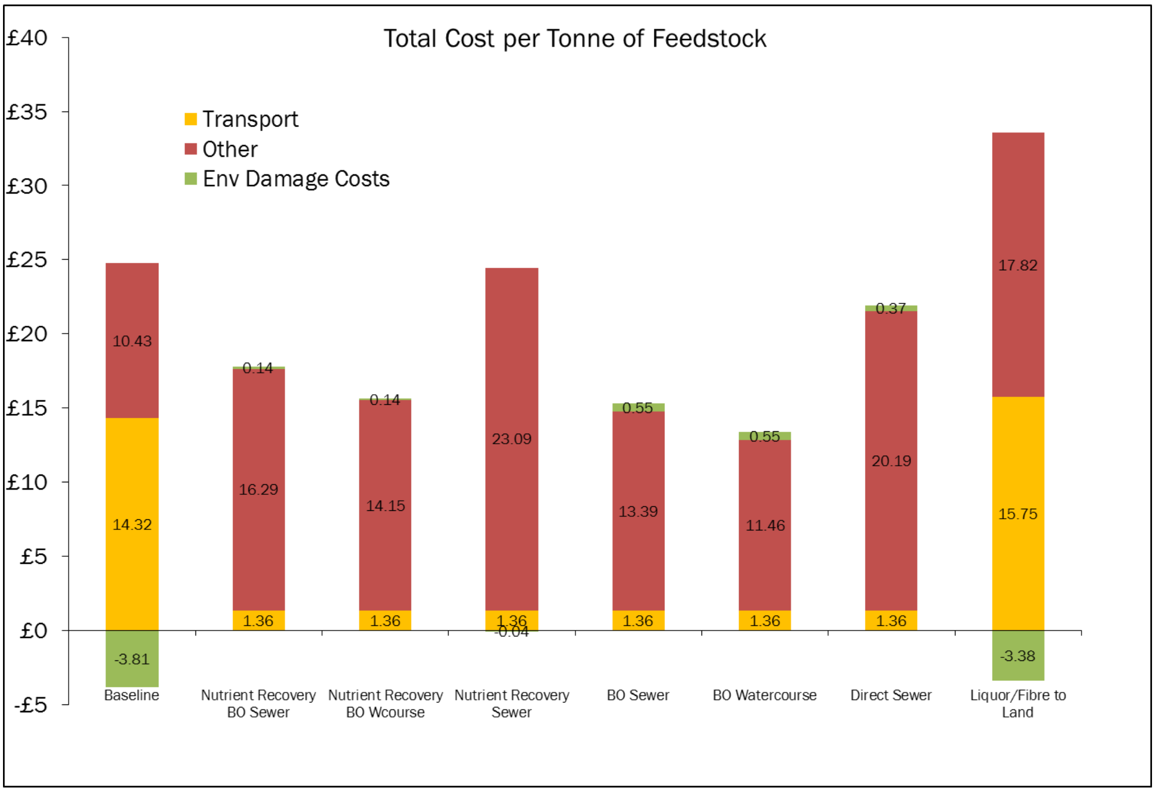


Figure 4-14: Cost Summary, Central Case 2: Dilution to 10% Dry Solids, using EEA Damage Costs



4.2.5 Spreading Costs

Under Central Case 1, Figure 4-15 shows that increasing the cost of spreading from £5 to £7.50 per tonne (net) has a significant effect on the results, particularly for the Baseline and for Scenario 7, whereby both fibre and liquor are spread direct to land. The higher price brings the cost of the baseline closer to some of the dewatering options, albeit it remains the most attractive option. Conversely, shows that decreasing the spreading costs to £2.50 per tonne (net) is such that the Baseline performs even better than all other scenarios, whilst Scenario 7 also becomes competitive with all dewatering scenarios.

Under Central Case 2, Figure 4-16 shows that increasing the cost of spreading to from £5 to £7.50 per tonne (net) is such that the Baseline and Scenario 7 both perform even worse compared with all other scenarios. Conversely, Figure 4-18 shows that a lower spreading price is such that baseline becomes more attractive than some of the dewatering scenarios and closer to the overall cost of the others.

Figure 4-15: Cost Summary, Central Case 1: Dilution to 20% Dry Solids, High Spreading Costs

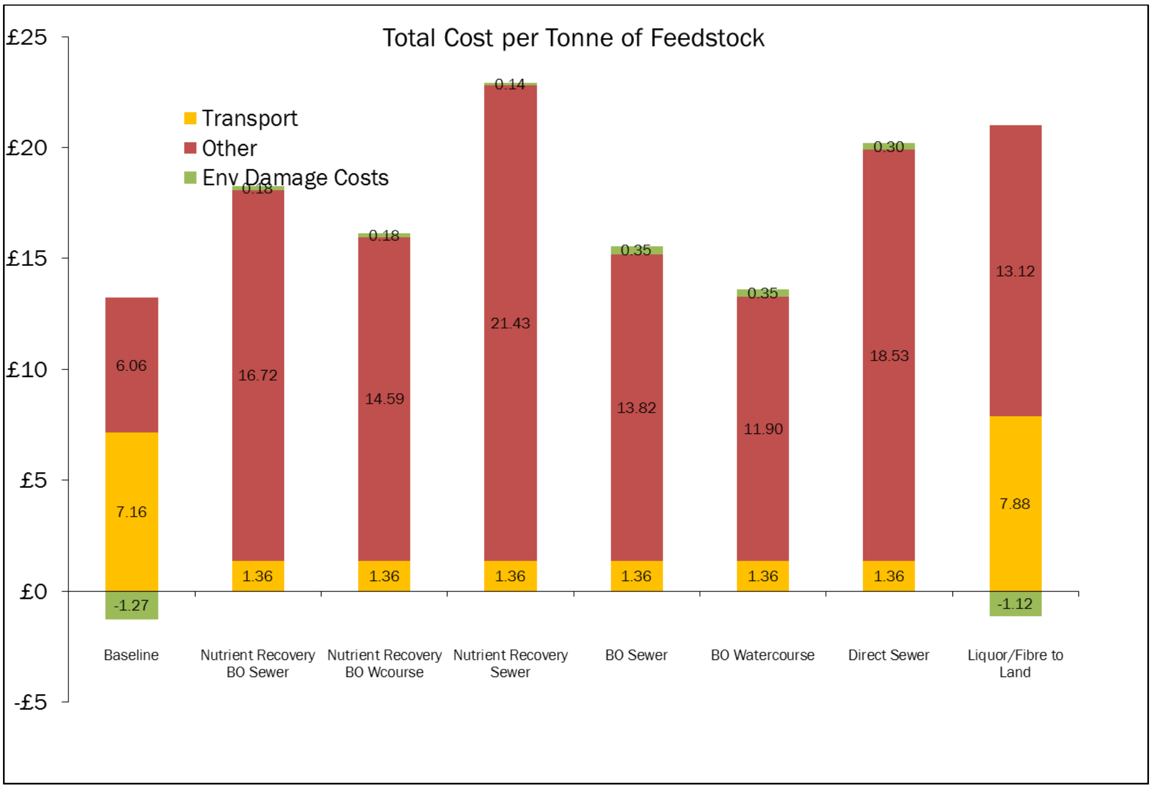


Figure 4-16: Cost Summary, Central Case 2: Dilution to 10% Dry Solids, High Spreading Costs

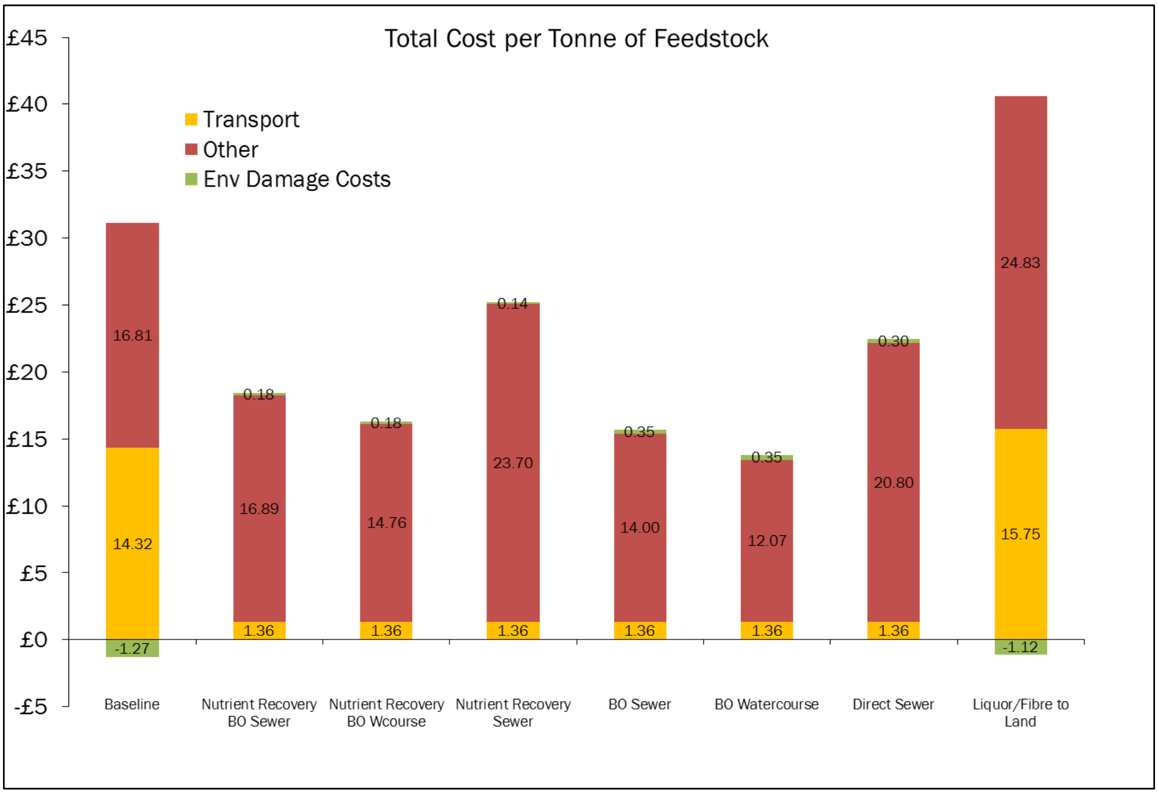


Figure 4-17: Cost Summary, Central Case 1: Dilution to 20% Dry Solids, Low Spreading Costs

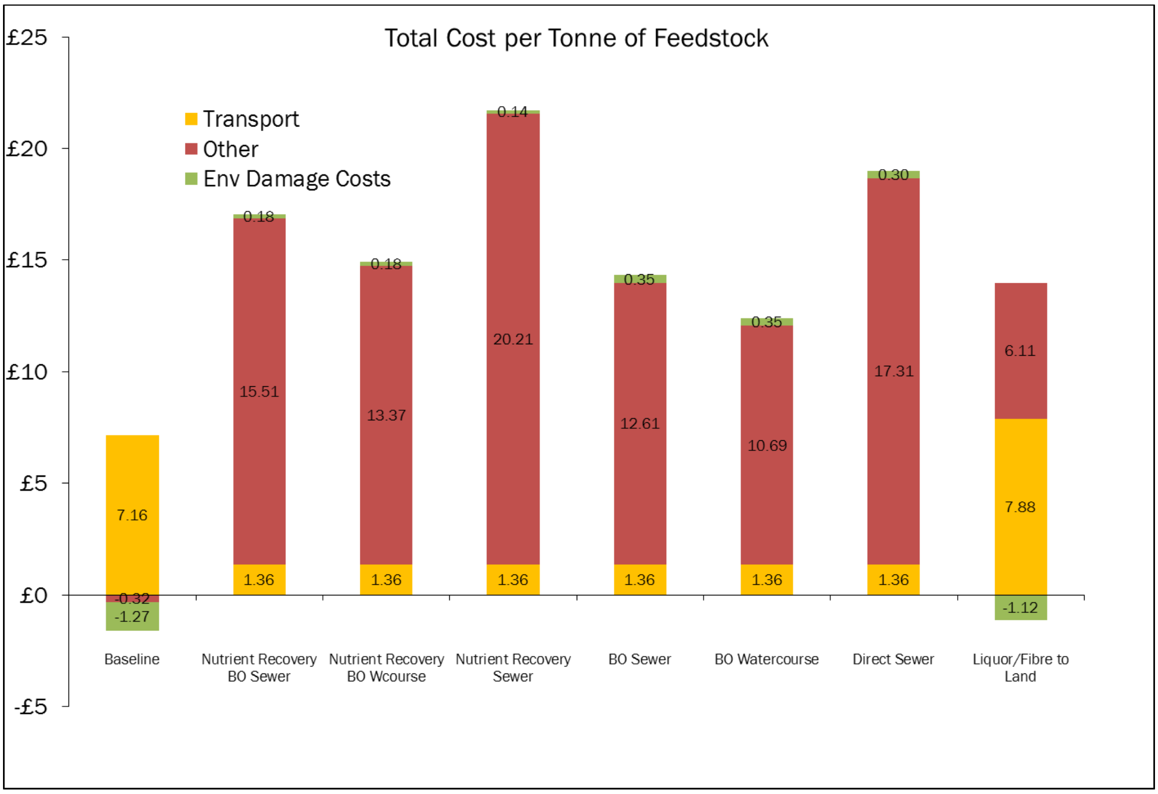
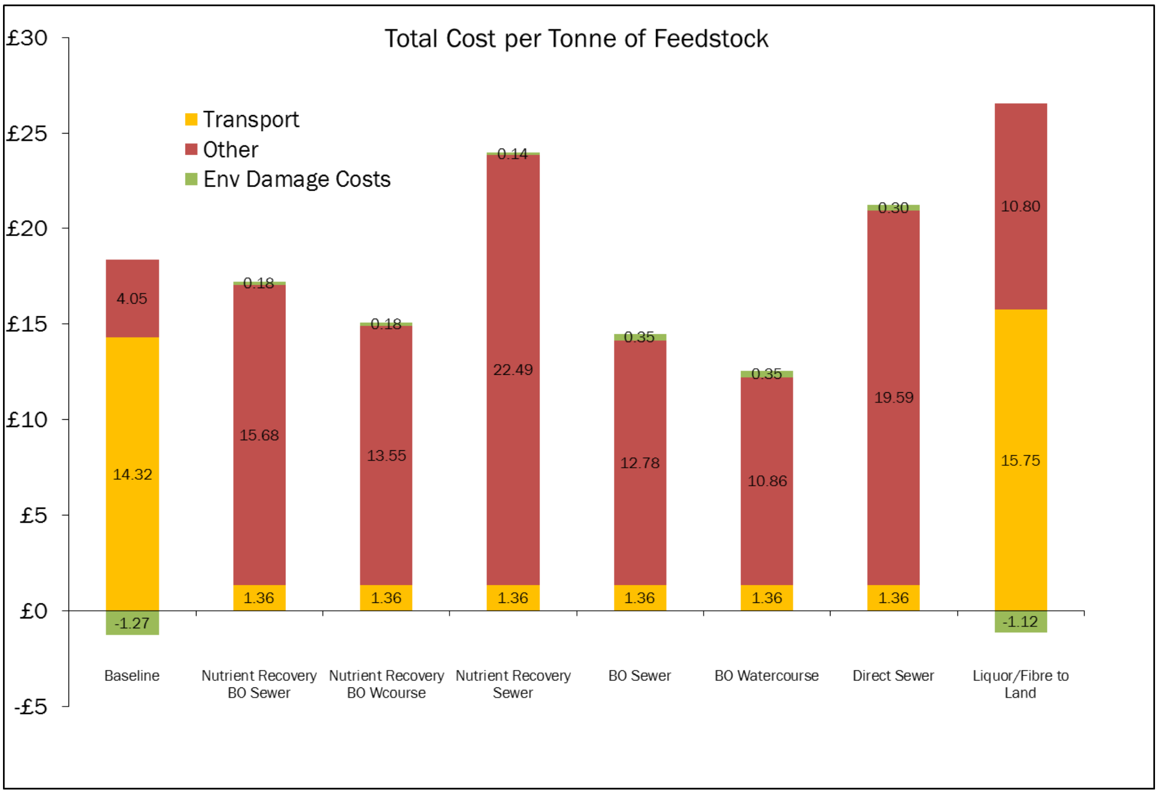


Figure 4-18: Cost Summary, Central Case 2: Dilution to 10% Dry Solids, Low Spreading Costs



4.3 Calculation of the Recycling Rate for Dewatering Approaches

As discussed in Section 1.1, the Welsh Government is currently consulting upon a proposed methodology for determining how management of digestate contributes to local authority recycling targets.[52] Through applying the formula set out within the Consultation Document, in Figure 4-19 we have presented the results for the recycling rate which would apply under both the Central Cases modelled for this study.

Figure 4-19 shows that the proposed Welsh Government methodology hugely favours solutions that involve the high capture of Nitrogen and dry solid content. Ultimately, only the Baseline Scenario and Scenario 7 (in which both liquor and fibre are applied directly to land after dewatering) are able to offer a high performance under the methodology. In respect of this analysis, we have made the following observations:

- It is not clarified within the Consultation document whether 'total Nitrogen' is all the Nitrogen in the digestate or just that part that is 'readily available' as a nutrient to plants. As the document states that the output should be 'beneficial' to agriculture or horticulture, we have assumed that only the Nitrogen that is in a form that is immediately available should count in the formula. It is possible, however, depending on land application methods, soil and weather conditions, that the organic Nitrogen (the fraction that is not immediately available for crop uptake) will become available as a slow-release nutrient. This would increase the reported total Nitrogen, thereby increasing the recycling rate;
- Conversely, after dewatering, if the liquor is sent to sewer or watercourse this is assumed to contain all available Nitrogen from the digestate, thus resulting in a 0% recycling rate.[53] The assumption within our model is therefore that the RAN (Ammonium-N), which is in a soluble form is entirely separated from the whole digestate into the liquor. In reality, however, it is recognised that this may not be the case, although there is little solid data on this specific area in the published literature;
- As stated in Section 3.4.3, BO processes convert BOD into a biological sludge as a by-product which could, in theory, be returned as a feedstock to the digester. It should be noted, however, that within the scope of this study, it has not been possible to model the impacts of returning this sludge (and its associated Nitrogen content) to the digester, in terms of calculation of the recycling rate under the proposed Welsh Government methodology; and
- It is clear that the methodology will function as a huge disincentive to dewatering scenarios whereby the liquor is not directly applied to land. This might seem appropriate in terms of direct land application being potentially the best option from a LCA (or 'environmental') perspective, which is borne out in one part of the results from this study.[54] Our scenario modelling, however, shows that when the dry solids content of the feedstock to the digester is at 10% (as under Central Case 2), when considered within the framework of CBA, other dewatering and digestate management scenarios appear to be preferable.

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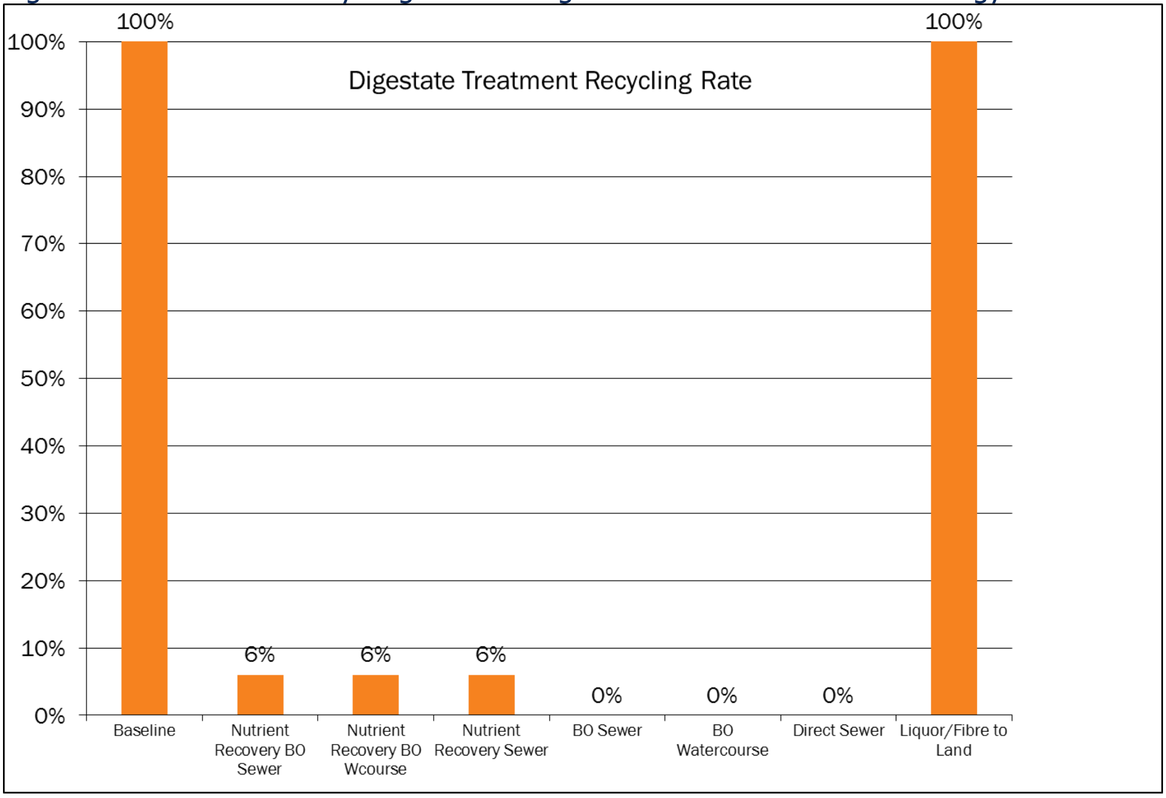
[52] *Welsh Government (2012) Consultation Document – Draft Guidance in support of The Recycling, Preparation for Re-use and Composting Targets (Definitions) (Wales) Order 2011, Regulations 4 and 5 of The Recycling, Preparation for Re-use and Composting Targets (Monitoring and Penalties) (Wales) Regulations 2011 Made under the Waste (Wales) Measure 2010 and Consultation on issues affecting de-watering, apportionment of recycling rates from anaerobic digestion, composting and the recycling of incinerator bottom ash (IBA)*

[53] *Only where nutrient recovery is employed is a small amount of Nitrogen captured*

[54] *For reasons set out in Section 2.4.5 , it should be noted, however, that the impact of emissions to air from transport has been excluded from the analysis of environmental impacts. Should this impact have been included, the environmental impacts from the management of whole digestate would have been higher than has been presented*

Figure 4-19: Potential Recycling Rates using Welsh Government Methodology



5.0 Conclusions and Recommendations

The conclusion and recommendations from the study can be summarised as follows:

- Under Central Case 1 (dilution of feedstock to 20% dry solids), at a net cost of £8.76 per tonne of feedstock, the Baseline scenario (direct application of the whole digestate to land) offers the solution with lowest net financial and environmental cost. Although transport costs are significantly higher than for other scenarios, the lack of requirement for additional processing and the assumed potential for the material to function as a substitute for the use of synthetic fertilisers, result in far lower costs than all other scenarios;
- Under our Central Case 2 (dilution of feedstock to 10% dry solids), however, at a net cost of £13.18 per tonne of feedstock, Scenario 5 (in which liquor undergoes biological oxidation prior to being discharged to watercourse) offers the solution with lowest net financial and environmental cost. At this level of dry solids content, the high transport and spreading costs associated with the Baseline scenario are such that it performs below all dewatering scenarios aside from Scenario 7, in which both fibre and liquor are separately applied directly to land;
- Our analysis therefore demonstrates that the attractiveness of digestate dewatering to plant developers and operators is highly dependent upon the level of dilution of the feedstock to the digester. This suggests that at plant design stage, any decision relating to dewatering of digestate cannot be taken in isolation from consideration of upstream costs relating to mixing and removal of contaminants and retention time within the digester, all which also depend on the level of dilution;
- Under both Central Cases, our model results show that the bulk of the costs are financial, with a relatively small impact from environmental damage costs or benefits. For this reason, we have undertaken sensitivity analysis on the value of damage costs, using damage cost data developed for the EEA, which uses higher values than under our Central Cases.[55] Whilst the performance of the Baseline scenario improves relatively better than when our central damage cost assumptions are used, under both Central Cases, the effective ranking of scenarios does not change;
- We have undertaken further sensitivity analysis on three other key variables, the outcomes from which can be summarised as follows:
  - The impact on the results of either increasing plant size under both Central Cases of 25 ktpa to 50 ktpa or decreasing it to 10 ktpa is not significant. The effect of doubling plant capacity is such that, under Central Case 1, the dewatering scenarios are slightly closer to, albeit still outperformed by, the Baseline scenario. Unsurprisingly, reducing plant capacity to 10 ktpa has the opposite effect, but it is important to note that neither extremes change the relative performance of the scenarios under both Central Cases;
  - The transport distance required to move digestate (either whole, fibre or liquor) to the land available has a significant bearing on costs. The round-trip distance under both Central Cases is 80km, but we have tested the sensitivity of the results to increasing this distance of 280km.[56] This longer distance has a significant impact on net costs, such that under Central Case 1, five of the six dewatering scenarios, which also involve some form of liquor treatment, become preferable to the Baseline. This increases to all six such scenarios outperforming the Baseline under Central Case 2;
  - The impact of raising the assumed weighted average cost of capital (WACC) to 10% or reducing this to 7% (from 8.5% under our central assumptions) is fairly minimal.

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[55] *European Environment Agency (2011) Revealing the Costs of Air Pollution from Industrial Facilities in Europe, EEA Technical Report No 15/2011*

[56] *This reflects the worst case scenario from a previous preferred bidder for one the Welsh Food Waste Hubs*

    These changes result in net cost variation of just £1-2 across the different scenarios and do not result in a change in relative performance under either sensitivity run;
  - The impact of reducing or raising 'spreading costs' (i.e. the amount paid to a farmer or landowner to take the material for land application) has a significant impact on the performance of the different scenarios. Under both Central Cases, increasing the cost of spreading to from £5 to £7.50 per tonne (net) is such that the performance of the Baseline scenario performs worse relative to the other scenarios. Conversely, when spreading costs are reduced to £2.50 per tonne (net) the Baseline's relative performance improves relative to all other scenarios. Ultimately, however, these levels of change in spreading costs do not significantly alter the ranking of the different scenarios.
- Our analysis shows that the proposed methodology to determine how management of digestate contributes to local authority recycling targets, on which the Welsh Government is currently consulting, hugely favours solutions that involve the high capture of Nitrogen and high dry solids content.[57] Ultimately, only the Baseline Scenario and Scenario 7 (in which both liquor and fibre are applied directly to land after dewatering) are able to offer a high performance under the proposed methodology; and
- It is clear that this methodology proposed by Welsh Government will function as a huge disincentive to dewatering scenarios whereby the liquor is not directly applied to land. This might seem appropriate in terms of direct land application being potentially the best option from a LCA (or 'environmental') perspective, which is borne out in one part of the results from this study.[58] Our scenario modelling, however, shows that when the dry solids content of the feedstock to the digester is at 10% (as under Central Case 2), when considered within the framework of CBA, other dewatering and digestate management scenarios appear to be preferable.

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[57] *Welsh Government (2012) Consultation Document – Draft Guidance in support of The Recycling, Preparation for Re-use and Composting Targets (Definitions) (Wales) Order 2011, Regulations 4 and 5 of The Recycling, Preparation for Re-use and Composting Targets (Monitoring and Penalties) (Wales) Regulations 2011 Made under the Waste (Wales) Measure 2010 and Consultation on issues affecting de-watering, apportionment of recycling rates from anaerobic digestion, composting and the recycling of incinerator bottom ash (IBA), 2012*

[58] *For reasons set out in Section 2.4.5 , it should be noted, however, that the impact of emissions to air from transport has been excluded from the analysis of environmental impacts. Should this impact have been included, the environmental impacts from the management of whole digestate would have been higher than has been presented*

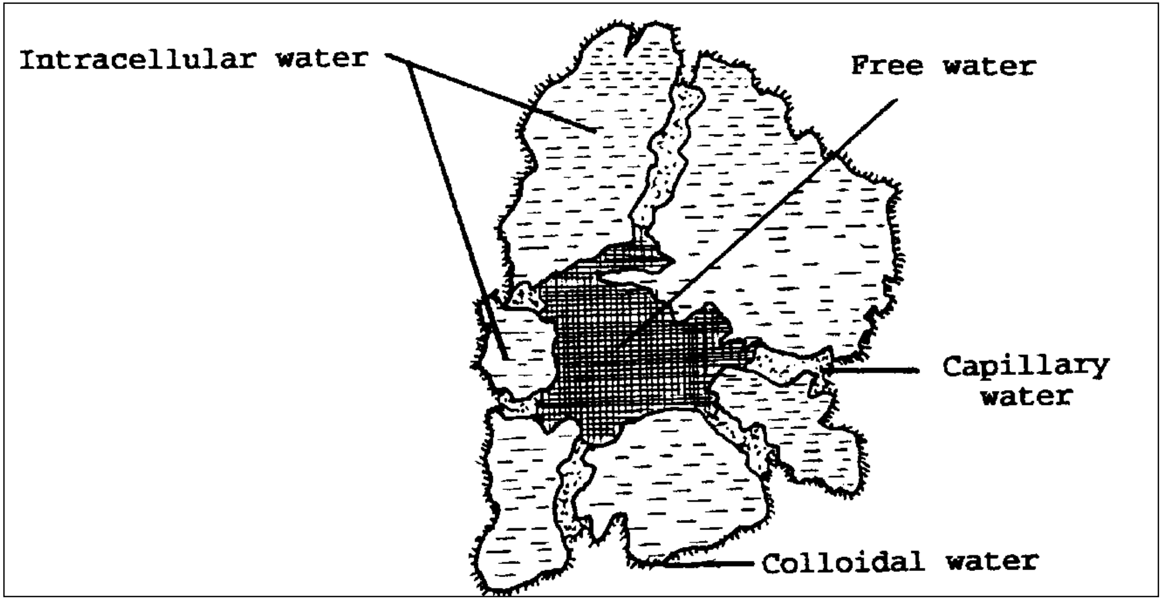
Appendix 1 Sludge Separation and Filtration

As highlighted in Section 3.3.1, there are relatively few data-points available with regard to the use of dewatering techniques on food waste digestate. In-house research by Aqua Enviro (outside of this study and not available in the public domain) has evaluated the factors influencing the relative dewaterability of food waste digestate versus sewage sludge. In particular, this testing has shown that it is extremely challenging to effectively filter food waste digestate, which significantly limits the throughput of filtration technologies. This, in turn, is likely to considerably increase the operating cost associated with using any of the filtration options.

A1.1 Sewage Sludge Digestate Dewaterability

The solids produced from the biological treatment of wastewater (biosolids) comprise a mixture of primary and secondary sludge. Primary sludge is recovered from the base of a settlement tank after simple solids settlement, and secondary sludge is the excess biomass that has been produced during the aerobic stage of treatment. The primary solids, by virtue of their settling characteristics, comprise larger particles (between 0.01 and 6 mm) that are able to settle under gravity. These are largely paper, small grit particles and large particles of faecal material. As shown in Figure A1-1 their thickening and dewatering characteristics are excellent because the discrete particles permit the release of both intracellular and capillary water during the physical process of dewatering.

Figure A1-1: The Sludge Particle



During the digestion of primary sludge, the organic fraction is broken down to leave a largely inert fraction which enhances the dewatering process. Secondary sludge is largely a mixture of bacteria and protozoa, together with much smaller colloidal solids. This secondary sludge is more difficult to biodegrade and many plants therefore now employ thermal hydrolysis to aid this process.[59] It is held together within a gelatinous matrix comprising extracellular polysaccharide produced by the bacteria and protozoa that grow during the treatment process. Unlike primary sludge they hold on tenaciously to the intracellular and capillary water. Exopolysaccharide material, however, is highly charged (around -70 millivolts) thus it is very amenable to flocculation using polyelectrolytes (poly) and in particular cationic poly. The exopolysaccharide is largely resistant to the digestion process and thus digested biosolids also have a large negative charge.

A1.2 Food Waste Digestate Dewaterability

Food waste is a predominantly organic material and after homogenisation contains almost no settleable solids. It is largely a colloidal suspension of organic material with the fibres associated with the feedstock. During the digestion process the particle size is further reduced due to hydrolysis, and the fibrous material swells and largely resists biodegradation. The anaerobic biomass does not produce exopolysaccharide and therefore whole digestate is uncharged and thus requires larger poly doses and potentially an additional source of cations (e.g. iron) to aid flocculation. Thus food waste digestate comprises a mixture of anaerobic biomass and swollen fibrous material. The fibrous material is loath to shed water and due to its large size will block conventional filter media, making this a material that is difficult to filter.

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[59] *Yao et al (2013, Anaerobic digestion of poplar processing residues for methane production after alkaline treatment, Bioresource Technology, vol 134, pages 347-352*

Appendix 2 Mass Balance Assumptions

Table A2-1 to Table A2-4 set out our mass balance assumptions which apply to all scenarios under our central case.

Table A2-1: Feedstock Assumptions

Parameter	**Value / Unit**
Dry solids content of feedstock received by the site, %	25.95[1]
Volatile solids content, as a % of DS	89.98[1]
Dry solids content of feed to digester, %	10-20[2]

Notes:
1. WRAP (2010) Food Waste Chemical Analysis, 2010
2. Refer to section 2.5.4, mass balance undertaken at two dry solids feed concentrations

Table A2-2: Summary of Mass Balance Assumptions, Whole Digestate

Parameter	**Value / Unit**	
	10% DS feed	**20% DS feed**
Dry solids content, %	2.8[1]	5.6[1]
Volatile solids, %	64.24[1]	64.24[1]
Total Nitrogen, g/kg FW	4.75[2]	9.5[3]
P_2O_5, g/kg FW	0.58[2]	1.16[3]
K_2O, g/kg FW	2.01[2]	4.02[3]

Notes:
1. Calculated on the basis of achieving a volatile solids destruction rate of 80%.
2. WRAP (2011). *Digestate & Compost in Agriculture, Bulletin 2* – November 2011
3. Figures doubled to reflect higher dry solids concentration and thus maintains balance in total nutrient load in the whole digestate

Table A2-3: Summary of Mass Balance Assumptions, Dewatering

Parameter	Value / Unit
Solids capture rate	85%[1]
Whole fibre	25%[1]
Polymer consumption	15 kg/tonne of dry solids[1]
Dilution water applied to centrifuge, as a percentage of whole digestate volume	10%[1]
Total Nitrogen, in fibre, as a percentage of amount in whole digestate	22.6%[2]
P_2O_5, in fibre, as a percentage of amount in whole digestate	50%[3]
K_2O , in fibre, as a percentage of amount in whole digestate	50%[3]

Notes:

1. Estimated from consideration and assessment of a range of data points obtained from equipment suppliers, the most robust of which have been aggregated to provide a single value
2. WRAP (2011). *Digestate & Compost in Agriculture, Bulletin 2* – November 2011. For modelling purposes RAN (77.4%), which is defined as soluble ammonia-nitrogen, is assumed to remain solely in the liquor fraction. In reality a proportion of this may remain within the separated fibre, but this proportion is not adequately reported upon / quantified in the scientific literature
3. Estimated from analysis undertaken by Aqua Enviro and Zhang, Z., Heaven, S. and Banks, C.J. (2012) *Co-digestion of source segregated domestic food waste to improve process stability*. Bioresource Technology, 114, 168–178

Table A2-4: Chemical Additive Requirements

Parameter	Unit	Value
Polymer (Dewatering)	kg / tonne feedstock	1.09[1]
Ferric (Dewatering, watercourse pre-treatment)	kg / tonne feedstock	1.82[1]
Magnesium Chloride (Nutrient Recovery)	kg / tonne feedstock	0.02[2]
Sodium Hydroxide (Nutrient Recovery)	kg / tonne feedstock	0.00191[2]

Notes:

1. Estimated from in house testing by Aqua Enviro and discussions with equipment suppliers
2. Estimated from consideration and assessment of a range of data points obtained from equipment suppliers, the most robust of which have been aggregated to provide a single value

Appendix 3 Detailed Cost Assumptions for Scenario Modelling

A3.1 Capex Data

Capex data has been drawn from supplier quotes and market intelligence gained by Aqua Enviro. Capital expenditure is required for storage, liquor processing, and for piping liquor to the sewer. Other Capex data were not included as they were estimated to be too small to be material to the modelling, such as equipment for disposal to watercourse, and disposal licenses. The estimated Capex requirements for purchasing and commissioning the additional plant are shown in Table A3-1.

Table A3-1: Summary of Capex Estimates

Item	**Throughput (tpa) and Cost (£)**[1]		
	10,000	**25,000**	**50,000**
Whole Digestate or Liquor Storage	175,000	360,000	690,000
Fibre Storage	60,000	140,000	270,000
Centrifuge	205,500	294,000	447,000
Nutrient Recovery	261,000	343,000	440,500
Biological Oxidation	328,000	525,000	820,000
Disposal to Sewer	5,000	8,000	10,000

Notes

1. All estimates have been developed from information derived from (commercially confidential) personal communications with equipment suppliers from the food waste and waste water industries. The data obtained has then been adapted to reflect the flow rates assumed for this study

When converted to an annualised figure for each tonne of feedstock presented to the AD plant the comparison of costs a comparison of the relative commercial performance can be calculated, as shown Table A3-2.

Table A3-2: Summary of Cost Assumptions, Capex

Item	Throughput (t p/a) and Cost per tonne (£)[1]		
	10,000	**25,000**	**50,000**
Whole Digestate or Liquor Storage	1.85	1.52	1.46
Fibre Storage	0.63	0.59	0.57
Centrifuge	2.17	1.24	0.94
Nutrient Recovery	2.76	1.45	0.93
Biological Oxidation	3.47	2.22	1.73
Disposal to Sewer	0.05	0.03	0.02
Notes: 1. Estimated total CAPEX (as provided in Table) per tonne of feedstock, spread over a 20 year payback period with payment terms of 8.5%.			

A3.2 Opex Data

Table A3-3 displays the costs for operational items, including the cost of process chemicals, labour and maintenance. Polymer is notably an essential but expensive item used within the dewatering process, costing around £2,000/tonne. Information regarding our assumptions for the volume of polymer used in the scenario modelling can be found in Table A3-1.

Table A3-3: Summary of Cost Assumptions, Opex

Item	Throughput (tpa) and Cost per tonne (£)		
	10,000	**25,000**	**50,000**
Centrifuge			
Polymer	2.29	2.29	2.29
Ferric	0.18	0.18	0.18
Electricity	1.42	1.04	0.78
Labour	0.88	0.35	0.18
Ancillary	0.18	0.07	0.04
Maintenance	0.55	0.34	0.27
TOTAL	5.50	4.27	3.73
Biological Oxidation			
Energy	1.31	1.31	1.31
Labour, maintenance, ancillary	1.31	1.31	1.31
TOTAL	2.63	2.63	2.63
Disposal to Sewer			
Mogden (direct to sewer)	11.65	11.65	11.65
Mogden (after Biological Oxidation)	2.1	2.1	2.1

Disposal to Watercourse			
Ferric Dosing (pre-treatment for disposal to watercourse)[1]	0.21	0.21	0.21
Nutrient Recovery			
Chemical	0.21	0.15	0.11
Energy	0.23	0.23	0.23
Labour	0.34	0.34	0.34
Patent	0.22	0.11	0.07
Maintenance	0.42	0.17	0.08
Avoided synthetic fertiliser costs	0.44	0.44	0.44
TOTAL Avoided cost: ferric	1.870.21	1.450.21	1.280.21
Notes: 1. Ferric is not required after nutrient recovery thus avoiding this costs where NR is modelled			

A3.3 Value of the Displacement of Fertiliser

The monetary value of nutrients in the digestate has been calculated in order to estimate avoided synthetic fertiliser costs, assuming current prices of £300 per tonne for nitrogen and potassium and £400 per tonne for phosphate.[60] These values have been applied to the nutrient content of the digestate based on the mass balance assumptions shown in Table A2-2 and for the calculation of available nitrogen in Table A2-3. The value of struvite is based on 6% of the nitrogen being recovered via the nutrient recovery process, as based on data collected from suppliers as part of this study.

Table A3-4 outlines the displacement value calculation, starting with the value of nutrients per tonne of fresh weight digestate after dilution, which lowers the concentration of nutrients, and therefore the displacement value per tonne.

Table A3-4: Monetary Value of Nutrients in the Digestate

	Unit	**% Feed**	**Available N**	**P**	**K**	**Total**
Value of nutrients in fresh weight digestate (Kg/t nutrient * £/kg cost of nutrient)	Kg / tonne fresh weight digestate	20%	7.35	1.16	4.02	
		10%	3.68	0.58	2.01	
	£ / kg synthetic fertiliser cost		0.30	0.40	0.30	
	£ / tonne fresh weight digestate	20%	2.21	0.46	1.21	£3.88
		10%	1.10	0.23	0.60	£1.94
Nutrients in whole digestate	£ / tonne feedstock		2.86	0.60	1.56	£5.03
Nutrients in liquor	£ / tonne feedstock		2.86	0.30	0.78	£3.95
Nutrients in fibre	£ / tonne feedstock		0.00	0.30	0.78	£1.08
Nutrients in struvite	£ / tonne feedstock		0.17	0.27	0.00	£0.44

A3.4 Haulage Costs

Haulage costs have been taken from a range of sources and reflect the competition in the market which inevitably results in a variation in pricing. Quotes from industry tend to be expressed as a flat rate per journey or tonnes/km, and not based on distance travelled. The data points gathered for this study include:

- £360 for a 480km round trip from one supplier which equates to £20 per tonne, and if pricing is proportionate to distance this would be £5 per tonne for a 120 km journey;
- £0.10/t/km round trip, which equates to a much higher price of £12 per tonne for 120 km although it is likely in real terms a discount would be applied for the longer distances used in the model; and
- £4.44 per tonne for a 80 km round trip.

Where pricing is based on £ / journey, we have assumed a vehicle capacity of 30 tonnes in order to arrive a per tonne figure. It is also acknowledged that some considerations are missing from these calculations, including whether loading/offloading is included, whether radial distances are used, and whether trailers or tankers are used to transport different digestate fractions.

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[60] *Prices taken from market information published by DairyCo - http://www.dairyco.org.uk/market-information/#.UrQVh_RdVaA*

Although there will be differing bulk densities for whole digestate, fibre or liquor (we estimate roughly 0.8t/m^3 for fibre, while whole and liquor would be about 1t/m^3), from our studies of vehicle configurations, we have assumed that the vehicle carrying fibre is likely to have the capacity to carry the equivalent tonnage to the liquor. We have therefore taken an average of the quoted figures to arrive at the costs in Table A3-5.

Table A3-5: Aggregated Haulage Costs used in Scenario Modelling

Metric	**Distance to Land (Km Round Trip)**	
	80	**280**
Cost Per Tonne	£5.52	£17.88

Appendix 4 Detailed Environmental Assumptions for Scenario Modelling

A4.1 Emissions from the Storage of Digestate

Ammonia in digestate has a propensity to volatilization, such that the ammonia in solution in the digestate may form ammonia gas during storage, particularly where the solution has a relatively high pH.[61] Depending on the stability of the digestate, emissions of CH_4 may also occur during storage and have been studied by other authors.[62] Fugitive emissions occurring during the AD process are outside the scope of the current study and are not included within the analysis.

The digestate under consideration in the current analysis is assumed to meet PAS110. Achievement of the standard indicates that the digestate will have a low residual biogas generation potential; in many cases biological activity will be further minimised as the product will have been pasteurised (although it is noted that in some cases the pasteurisation step occurs prior to the commencement of the digestion process). In addition, the conditions of the environmental permit require all operators of food waste AD plant to store the digestate in covered containers even where the product is being 'temporarily' stored (guidance produced by the Agency suggests that even temporary storage could account for up to three years of storage) – with such conditions being applicable even where the plant does not achieve PAS110.[63]

In particularly in wet years, however, it likely that some of the digestate will need to be stored for 6-12 months before application to land is possible. In addition, there is at present no requirement for the covering on the storage vessel to be air tight, although it is noted that such a stipulation is often made in other countries such as Germany.[64] This suggests that some emissions may occur even where the product being stored is relatively stable.

A recent published study considered the volatilisation of ammonia from digestate produced from food waste co-digested with animal slurry.[65] Emissions were measured in a laboratory using sealed chambers, and were related to the exposed surface area across which volatilisation could occur. The results indicated emissions of 5.2 g N per square metre per week from the digestate, suggesting relatively large losses could occur over the course of a lengthy storage period. However, the authors indicated that losses were likely to be relatively small if the digestate was stored in a poorly ventilated (sealed) storage unit, as is likely to be the case for plant operating in the UK, given the above requirements of the Permitting Regulations with regard to the storage of digestate.

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[61] *Whelan M, Everitt T and Villa R (2010) A Mass Transfer Model of Ammonia Volatilisation from Anaerobic Digestate, Waste Management, 30(10), pp1088-1812*

[62] *Liebetrau J, Clemens J, Cuhls C, Hafermann C, Friehe J, Weiland P and Daniel-Gromke J (2010) Methane Emissions from Biogas-producing Facilities within the Agricultural Sector, Engineering in Life Sciences, 10(6), p595-599*

[63] *Environment Agency (2010) Standard Rules: Chapter 4, The Environmental Permitting (England and Wales) Regulations 2010: Standard Rules SR2010No17 – Storage of Digestate from Anaerobic Digestion Plants*

[64] *IEA Bioenergy (2010) Utilisation of Digestate from Biogas Plants as Biofertiliser, IEA Task 37, June 2010*

[65] *Whelan M, Everitt T and Villa R (2010) A Mass Transfer Model of Ammonia Volatilisation from Anaerobic Digestate, Waste Management, 30(10), pp1088-1812*

A study of co-digestion plants operating in Finland considered both the changes in the nitrogen content of the digestate as well as the methane emission potential associated with the long term storage of the product - in this instance, the feedstock was manure mixed with biowaste from households.[66] Impacts were considered at three month intervals over the course of a year using data obtained from laboratory AD plant. The authors concluded that nitrogen losses were not significant, although the experimental data indicated nitrogen losses of 0-4% of the total nitrogen content across the samples taken within the experiment where the digestate was pasteurised. Relatively little information was provided with regard to the storage tanks used in the experiment, although the authors confirmed that this took place at 5°C (reflecting the storage of digestate in Finland over winter). The authors suggested their results were within the range of those seen elsewhere within the literature.

The authors of the Finnish study suggested that CH_4 losses were potentially of greater significance although – perhaps not unexpectedly – here the retention time within the AD process is negatively correlated with the outcome (emissions were higher where the retention time of the AD process was shorter). The authors suggested CH_4 impacts of up to 10% of the total methane generation potential of the feedstock were emitted during storage. However, it is important to note that these results were obtained using a feedstock that is relatively more difficult to digestate than food waste, such that the residual biogas potential is likely to be greater than will be the case for the modelled Welsh AD plant. In addition, as the authors of the Finnish also noted, emissions are greatly reduced where the digestate is stored in covered tanks. Furthermore, as was previously indicated, digestate achieving PAS110 will have a low residual biogas potential. Taken together, these points suggest that the impacts from the storage of digestate complying with PAS110 from UK plant treating food waste will be towards the bottom end of the range of impacts seen in the Finnish experiment.

A German study measured fugitive CH_4 emissions at 17 agricultural biogas facilities treating a range of feedstocks.[67] Only in one case was CH_4 detected at one of the connections to the storage tank, and in this instance emissions were calculated to be 0.17% of the methane contained in the biogas at the end of the AD process.[68] The study measured fugitive emissions occurring at a specific point in time, and did not consider the long term emissions. The authors noted the technical difficulties associated with making these "spot" emissions measurements, but also reiterated the potential for reducing emissions by increasing the retention time of the AD process, and by storing digestate in sealed containers.

We have assumed that emissions during storage will be minimised through the use of sealed storage tanks and by virtue of the requirement to meet PAS110. Methane emissions are also likely to be lower than those seen in the literature previously cited as food waste is much more readily degraded in the AD process than is the case where slurries and manures are digested, such that relatively little is likely to be emitted during storage.

Assumptions for emissions from storing digestate are as follows:

- 0.5% of the nitrogen is assumed to be emitted as NH_3;
- 0.5% of the carbon is assumed to be emitted as CH_4.

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[66] *Paavola and Rintala (2008) Effects of Storage on Characteristics and Hygienic Quality of Digestates from Four Co-Digestion Concepts of Manure and Biowaste, Bioresource Technology, 99, pp7041-7050*

[67] *Liebetrau J, Clemens J, Cuhls C, Hafermann C, Friehe J, Weiland P and Daniel-Gromke J (2010) Methane Emissions from Biogas-producing Facilities within the Agricultural Sector, Engineering in Life Sciences, 10(6), p595-599*

[68] *This suggests the measured gas sample contained less than 0.1% methane*

A4.2 Energy Use

The majority of the scenarios modelled result in the consumption of electricity and/or diesel. For electricity impacts, the mix of fuels was modelled using data from the Digest of UK Energy Statistics.[69] Pollution impacts associated with the different electricity generation methods and with the use of diesel have been developed using data from ecoinvent (the industry standard database used for LCA calculations).[70] Assumptions are presented in Table A4-1.

Table A4-1: Pollution Impacts from Electricity and Diesel Use

		Electricity, kg pollutant per kWh of energy generated	**Diesel, kg pollutant per kWh of fuel**
Climate change	CO_2 equivalent	0.50	0.07
Air quality	NH_4	1.84E-07	1.80E-08
	NOx	3.22E-04	3.43E-05
	SOx	3.13E-05	6.25E-05
	PM	2.22E-06	1.66E-06

Sources: Digest of UK Energy Statistics (published by DECC); ecoinvent database

A4.3 Emissions from the Application of Digestate to Land

The ammonium contained within digestate is a relatively volatile substance. As such, its application to the soil may result in emissions to air of both NH_3 and N_2O. However, similar emissions will also occur through the application of synthetic liquid fertiliser, as the same nutrient is contained in such liquid fertilisers. The important consideration is, therefore, the extent to which the application of digestate will result in an *increase* in emissions relative to that which would have occurred where a synthetic fertiliser was applied.

It is not uncommon to see in the literature assumptions indicating a higher emission from the use of digestate to that of synthetic fertiliser. For example, in their recent analysis of the climate change impacts of AD facilities, Møller et al assumed an emission of 33-60 kg CO_2 equivalent per tonne of MSW for digestate compared to 26-36 kg CO_2 equivalent per tonne of synthetic fertiliser.[71] These ranges suggest that the authors anticipated the nitrogen in digestate was likely to be more volatile than that contained in the synthetic fertiliser, although no rationale was provided by the authors of that study for the differential in performance.

The nitrogen contained in compost is mostly in the organic form, which is less prone to volatilisation. As such, some have suggested that the application of compost will result in a reduction in nitrogenous emissions in comparison to the application of the same amount of

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[69] *Digest available from: https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/digest-of-uk-energy-statistics-dukes*

[70] *www.ecoinvent.ch/*

[71] *Møller J, Boldrin A, Christensen T (2009) Anaerobic Digestion and Digestate Use: Accounting of Greenhouse Gases and Global Warming Contribution, Waste Management & Research, 27, pp813-824*

nitrogen in synthetic fertiliser.[72] However, only a relatively small proportion of the nitrogen in digestate is in the organic form. As such, the potential for reduction in emissions associated with the application of the organic nitrogen are anticipated to be relatively small for digestate, although this is an area where further research is needed.

Recent research published by WRAP indicates that the efficiency of utilisation of the nitrogen contained in digestate may be much lower where this product is applied during a period of relatively low plant growth than that of materials such as green waste compost and slurries.[73] The authors noted that this reflected the relatively high available nitrogen content of digestate in comparison to the other products considered in the study. However, the WRAP research did not consider impacts associated with the application of a synthetic liquid fertiliser to the same crops at the same time of year. Such a product would be expected to behave in a similar way to the digestate, as the available nitrogen content is likely to be similarly high.

The digestate considered in this study is assumed to meet the requirements of PAS110, and as such will be a relatively stable product.[74] Given this, it is anticipated that the digestate will behave similarly to that of a synthetic fertiliser in respect of the nitrogenous emissions, with any slight increase in volatility in the inorganic nitrogen being offset by the reduced volatility associated with the organic nitrogen. The model therefore does not assume any emissions associated with the application of the digestate, as these are considered to be the same as those associated with the application of the synthetic fertiliser.

A4.4 Environmental Benefits – Synthetic Fertiliser Displacement

The environmental benefits associated with the displacement of synthetic fertiliser are calculated on the basis of the nutrient content of the digestate product (whole digestate / fibre / liquor, as appropriate). For ammonium-based fertilisers, impacts for the digestate are calculated on the basis of the available N content of the digestate. Assumptions in this respect have already been outlined in Appendix 2 as part of the mass balance.

Environmental impacts associated with the manufacture of synthetic fertiliser are outlined in Table A4-. Assumptions here have been developed using data from ecoinvent.[75]

Table A4-2: Environmental Impacts of Fertiliser Manufacture

Synthetic nutrient displaced by digestate	Tonnes pollutant per tonne of fertiliser product				
	GHG	NH_4	NOx	SOx	PM
NH_4 (as N)	6.94	1.00E-03	3.62E-02	1.00E-03	5.58E-05

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[72] *Favoino, E and Hogg, D (2008) The Potential Role of Compost in Reducing Greenhouse Gases, Waste Management & Research, 26, pp61-69*

[73] *WRAP (2013) Good Practice in Digestate Management Improves Nitrogen Use Efficiency, Digestate & Compost in Agriculture, Bulletin 5, April 2013*

[74] *It is acknowledged that the ammonia contained in digestate is highly volatile. However, in analysis of this type it is important to establish the extent to which the ammonia in digestate can be expected to behave with greater volatility than that of a comparable synthetic product. This is more likely to be the case where the product is still undergoing some form of biological degradation, such that the microbial activity within the digestate results in the take up of nitrogen by the micro-organisms.*

[75] *www.ecoinvent.ch/*

P_2O_5 (as P)	1.80	4.73E-06	2.00E-03	3.00E-02	1.10E-04
K	0.93	6.49E-06	6.60E-04	2.00E-04	2.66E-05

A4.5 Chemicals used in Treatment Options

A number of the processes used to treat the separated digestate products require the use of chemicals. The assumed volumes of process additives were based on Aqua Enviro research and analysis of current industry practices, and the application to these of the flow rate assumptions used in this report. Estimated polymer consumption is provided in Table 3-1.

Assumptions on the environmental impacts associated with the manufacture of these chemicals are outlined in Table A4-3. Assumptions in this respect were derived from the ecoinvent database of life-cycle data. Although the database includes data on a wide range of chemicals and industrial processes, it was not possible to obtain specific information for all the chemicals used within the treatment processes considered within the current analysis. Where this was the case, a suitable proxy was selected from the database. In addition, we understand that in some cases the chemicals used within a specific process may vary, suggesting the potential for some variation in the pollution impacts as a consequence. However, these impacts make only a relatively minor contribution to the environmental impacts associated with the digestate treatment process. As such, this source of uncertainty is unlikely to have a significant impact on the results.

Table A4-3: Environmental Impacts of Chemicals Used in Digestate Treatment

	Pollution impacts from chemicals used in digestate treatment processes, tonnes pollutant			
	Polymer[1]	**Ferric**[2]	**Sodium hydroxide**[3]	**Magnesium chloride**[3]
Climate change (CO_2 eq)	2.26	0.49	1.12	0.67
NH_4	1.08E-06	3.00E-06	2.08E-05	2.64E-05
NOx	2.87E-04	6.60E-04	1.30E-03	3.00E-04
SOx	7.40E-04	1.00E-03	3.00E-03	5.15E-04
PM	1.50E-04	6.00E-04	1.58E-05	2.00E-03

Notes:

1. Used in the dewatering process. Impacts modelled based on acrylic acid. See Table 3-1 for estimated volumes added to food waste digestate
2. Used in the dewatering process. Impacts modelled on the basis of aluminium sulphate.
3. Used in the nutrient recovery process.

Appendix 5 Detailed Results from CBA Modelling – Central Case 1

As described above, eight scenarios (including the baseline) have been included in the model for this study. The following tables provide in detail the model results for the financial and environmental costs of each option for Central Case 1: Dilution to 20% Dry Solids.

The rationales for the 'per tonne' financial costs contained in the tables below can be found in the following parts of this report:

- CAPEX – Appendix 3;
- Haulage – Appendix 3;
- Spreading - Section 2.5.5; and
- Avoided synthetic fertiliser costs – Appendix 3.

It should be noted that the 'cost per tonne of *digestate*' values described in these sections have been converted to 'cost per tonne of *feedstock*', i.e. before dilution and entry into the digester (as described in Section 2.4.1), in the tables below.

A schematic diagram of the process for each option is shown at the beginning of each section with the relevant sub-processes highlighted in green.

A5.1 Baseline: Whole Digestate Applied to Land

Table A5-1: Outline Process

Option	Dewatering process	Liquor Management			Fibre Management
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A5-2: Environmental Unit Costs

Process	**Environmental Aspect**	**Unit**		**Value**	**Damage Cost per Tonne Feedstock to Plant**		
					GHG	**AQ**	**Total**
Land Application	Storage emissions	CH4	kg / t feedstock	0.0002	£0.29	-	£0.29
		NH3	kg / t feedstock	0.04	-	£0.14	£0.14
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	9.52	-£0.40	-£1.06	-£1.46
		P	kg P fert / t feedstock	1.51	-£0.02	-£0.18	-£0.19
		K	kg K fert / t feedstock	5.22	-£0.03	-£0.02	-£0.05
	Total £/t Feedstock for Process:				**-£0.15**	**-£1.12**	**-£1.27**

Table A5-3: Financial Unit Costs

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
Direct Application to Land	CAPEX	Storage	£	175,000	360,000	690,000
		Total	£	175,000	360,000	690,000
		Total per tonne capacity	£/t feedstock	17.50	14.40	13.80
		Total CAPEX	£/t feedstock	1.85	1.52	1.46
	OPEX	Haulage	£/t feedstock	7.16	7.16	7.16
		Spreading	£/t feedstock	6.49	6.49	6.49
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.11	-0.11	-0.11
		Avoided synthetic fertiliser costs	£/t feedstock	-5.03	-5.03	-5.03
		Total OPEX	£/t feedstock	8.51	8.51	8.51
	Total £/t Feedstock for Process:			**10.36**	**10.03**	**9.97**

A5.2 Scenario 1: Dewatering, NR, BO, Sewer, Fibre to Land

Table A5-4: Outline Process

Option	Dewatering Process	Liquor Management			Fibre Management
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A5-5: Environmental Unit Costs

Process	**Environmental Aspect**		**Unit**	**Value**	**Damage Cost per Tonne Feedstock to Plant**		
					GHG	**AQ**	**Total**
Dewatering (Centrifuge)	Energy	Electricity	kWh/t feedstock	15.77	£0.05	£0.02	£0.06
	Chemicals used	Polymer	kg/t feedstock	1.09	£0.01	£0.01	£0.02
		Ferric	kg/t feedstock	1.82	£0.01	£0.05	£0.06
	Total £/t Feedstock for Process:				**£0.07**	**£0.08**	**£0.15**
Nutrient Recovery	Energy	Electricity	kWh/t feedstock	1.23	£0.004	£0.001	£0.005
	Chemicals	Magnesium Chloride	kg/t feedstock	0.019	£0.000	£0.001	£0.002
		Sodium Hydroxide	kg/t feedstock	0.002	£0.000	£0.000	£0.000
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.57	-£0.02	-£0.06	-£0.087
		P	kg P fert / t feedstock	0.68	-£0.01	-£0.08	-£0.09
Biological Oxidation	Energy	Electricity	kWh/t feedstock	10.83	£0.03	£0.01	£0.04
Disposal to Sewer	Energy	Electricity	kWh/t feedstock	0	£0.00	£0.00	£0.00
	Total £/t Feedstock for Process:				**£0.01**	**-£0.13**	**-£0.12**
Land Application	Storage emissions	CH4	kg / t feedstock	0.0002	£0.25	-	£0.25
		NH3	kg / t feedstock	0.01	-	£0.03	£0.03
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.00	£0.00	£0.00	£0.00
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**£0.22**	**-£0.07**	**£0.16**

Table A5-6: Financial Unit Costs

Process	Cost Item		Unit	Capacity tpa		
				10,000	25,000	50,000
Dewatering (Centrifuge)	CAPEX	Main equipment item	£	72,000	106,000	179,000
		Control system	£	31,000	47,000	77,000
		Ancillaries	£	17,500	26,000	41,000
		Poly make up system	£	25,000	35,000	50,000
		Building	£	60,000	80,000	100,000
		Total	£	205,500	294,000	447,000
		Total per tonne capacity	£/t feedstock	20.55	11.76	8.94
		Total CAPEX	£/t feedstock	2.17	1.24	0.94
	OPEX	Polymer	£/t feedstock	2.29	2.29	2.29
		Ferric	£/t feedstock	0.18	0.18	0.18
		Electricity	£/t feedstock	1.42	1.04	0.78
		Labour	£/t feedstock	0.88	0.35	0.18
		Ancillary	£/t feedstock	0.18	0.07	0.04
		Maintenance	£/t feedstock	0.55	0.34	0.27
		Total OPEX	£/t feedstock	5.50	4.27	3.73
	Total £/t Feedstock for Process:			**7.67**	**5.51**	**4.67**
Nutrient Recovery	CAPEX	Total base, extras, storage	£	231,000	308,000	400,500
		Installation, commissioning, pipework	£	30,000	35,000	40,000
		Total	£	261,000	343,000	440,500

Process	Cost Item		Unit	Capacity tpa		
				10,000	25,000	50,000
		Total per tonne capacity	£/t feedstock	26.10	13.72	8.81
		Total CAPEX	£/t feedstock	2.76	1.45	0.93
	OPEX	Electricity	£/t feedstock	0.21	0.15	0.11
		Patent charge	£/t feedstock	0.23	0.23	0.23
		Chemicals	£/t feedstock	0.34	0.34	0.34
		Maintenance	£/t feedstock	0.22	0.11	0.07
		Labour	£/t feedstock	0.42	0.17	0.08
		Avoided synthetic fertiliser costs	£/t feedstock	0.44	0.44	0.44
		Total OPEX	£/t feedstock	1.87	1.45	1.28
Biological Oxidation (SBR)	CAPEX	Main equipment item	£	328,000	525,000	820,000
		Total	£	328,000	525,000	820,000
		Total per tonne capacity	£/t feedstock	32.80	21.00	16.40
		Total CAPEX	£/t feedstock	3.47	2.22	1.73
	OPEX	Electricity (Aeration)	£/t feedstock	1.31	1.31	1.31
		Other costs	£/t feedstock	1.31	1.31	1.31
		Total OPEX	£/t feedstock	2.63	2.63	2.63
Disposal to Sewer	CAPEX	Pipework	£	5,000	8,000	10,000
		Total	£	5,000	8,000	10,000
		Total per tonne capacity	£/t feedstock	0.50	0.32	0.20
		Total CAPEX	£/t feedstock	0.05	0.03	0.02

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
	OPEX	Mogden	£/t feedstock	2.1	2.1	2.1
		Total OPEX	£/t feedstock	2.100	2.100	2.100
	Total £/t Feedstock for Process:			**12.87**	**9.88**	**8.69**
Land Application	CAPEX	Storage	£	60,000	140,000	270,000
		Total	£	60,000	140,000	270,000
		Total per tonne capacity	£/t feedstock	6.00	5.60	5.40
		Annualised CAPEX	£/t feedstock	0.63	0.59	0.57
	OPEX	Haulage	£/t feedstock	1.36	1.36	1.36
		Spreading	£/t feedstock	1.24	1.24	1.24
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.02	-0.02	-0.02
		Avoided synthetic fertiliser costs	£/t feedstock	-1.08	-1.08	-1.08
		Total OPEX	£/t feedstock	1.50	1.50	1.50
	Total £/t Feedstock for Process:			**2.13**	**2.09**	**2.07**

A5.3 Scenario 2: Dewatering, NR, BO, Watercourse, Fibre to Land

Table A5-7: Outline Process

Option	Dewatering Process	Liquor Management			Fibre Management
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A5-8: Environmental Unit Costs

Process	Environmental Aspect		Unit	Value	Damage Cost per Tonne Feedstock to Plant		
					GHG	**AQ**	**Total**
Dewatering (Centrifuge)	Energy	Electricity	kWh/t feedstock	15.77	£0.05	£0.02	£0.06
	Chemicals used	Polymer	Kg/t feedstock	1.09	£0.01	£0.01	£0.02
		Ferric	Kg/t feedstock	1.82	£0.01	£0.05	£0.06
	Total £/t Feedstock for Process:				**£0.07**	**£0.08**	**£0.15**
Nutrient Recovery	Energy	Electricity	kWh/t feedstock	1.23	£0.004	£0.001	£0.01
	Chemicals	Magnesium Chloride	kg/t feedstock	0.019	£0.000	£0.001	£0.002
		Sodium Hydroxide	kg/t feedstock	0.002	£0.000	£0.000	£0.000
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.57	-£0.02	-£0.06	-£0.087
		P	kg P fert / t feedstock	0.68	-£0.01	-£0.08	-£0.09
Biological Oxidation (SBR)	Energy	Electricity	kWh/t feedstock	10.83	£0.03	£0.01	£0.04
Disposal to Watercourse	Energy	Electricity	kWh/t feedstock	0	£0.00	£0.00	£0.00
	Total £/t Feedstock for Process:				**£0.01**	**-£0.13**	**-£0.12**
Land Application	Storage emissions	CH4	kg / t feedstock	0.0002	£0.25		£0.25
		NH3	kg / t feedstock	0.01		£0.03	£0.03
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.00	£0.00	£0.00	£0.00
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**£0.22**	**-£0.07**	**£0.16**

Table A5-9: Financial Unit Costs

Process	Cost Item		Unit	Capacity tpa		
				10,000	**25,000**	**50,000**
Dewatering (Centrifuge)	CAPEX	Main equipment item	£	72,000	106,000	179,000
		Control system	£	31,000	47,000	77,000
		Ancillaries	£	17,500	26,000	41,000
		Poly make up system	£	25,000	35,000	50,000
		Building	£	60,000	80,000	100,000
		Total	£	205,500	294,000	447,000
		Total per tonne capacity	£/t feedstock	20.55	11.76	8.94
		Total CAPEX	£/t feedstock	2.17	1.24	0.94
	OPEX	Polymer	£/t feedstock	2.29	2.29	2.29
		Ferric	£/t feedstock	0.18	0.18	0.18
		Electricity	£/t feedstock	1.42	1.04	0.78
		Labour	£/t feedstock	0.88	0.35	0.18
		Ancillary	£/t feedstock	0.18	0.07	0.04
		Maintenance	£/t feedstock	0.55	0.34	0.27
		Total OPEX	£/t feedstock	5.50	4.27	3.73
	Total £/t Feedstock for Process:			**7.67**	**5.51**	**4.67**
Nutrient Recovery	CAPEX	Total base, extras, storage	£	231,000	308,000	400,500
		Installation, commissioning, pipework	£	30,000	35,000	40,000
		Total	£	261,000	343,000	440,500

Process	Cost Item		Unit	Capacity tpa		
				10,000	25,000	50,000
		Total per tonne capacity	£/t feedstock	26.10	13.72	8.81
		Total CAPEX	£/t feedstock	2.76	1.45	0.93
	OPEX	Electricity	£/t feedstock	0.21	0.15	0.11
		Patent charge	£/t feedstock	0.23	0.23	0.23
		Chemicals	£/t feedstock	0.34	0.34	0.34
		Maintenance	£/t feedstock	0.22	0.11	0.07
		Labour	£/t feedstock	0.42	0.17	0.08
		Avoided synthetic fertiliser costs	£/t feedstock	0.44	0.44	0.44
		Total OPEX	£/t feedstock	1.87	1.45	1.28
Biological Oxidation (SBR)	CAPEX	Main equipment item	£	328,000	525,000	820,000
		Total	£	328,000	525,000	820,000
		Total per tonne capacity	£/t feedstock	32.80	21.00	16.40
		Total CAPEX	£/t feedstock	3.47	2.22	1.73
	OPEX	Electricity (Aeration)	£/t feedstock	1.31	1.31	1.31
		Other costs	£/t feedstock	1.31	1.31	1.31
		Total OPEX	£/t feedstock	2.63	2.63	2.63
Disposal to Watercourse	CAPEX		£	0.00	0.00	0.00
		Total	£	0.00	0.00	0.00
		Total per tonne capacity	£/t feedstock	0.00	0.00	0.00
		Total CAPEX	£/t feedstock	0.00	0.00	0.00

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
	OPEX		£/t feedstock	0.00	0.00	0.00
		Total OPEX	£/t feedstock	0.000	0.000	0.000
	Total £/t Feedstock for Process:			**10.72**	**7.74**	**6.57**
Land Application	CAPEX	Storage	£	60,000	140,000	270,000
		Total	£	60,000	140,000	270,000
		Total per tonne capacity	£/t feedstock	6.00	5.60	5.40
		Annualised CAPEX	£/t feedstock	0.63	0.59	0.57
	OPEX	Haulage	£/t feedstock	1.36	1.36	1.36
		Spreading	£/t feedstock	1.24	1.24	1.24
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.02	-0.02	-0.02
		Avoided synthetic fertiliser costs	£/t feedstock	-1.08	-1.08	-1.08
		Total OPEX	£/t feedstock	1.50	1.50	1.50
	Total £/t Feedstock for Process:			**2.13**	**2.09**	**2.07**

A5.4 Scenario 3: Dewatering, NR, Sewer, Fibre to Land

Table A5-10: Outline Process

Option	**Dewatering Process**	**Liquor Management**			**Fibre Management**
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A5-11: Environmental Costs

Process	**Environmental Aspect**		**Unit**	**Value**	**Damage Cost per Tonne Feedstock to Plant**		
					GHG	**AQ**	**Total**
Dewatering (Centrifuge)	Energy	Electricity	kWh/t feedstock	15.77	£0.05	£0.02	£0.06
	Chemicals used	Polymer	kg/t feedstock	1.09	£0.01	£0.01	£0.02
		Ferric	kg/t feedstock	1.82	£0.01	£0.05	£0.06
	Total £/t Feedstock for Process:				**£0.07**	**£0.08**	**£0.15**
Nutrient Recovery	Energy	Electricity	kWh/t feedstock	1.23	£0.004	£0.001	£0.01
	Chemicals	Magnesium Chloride	kg/t feedstock	0.019	£0.000	£0.001	£0.002
		Sodium Hydroxide	kg/t feedstock	0.002	£0.000	£0.000	£0.000
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.57	-£0.02	-£0.06	-£0.087
		P	kg P fert / t feedstock	0.68	-£0.01	-£0.08	-£0.087
Disposal to Sewer	Energy	Electricity	kWh/t feedstock	0	£0.00	£0.00	£0.00
	Total £/t Feedstock for Process:				**-£0.03**	**-£0.14**	**-£0.17**
Land Application	Storage emissions	CH4	kg / t feedstock	0.0002	£0.25		£0.25
		NH3	kg / t feedstock	0.01		£0.03	£0.03
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.00	£0.00	£0.00	£0.00
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**£0.22**	**-£0.07**	**£0.16**

Table A5-12: Financial Costs

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
Dewatering (Centrifuge)	CAPEX	Main equipment item	£	72,000	106,000	179,000
		Control system	£	31,000	47,000	77,000
		Ancillaries	£	17,500	26,000	41,000
		Poly make up system	£	25,000	35,000	50,000
		Building	£	60,000	80,000	100,000
		Total	£	205,500	294,000	447,000
		Total per tonne capacity	£/t feedstock	20.55	11.76	8.94
		Total CAPEX	£/t feedstock	2.17	1.24	0.94
	OPEX	Polymer	£/t feedstock	2.29	2.29	2.29
		Ferric	£/t feedstock	0.18	0.18	0.18
		Electricity	£/t feedstock	1.42	1.04	0.78
		Labour	£/t feedstock	0.88	0.35	0.18
		Ancillary	£/t feedstock	0.18	0.07	0.04
		Maintenance	£/t feedstock	0.55	0.34	0.27
		Total OPEX	£/t feedstock	5.50	4.27	3.73
	Total £/t Feedstock for Process:			**7.67**	**5.51**	**4.67**
Nutrient Recovery	CAPEX	Total base, extras, storage	£	231,000	308,000	400,500
		Installation, commissioning, pipework	£	30,000	35,000	40,000
		Total	£	261,000	343,000	440,500

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
		Total per tonne capacity	£/t feedstock	26.10	13.72	8.81
		Total CAPEX	£/t feedstock	2.76	1.45	0.93
	OPEX	Electricity	£/t feedstock	0.21	0.15	0.11
		Patent charge	£/t feedstock	0.23	0.23	0.23
		Chemicals	£/t feedstock	0.34	0.34	0.34
		Maintenance	£/t feedstock	0.22	0.11	0.07
		Labour	£/t feedstock	0.42	0.17	0.08
		Avoided synthetic fertiliser costs	£/t feedstock	0.44	0.44	0.44
		Total OPEX	£/t feedstock	1.87	1.45	1.28
Disposal to Sewer	CAPEX	Pipework	£	5,000	8,000	10,000
		Total	£	5,000	8,000	10,000
		Total per tonne capacity	£/t feedstock	0.50	0.32	0.20
		Total CAPEX	£/t feedstock	0.05	0.03	0.02
	OPEX	Mogden	£/t feedstock	11.65	11.65	11.65
		Total OPEX	£/t feedstock	11.65	11.65	11.65
	Total £/t Feedstock for Process:			**16.33**	**14.58**	**13.88**
Land Application	CAPEX	Storage	£	60,000	140,000	270,000
		Total	£	60,000	140,000	270,000
		Total per tonne capacity	£/t feedstock	6.00	5.60	5.40
		Annualised CAPEX	£/t feedstock	0.63	0.59	0.57

Process	Cost Item		Unit	Capacity tpa		
				10,000	25,000	50,000
	OPEX	Haulage	£/t feedstock	1.36	1.36	1.36
		Spreading	£/t feedstock	1.24	1.24	1.24
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.02	-0.02	-0.02
		Avoided synthetic fertiliser costs	£/t feedstock	-1.08	-1.08	-1.08
		Total OPEX	£/t feedstock	1.50	1.50	1.50
	Total £/t Feedstock for Process:			**2.13**	**2.09**	**2.07**

A5.5 Scenario 4: Dewatering, BO, Sewer, Fibre to Land

Table A5-13: Outline Process

Option	**Dewatering Process**	**Liquor Management**			**Fibre Management**
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A5-14: Environmental Costs

Process	**Environmental Aspect**		**Unit**	**Value**	**Damage Cost per Tonne Feedstock to Plant**		
					GHG	**AQ**	**Total**
Dewatering (Centrifuge)	Energy	Electricity	kWh/t feedstock	15.77	£0.05	£0.02	£0.06
	Chemicals used	Polymer	Kg/t feedstock	1.09	£0.01	£0.01	£0.02
		Ferric	Kg/t feedstock	1.82	£0.01	£0.05	£0.06
	Total £/t Feedstock for Process:				**£0.07**	**£0.08**	**£0.15**
Biological Oxidation (SBR)	Energy	Electricity	kWh/t feedstock	10.83	£0.03	£0.01	£0.04
Disposal to Sewer	Energy	Electricity	kWh/t feedstock	0	£0.00	£0.0000	£0.000
	Total £/t Feedstock for Process:				**£0.03**	**£0.01**	**£0.04**
Land Application	Storage emissions	CH4	kg / t feedstock	0.0002	£0.25		£0.25
		NH3	kg / t feedstock	0.01		£0.03	£0.03
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.00	£0.00	£0.00	£0.00
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**£0.22**	**-£0.07**	**£0.16**

Table A5-15: Financial Costs

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
Dewatering (Centrifuge)	CAPEX	Main equipment item	£	72,000	106,000	179,000
		Control system	£	31,000	47,000	77,000
		Ancillaries	£	17,500	26,000	41,000
		Poly make up system	£	25,000	35,000	50,000
		Building	£	60,000	80,000	100,000
		Total	£	205,500	294,000	447,000
		Total per tonne capacity	£/t feedstock	20.55	11.76	8.94
		Total CAPEX	£/t feedstock	2.17	1.24	0.94
	OPEX	Polymer	£/t feedstock	2.29	2.29	2.29
		Ferric	£/t feedstock	0.18	0.18	0.18
		Electricity	£/t feedstock	1.42	1.04	0.78
		Labour	£/t feedstock	0.88	0.35	0.18
		Ancillary	£/t feedstock	0.18	0.07	0.04
		Maintenance	£/t feedstock	0.55	0.34	0.27
		Total OPEX	£/t feedstock	5.50	4.27	3.73
	Total £/t Feedstock for Process:			**7.67**	**5.51**	**4.67**
Biological Oxidation (SBR)	CAPEX	Main equipment item	£	328,000	525,000	820,000
		Total	£	328,000	525,000	820,000
		Total per tonne capacity	£/t feedstock	32.80	21.00	16.40
		Total CAPEX	£/t feedstock	3.47	2.22	1.73

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
	OPEX	Electricity (Aeration)	£/t feedstock	1.31	1.31	1.31
		Other costs	£/t feedstock	1.31	1.31	1.31
		Total OPEX	£/t feedstock	2.63	2.63	2.63
Disposal to Sewer	CAPEX	Pipework	£	5,000	8,000	10,000
		Total	£	5,000	8,000	10,000
		Total per tonne capacity	£/t feedstock	0.50	0.32	0.20
		Total CAPEX	£/t feedstock	0.05	0.03	0.02
	OPEX	Mogden	£/t feedstock	2.1	2.1	2.1
		Total OPEX	£/t feedstock	2.100	2.100	2.100
	Total £/t Feedstock for Process:			**8.24**	**6.98**	**6.48**
Land Application	CAPEX	Storage	£	60,000	140,000	270,000
		Total	£	60,000	140,000	270,000
		Total per tonne capacity	£/t feedstock	6.00	5.60	5.40
		Annualised CAPEX	£/t feedstock	0.63	0.59	0.57
	OPEX	Haulage	£/t feedstock	1.36	1.36	1.36
		Spreading	£/t feedstock	1.24	1.24	1.24
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.02	-0.02	-0.02
		Avoided synthetic fertiliser costs	£/t feedstock	-1.08	-1.08	-1.08
		Total OPEX	£/t feedstock	1.50	1.50	1.50
	Total £/t Feedstock for Process:			**2.13**	**2.09**	**2.07**

A5.6 Scenario 5: Dewatering, BO, Watercourse, Fibre to Land

Table A5-16: Outline Process

Option	**Dewatering Process**	**Liquor Management**			**Fibre Management**
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A5-17: Environmental Costs

Process	**Environmental Aspect**		**Unit**	**Value**	**Damage Cost per Tonne Feedstock to Plant**		
					GHG	**AQ**	**Total**
Dewatering (Centrifuge)	Energy	Electricity	kWh/t feedstock	15.77	£0.05	£0.02	£0.06
	Chemicals used	Polymer	Kg/t feedstock	1.09	£0.01	£0.01	£0.02
		Ferric	Kg/t feedstock	1.82	£0.01	£0.05	£0.06
	Total £/t Feedstock for Process:				**£0.07**	**£0.08**	**£0.15**
Nutrient Recovery	Energy	Electricity	kWh/t feedstock	1.23	£0.004	£0.001	£0.01
	Chemicals	Magnesium Chloride	kg/t feedstock	0.019	£0.000	£0.001	£0.002
		Sodium Hydroxide	kg/t feedstock	0.002	£0.000	£0.000	£0.000
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.57	-£0.02	-£0.06	-£0.087
		P	kg P fert / t feedstock	0.68	-£0.01	-£0.08	-£0.09
Biological Oxidation (SBR)	Energy	Electricity	kWh/t feedstock	10.83	£0.03	£0.01	£0.04
Disposal to Watercourse	Energy	Electricity	kWh/t feedstock	0	£0.00	£0.00	£0.00
	Total £/t Feedstock for Process:				**£0.01**	**-£0.13**	**-£0.12**
Land Application	Storage emissions	CH4	kg / t feedstock	0.0002	£0.25		£0.25
		NH3	kg / t feedstock	0.01		£0.03	£0.03
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.00	£0.00	£0.00	£0.00
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**£0.22**	**-£0.07**	**£0.16**

Table A5-18: Financial Costs

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
Dewatering (Centrifuge)	CAPEX	Main equipment item	£	72,000	106,000	179,000
		Control system	£	31,000	47,000	77,000
		Ancillaries	£	17,500	26,000	41,000
		Poly make up system	£	25,000	35,000	50,000
		Building	£	60,000	80,000	100,000
		Total	£	205,500	294,000	447,000
		Total per tonne capacity	£/t feedstock	20.55	11.76	8.94
		Total CAPEX	£/t feedstock	2.17	1.24	0.94
	OPEX	Polymer	£/t feedstock	2.29	2.29	2.29
		Ferric	£/t feedstock	0.18	0.18	0.18
		Electricity	£/t feedstock	1.42	1.04	0.78
		Labour	£/t feedstock	0.88	0.35	0.18
		Ancillary	£/t feedstock	0.18	0.07	0.04
		Maintenance	£/t feedstock	0.55	0.34	0.27
		Total OPEX	£/t feedstock	5.50	4.27	3.73
	Total £/t Feedstock for Process:			**7.67**	**5.51**	**4.67**
Biological Oxidation (SBR)	CAPEX	Main equipment item	£	328,000	525,000	820,000
		Total	£	328,000	525,000	820,000
		Total per tonne capacity	£/t feedstock	32.80	21.00	16.40
		Total CAPEX	£/t feedstock	3.47	2.22	1.73

Process	Cost Item		Unit	Capacity tpa		
				10,000	25,000	50,000
	OPEX	Electricity (Aeration)	£/t feedstock	1.31	1.31	1.31
		Other costs	£/t feedstock	1.31	1.31	1.31
		Total OPEX	£/t feedstock	2.63	2.63	2.63
Disposal to Watercourse	CAPEX		£	0.00	0.00	0.00
		Total	£	0.00	0.00	0.00
		Total per tonne capacity	£/t feedstock	0.00	0.00	0.00
		Total CAPEX	£/t feedstock	0.00	0.00	0.00
	OPEX	Ferric	£/t feedstock	0.21	0.21	0.21
		Total OPEX	£/t feedstock	0.210	0.210	0.210
	Total £/t Feedstock for Process:			**6.30**	**5.06**	**4.57**
Land Application	CAPEX	Storage	£	60,000	140,000	270,000
		Total	£	60,000	140,000	270,000
		Total per tonne capacity	£/t feedstock	6.00	5.60	5.40
		Annualised CAPEX	£/t feedstock	0.63	0.59	0.57
	OPEX	Haulage	£/t feedstock	1.36	1.36	1.36
		Spreading	£/t feedstock	1.24	1.24	1.24
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.02	-0.02	-0.02
		Avoided synthetic fertiliser costs	£/t feedstock	-1.08	-1.08	-1.08
		Total OPEX	£/t feedstock	1.50	1.50	1.50
	Total £/t Feedstock for Process:			**2.13**	**2.09**	**2.07**

A5.7 Scenario 6: Dewatering, Sewer, Fibre to Land

Table A5-19: Outline Process

Option	Dewatering Process	Liquor Management			Fibre Management
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A5-20: Environmental Costs

Process	**Environmental Aspect**		**Unit**	**Value**	**Damage Cost per Tonne Feedstock to Plant**		
					GHG	**AQ**	**Total**
Dewatering (Centrifuge)	Energy	Electricity	kWh/t feedstock	15.77	£0.05	£0.02	£0.06
	Chemicals used	Polymer	Kg/t feedstock	1.09	£0.01	£0.01	£0.02
		Ferric	Kg/t feedstock	1.82	£0.01	£0.05	£0.06
	Total £/t Feedstock for Process:				**£0.07**	**£0.08**	**£0.15**
Direct Disposal to Sewer	Energy	Electricity	kWh/t feedstock	0	£0.00	£0.00	£0.00
	Total £/t Feedstock for Process:						**£0.00**
Land Application	Storage emissions	CH4	kg / t feedstock	0.0002	£0.25		£0.25
		NH3	kg / t feedstock	0.01		£0.03	£0.03
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.00	£0.00	£0.00	£0.00
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**£0.22**	**-£0.07**	**£0.16**

Table A5-21: Financial Costs

Process	Cost Item		Unit	Capacity tpa		
				10,000	25,000	50,000
Dewatering (Centrifuge)	CAPEX	Main equipment item	£	72,000	106,000	179,000
		Control system	£	31,000	47,000	77,000
		Ancillaries	£	17,500	26,000	41,000
		Poly make up system	£	25,000	35,000	50,000
		Building	£	60,000	80,000	100,000
		Total	£	205,500	294,000	447,000
		Total per tonne capacity	£/t feedstock	20.55	11.76	8.94
		Total CAPEX	£/t feedstock	2.17	1.24	0.94
	OPEX	Polymer	£/t feedstock	2.29	2.29	2.29
		Ferric	£/t feedstock	0.18	0.18	0.18
		Electricity	£/t feedstock	1.42	1.04	0.78
		Labour	£/t feedstock	0.88	0.35	0.18
		Ancillary	£/t feedstock	0.18	0.07	0.04
		Maintenance	£/t feedstock	0.55	0.34	0.27
		Total OPEX	£/t feedstock	5.50	4.27	3.73
	Total £/t Feedstock for Process:			**7.67**	**5.51**	**4.67**
Disposal to Sewer	CAPEX	Pipework	£	5,000	8,000	10,000
		Total	£	5,000	8,000	10,000
		Total per tonne capacity	£/t feedstock	0.50	0.32	0.20
		Annualised CAPEX	£/t feedstock	0.05	0.03	0.02

Process	Cost Item		Unit	Capacity tpa		
				10,000	**25,000**	**50,000**
	OPEX	Mogden	£/t feedstock	11.65	11.65	11.65
		Total OPEX	£/t feedstock	11.65	11.65	11.65
	Total £/t Feedstock for Process:			**11.70**	**11.68**	**11.67**
Land Application	CAPEX	Storage	£	60,000	140,000	270,000
		Total	£	60,000	140,000	270,000
		Total per tonne capacity	£/t feedstock	6.00	5.60	5.40
		Annualised CAPEX	£/t feedstock	0.63	0.59	0.57
	OPEX	Haulage	£/t feedstock	1.36	1.36	1.36
		Spreading	£/t feedstock	1.24	1.24	1.24
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.02	-0.02	-0.02
		Avoided synthetic fertiliser costs	£/t feedstock	-1.08	-1.08	-1.08
		Total OPEX	£/t feedstock	1.50	1.50	1.50
	Total £/t Feedstock for Process:			**2.13**	**2.09**	**2.07**

A5.8 Scenario 7: Dewatering, Liquor to Land, Fibre to Land

Table A5-22: Outline Process

Option	Dewatering Process	Liquor Management			Fibre Management
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A5-23: Environmental Costs

Process	**Environmental Aspect**		**Unit**	**Value**	**Damage Cost per Tonne Feedstock to Plant**		
					GHG	**AQ**	**Total**
Dewatering (Centrifuge)	Energy	Electricity	kWh/t feedstock	15.77	£0.05	£0.02	£0.06
	Chemicals used	Polymer	Kg/t feedstock	1.09	£0.01	£0.01	£0.02
		Ferric	Kg/t feedstock	1.82	£0.01	£0.05	£0.06
	Total £/t Feedstock for Process:				**£0.07**	**£0.08**	**£0.15**
Land Application	Storage emissions	CH4	kg / t feedstock	0.0000	£0.04		£0.04
		NH3	kg / t feedstock	0.0290		£0.11	£0.11
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	9.52	-£0.40	-£1.06	-£1.46
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**-£0.38**	**-£1.05**	**-£1.43**
Land Application	Storage emissions	CH4	kg / t feedstock	0.0002	£0.25		£0.25
		NH3	kg / t feedstock	0.01		£0.03	£0.03
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.00	£0.00	£0.00	£0.00
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**£0.22**	**-£0.07**	**£0.16**

Table A5-24: Financial Costs

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
Dewatering (Centrifuge)	CAPEX	Main equipment item	£	72,000	106,000	179,000
		Control system	£	31,000	47,000	77,000
		Ancillaries	£	17,500	26,000	41,000
		Poly make up system	£	25,000	35,000	50,000
		Building	£	60,000	80,000	100,000
		Total	£	205,500	294,000	447,000
		Total per tonne capacity	£/t feedstock	20.55	11.76	8.94
		Total CAPEX	£/t feedstock	2.17	1.24	0.94
	OPEX	Polymer	£/t feedstock	2.29	2.29	2.29
		Ferric	£/t feedstock	0.18	0.18	0.18
		Electricity	£/t feedstock	1.42	1.04	0.78
		Labour	£/t feedstock	0.88	0.35	0.18
		Ancillary	£/t feedstock	0.18	0.07	0.04
		Maintenance	£/t feedstock	0.55	0.34	0.27
		Total OPEX	£/t feedstock	5.50	4.27	3.73
	Total £/t Feedstock for Process:			**7.67**	**5.51**	**4.67**
Land Application	CAPEX	Storage	£	175,000	360,000	690,000
		Total	£	175,000	360,000	690,000
		Total per tonne capacity	£/t feedstock	17.50	14.40	13.80
		Annualised CAPEX	£/t feedstock	1.85	1.52	1.46

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
	OPEX	Haulage	£/t feedstock	6.51	6.51	6.51
		Spreading	£/t feedstock	5.90	5.90	5.90
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.10	-0.10	-0.10
		Avoided synthetic fertiliser costs	£/t feedstock	-3.95	-3.95	-3.95
		Total OPEX	£/t feedstock	8.37	8.37	8.37
	Total £/t Feedstock for Process:			**10.22**	**9.89**	**9.83**
Land Application	CAPEX	Storage	£	60,000	140,000	270,000
		Total	£	60,000	140,000	270,000
		Total per tonne capacity	£/t feedstock	6.00	5.60	5.40
		Annualised CAPEX	£/t feedstock	0.63	0.59	0.57
	OPEX	Haulage	£/t feedstock	1.36	1.36	1.36
		Spreading	£/t feedstock	1.24	1.24	1.24
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.02	-0.02	-0.02
		Avoided synthetic fertiliser costs	£/t feedstock	-1.08	-1.08	-1.08
		Total OPEX	£/t feedstock	1.50	1.50	1.50
	Total £/t Feedstock for Process:			**2.13**	**2.09**	**2.07**

Appendix 6 Detailed Results from CBA Modelling – Central Case 2

As described above, eight scenarios (including the baseline) have been included in the model. The following tables provide in detail the model results for the financial and environmental costs of each option for Central Case 2: Dilution to 10% Dry Solids. A schematic diagram of the process for each option is shown at the beginning of each section with the relevant sub-processes highlighted in green.

A6.1 Baseline: Whole Digestate Applied to Land

Table A6-1: Outline Process

Option	**Dewatering process**	**Liquor Management**			**Fibre Management**
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A6-2: Environmental Unit Costs

Process	Environmental Aspect	Unit		Value	Damage Cost per Tonne Feedstock to Plant		
					GHG	AQ	Total
Land Application	Storage emissions	CH4	kg / t feedstock	0.0002	£0.29	-	£0.29
		NH3	kg / t feedstock	0.04	-	£0.14	£0.14
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	9.52	-£0.40	-£1.06	-£1.46
		P	kg P fert / t feedstock	1.51	-£0.02	-£0.18	-£0.19
		K	kg K fert / t feedstock	5.22	-£0.03	-£0.02	-£0.05
	Total £/t Feedstock for Process:				**-£0.15**	**-£1.12**	**-£1.27**

Table A6-3: Financial Unit Costs

Process	Cost Item		Unit	Capacity tpa		
				10,000	25,000	50,000
Direct Application to Land	CAPEX	Storage	£	310,000	640,000	1,150,000
		Total	£	310,000	640,000	1,150,000
		Total per tonne capacity	£/t feedstock	31.00	25.60	23.00
		Total CAPEX	£/t feedstock	3.28	2.71	2.43
	OPEX	Haulage	£/t feedstock	14.32	14.32	14.32
		Spreading	£/t feedstock	12.98	12.98	12.98
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.22	-0.22	-0.22
		Avoided synthetic fertiliser costs	£/t feedstock	-5.03	-5.03	-5.03
		Total OPEX	£/t feedstock	22.05	22.05	22.05
	Total £/t Feedstock for Process:			**25.32**	**24.75**	**24.48**

A6.2 Scenario 1: Dewatering, NR, BO, Sewer, Fibre to Land

Table A6-4: Outline Process

Option	Dewatering Process	Liquor Management			Fibre Management
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A6-5 Environmental Unit Costs

Process	Environmental Aspect		Unit	Value	Damage Cost per Tonne Feedstock to Plant		
					GHG	AQ	Total
Dewatering (Centrifuge)	Energy	Electricity	kWh/t feedstock	15.77	£0.05	£0.02	£0.06
	Chemicals used	Polymer	kg/t feedstock	1.09	£0.01	£0.01	£0.02
		Ferric	kg/t feedstock	1.82	£0.01	£0.05	£0.06
	Total £/t Feedstock for Process:			**2**	**£0.07**	**£0.08**	**£0.15**
Nutrient Recovery	Energy	Electricity	kWh/t feedstock	1.23	£0.004	£0.001	£0.005
	Chemicals	Magnesium Chloride	kg/t feedstock	0.019	£0.000	£0.001	£0.002
		Sodium Hydroxide	kg/t feedstock	0.002	£0.000	£0.000	£0.000
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.57	-£0.02	-£0.06	-£0.087
		P	kg P fert / t feedstock	0.68	-£0.01	-£0.08	-£0.09
Biological Oxidation	Energy	Electricity	kWh/t feedstock	10.83	£0.03	£0.01	£0.04
Disposal to Sewer	Energy	Electricity	kWh/t feedstock	0	£0.00	£0.00	£0.00
	Total £/t Feedstock for Process:			**3**	**£0.01**	**-£0.13**	**-£0.12**
Land Application (Fibre)	Storage emissions	CH4	kg / t feedstock	0.0002	£0.25		£0.25
		NH3	kg / t feedstock	0.01		£0.03	£0.03
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.00	£0.00	£0.00	£0.00
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:			**10**	**£0.22**	**-£0.07**	**£0.16**

Table A6-6: Financial Unit Costs

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
Dewatering (Centrifuge)	CAPEX	Main equipment item	£	72,000	106,000	179,000
		Control system	£	31,000	47,000	77,000
		Ancillaries	£	17,500	26,000	41,000
		Poly make up system	£	25,000	35,000	50,000
		Building	£	60,000	80,000	100,000
		Total	£	205,500	294,000	447,000
		Total per tonne capacity	£/t feedstock	20.55	11.76	8.94
		Total CAPEX	£/t feedstock	2.17	1.24	0.94
	OPEX	Polymer	£/t feedstock	2.29	2.29	2.29
		Ferric	£/t feedstock	0.18	0.18	0.18
		Electricity	£/t feedstock	1.42	1.04	0.78
		Labour	£/t feedstock	0.88	0.35	0.18
		Ancillary	£/t feedstock	0.18	0.07	0.04
		Maintenance	£/t feedstock	0.55	0.34	0.27
		Total OPEX	£/t feedstock	5.50	4.27	3.73
	Total £/t Feedstock for Process:			**7.67**	**5.51**	**4.67**
Nutrient Recovery	CAPEX	Total base, extras, storage	£	231,000	308,000	400,500
		Installation, commissioning, pipework	£	30,000	35,000	40,000
		Total	£	261,000	343,000	440,500

Process	Cost Item		Unit	Capacity tpa		
				10,000	25,000	50,000
		Total per tonne capacity	£/t feedstock	26.10	13.72	8.81
		Total CAPEX	£/t feedstock	2.76	1.45	0.93
	OPEX	Electricity	£/t feedstock	0.21	0.15	0.11
		Patent charge	£/t feedstock	0.23	0.23	0.23
		Chemicals	£/t feedstock	0.34	0.34	0.34
		Maintenance	£/t feedstock	0.22	0.11	0.07
		Labour	£/t feedstock	0.42	0.17	0.08
		Avoided synthetic fertiliser costs	£/t feedstock	0.44	0.44	0.44
		Total OPEX	£/t feedstock	1.87	1.45	1.28
Biological Oxidation (SBR)	CAPEX	Main equipment item	£	328,000	525,000	820,000
		Total	£	328,000	525,000	820,000
		Total per tonne capacity	£/t feedstock	32.80	21.00	16.40
		Total CAPEX	£/t feedstock	3.47	2.22	1.73
	OPEX	Electricity (Aeration)	£/t feedstock	1.40	1.40	1.40
		Other costs	£/t feedstock	1.40	1.40	1.40
		Total OPEX	£/t feedstock	2.80	2.80	2.80
Disposal to Sewer	CAPEX	Pipework	£	5,000	8,000	10,000
		Total	£	5,000	8,000	10,000
		Total per tonne capacity	£/t feedstock	0.50	0.32	0.20
		Total CAPEX	£/t feedstock	0.05	0.03	0.02

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
	OPEX	Mogden	£/t feedstock	2.1	2.1	2.1
		Total OPEX	£/t feedstock	2.100	2.100	2.100
	Total £/t Feedstock for Process:			**13.04**	**10.05**	**8.86**
Land Application (Fibre)	CAPEX	Storage	£	60,000	140,000	270,000
		Total	£	60,000	140,000	270,000
		Total per tonne capacity	£/t feedstock	6.00	5.60	5.40
		Annualised CAPEX	£/t feedstock	0.63	0.59	0.57
	OPEX	Haulage	£/t feedstock	1.36	1.36	1.36
		Spreading	£/t feedstock	1.24	1.24	1.24
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.02	-0.02	-0.02
		Avoided synthetic fertiliser costs	£/t feedstock	-1.08	-1.08	-1.08
		Total OPEX	£/t feedstock	1.50	1.50	1.50
	Total £/t Feedstock for Process:			**2.13**	**2.09**	**2.07**

A6.3 Scenario 2: Dewatering, NR, BO, Watercourse, Fibre to Land

Table A6-7: Outline Process

Option	Dewatering Process	Liquor Management			Fibre Management
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A6-8: Environmental Unit Costs

Process	Environmental Aspect		Unit	Value	Damage Cost per Tonne Feedstock to Plant		
					GHG	**AQ**	**Total**
Dewatering (Centrifuge)	Energy	Electricity	kWh/t feedstock	15.77	£0.05	£0.02	£0.06
	Chemicals used	Polymer	Kg/t feedstock	1.09	£0.01	£0.01	£0.02
		Ferric	Kg/t feedstock	1.82	£0.01	£0.05	£0.06
	Total £/t Feedstock for Process:				**£0.07**	**£0.08**	**£0.15**
Nutrient Recovery	Energy	Electricity	kWh/t feedstock	1.23	£0.004	£0.001	£0.01
	Chemicals	Magnesium Chloride	kg/t feedstock	0.019	£0.000	£0.001	£0.002
		Sodium Hydroxide	kg/t feedstock	0.002	£0.000	£0.000	£0.000
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.57	-£0.02	-£0.06	-£0.087
		P	kg P fert / t feedstock	0.68	-£0.01	-£0.08	-£0.09
Biological Oxidation (SBR)	Energy	Electricity	kWh/t feedstock	10.83	£0.03	£0.01	£0.04
Disposal to Watercourse	Energy	Electricity	kWh/t feedstock	0	£0.00	£0.00	£0.00
	Total £/t Feedstock for Process:				**£0.01**	**-£0.13**	**-£0.12**
Land Application (Fibre)	Storage emissions	CH4	kg / t feedstock	0.0002	£0.25		£0.25
		NH3	kg / t feedstock	0.01		£0.03	£0.03
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.00	£0.00	£0.00	£0.00
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**£0.22**	**-£0.07**	**£0.16**

Table A6-9: Financial Unit Costs

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
Dewatering (Centrifuge)	CAPEX	Main equipment item	£	72,000	106,000	179,000
		Control system	£	31,000	47,000	77,000
		Ancillaries	£	17,500	26,000	41,000
		Poly make up system	£	25,000	35,000	50,000
		Building	£	60,000	80,000	100,000
		Total	£	205,500	294,000	447,000
		Total per tonne capacity	£/t feedstock	20.55	11.76	8.94
		Total CAPEX	£/t feedstock	2.17	1.24	0.94
	OPEX	Polymer	£/t feedstock	2.29	2.29	2.29
		Ferric	£/t feedstock	0.18	0.18	0.18
		Electricity	£/t feedstock	1.42	1.04	0.78
		Labour	£/t feedstock	0.88	0.35	0.18
		Ancillary	£/t feedstock	0.18	0.07	0.04
		Maintenance	£/t feedstock	0.55	0.34	0.27
		Total OPEX	£/t feedstock	5.50	4.27	3.73
	Total £/t Feedstock for Process:			**7.67**	**5.51**	**4.67**
Nutrient Recovery	CAPEX	Total base, extras, storage	£	231,000	308,000	400,500
		Installation, commissioning, pipework	£	30,000	35,000	40,000
		Total	£	261,000	343,000	440,500

Process	Cost Item		Unit	Capacity tpa		
				10,000	25,000	50,000
		Total per tonne capacity	£/t feedstock	26.10	13.72	8.81
		Total CAPEX	£/t feedstock	2.76	1.45	0.93
	OPEX	Electricity	£/t feedstock	0.21	0.15	0.11
		Patent charge	£/t feedstock	0.23	0.23	0.23
		Chemicals	£/t feedstock	0.34	0.34	0.34
		Maintenance	£/t feedstock	0.22	0.11	0.07
		Labour	£/t feedstock	0.42	0.17	0.08
		Avoided synthetic fertiliser costs	£/t feedstock	0.44	0.44	0.44
		Total OPEX	£/t feedstock	1.87	1.45	1.28
Biological Oxidation (SBR)	CAPEX	Main equipment item	£	328,000	525,000	820,000
		Total	£	328,000	525,000	820,000
		Total per tonne capacity	£/t feedstock	32.80	21.00	16.40
		Total CAPEX	£/t feedstock	3.47	2.22	1.73
	OPEX	Electricity (Aeration)	£/t feedstock	1.40	1.40	1.40
		Other costs	£/t feedstock	1.40	1.40	1.40
		Total OPEX	£/t feedstock	2.80	2.80	2.80
Disposal to Watercourse	CAPEX		£	0.00	0.00	0.00
		Total	£	0.00	0.00	0.00
		Total per tonne capacity	£/t feedstock	0.00	0.00	0.00
		Total CAPEX	£/t feedstock	0.00	0.00	0.00

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
	OPEX		£/t feedstock	0.00	0.00	0.00
		Total OPEX	£/t feedstock	0.000	0.000	0.000
	Total £/t Feedstock for Process:			**10.89**	**7.92**	**6.74**
Land Application (Fibre)	CAPEX	Storage	£	60,000	140,000	270,000
		Total	£	60,000	140,000	270,000
		Total per tonne capacity	£/t feedstock	6.00	5.60	5.40
		Annualised CAPEX	£/t feedstock	0.63	0.59	0.57
	OPEX	Haulage	£/t feedstock	1.36	1.36	1.36
		Spreading	£/t feedstock	1.24	1.24	1.24
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.02	-0.02	-0.02
		Avoided synthetic fertiliser costs	£/t feedstock	-1.08	-1.08	-1.08
		Total OPEX	£/t feedstock	1.50	1.50	1.50
	Total £/t Feedstock for Process:			**2.13**	**2.09**	**2.07**

A6.4 Scenario 3: Dewatering, NR, Sewer, Fibre to Land

Table A6-10: Outline Process

Option	Dewatering Process	Liquor Management			Fibre Management
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A6-11: Environmental Costs

Process	**Environmental Aspect**		**Unit**	**Value**	**Damage Cost per Tonne Feedstock to Plant**		
					GHG	**AQ**	**Total**
Dewatering (Centrifuge)	Energy	Electricity	kWh/t feedstock	15.77	£0.05	£0.02	£0.06
	Chemicals used	Polymer	Kg/t feedstock	1.09	£0.01	£0.01	£0.02
		Ferric	Kg/t feedstock	1.82	£0.01	£0.05	£0.06
	Total £/t Feedstock for Process:				**£0.07**	**£0.08**	**£0.15**
Nutrient Recovery	Energy	Electricity	kWh/t feedstock	1.23	£0.004	£0.001	£0.01
	Chemicals	Magnesium Chloride	kg/t feedstock	0.019	£0.000	£0.001	£0.002
		Sodium Hydroxide	kg/t feedstock	0.002	£0.000	£0.000	£0.000
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.57	-£0.02	-£0.06	-£0.087
		P	kg P fert / t feedstock	0.68	-£0.01	-£0.08	-£0.087
Disposal to Sewer	Energy	Electricity	kWh/t feedstock	0	£0.00	£0.00	£0.00
	Total £/t Feedstock for Process:				**-£0.03**	**-£0.14**	**-£0.17**
Land Application (Fibre)	Storage emissions	CH4	kg / t feedstock	0.0002	£0.25	-	£0.25
		NH3	kg / t feedstock	0.01	-	£0.03	£0.03
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.00	£0.00	£0.00	£0.00
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**£0.22**	**-£0.07**	**£0.16**

Table A6-12: Financial Costs

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
Dewatering (Centrifuge)	CAPEX	Main equipment item	£	72,000	106,000	179,000
		Control system	£	31,000	47,000	77,000
		Ancillaries	£	17,500	26,000	41,000
		Poly make up system	£	25,000	35,000	50,000
		Building	£	60,000	80,000	100,000
		Total	£	205,500	294,000	447,000
		Total per tonne capacity	£/t feedstock	20.55	11.76	8.94
		Total CAPEX	£/t feedstock	2.17	1.24	0.94
	OPEX	Polymer	£/t feedstock	2.29	2.29	2.29
		Ferric	£/t feedstock	0.18	0.18	0.18
		Electricity	£/t feedstock	1.42	1.04	0.78
		Labour	£/t feedstock	0.88	0.35	0.18
		Ancillary	£/t feedstock	0.18	0.07	0.04
		Maintenance	£/t feedstock	0.55	0.34	0.27
		Total OPEX	£/t feedstock	5.50	4.27	3.73
	Total £/t Feedstock for Process:			**7.67**	**5.51**	**4.67**
Nutrient Recovery	CAPEX	Total base, extras, storage	£	231,000	308,000	400,500
		Installation, commissioning, pipework	£	30,000	35,000	40,000
		Total	£	261,000	343,000	440,500

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
		Total per tonne capacity	£/t feedstock	26.10	13.72	8.81
		Total CAPEX	£/t feedstock	2.76	1.45	0.93
	OPEX	Electricity	£/t feedstock	0.21	0.15	0.11
		Patent charge	£/t feedstock	0.23	0.23	0.23
		Chemicals	£/t feedstock	0.34	0.34	0.34
		Maintenance	£/t feedstock	0.22	0.11	0.07
		Labour	£/t feedstock	0.42	0.17	0.08
		Avoided synthetic fertiliser costs	£/t feedstock	0.44	0.44	0.44
		Total OPEX	£/t feedstock	1.87	1.45	1.28
Disposal to Sewer	CAPEX	Pipework	£	5,000	8,000	10,000
		Total	£	5,000	8,000	10,000
		Total per tonne capacity	£/t feedstock	0.50	0.32	0.20
		Total CAPEX	£/t feedstock	0.05	0.03	0.02
	OPEX	Mogden	£/t feedstock	13.92	13.92	13.92
		Total OPEX	£/t feedstock	13.92	13.92	13.92
	Total £/t Feedstock for Process:			**18.60**	**16.86**	**16.15**
Land Application (Fibre)	CAPEX	Storage	£	60,000	140,000	270,000
		Total	£	60,000	140,000	270,000
		Total per tonne capacity	£/t feedstock	6.00	5.60	5.40
		Annualised CAPEX	£/t feedstock	0.63	0.59	0.57

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
	OPEX	Haulage	£/t feedstock	1.36	1.36	1.36
		Spreading	£/t feedstock	1.24	1.24	1.24
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.02	-0.02	-0.02
		Avoided synthetic fertiliser costs	£/t feedstock	-1.08	-1.08	-1.08
		Total OPEX	£/t feedstock	1.50	1.50	1.50
	Total £/t Feedstock for Process:			**2.13**	**2.09**	**2.07**

A6.5 Scenario 4: Dewatering, BO, Sewer, Fibre to Land

Table A6-13: Outline Process

Option	**Dewatering Process**	**Liquor Management**			**Fibre Management**
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A6-14: Environmental Costs

Process	**Environmental Aspect**		**Unit**	**Value**	**Damage Cost per Tonne Feedstock to Plant**		
					GHG	**AQ**	**Total**
Dewatering (Centrifuge)	Energy	Electricity	kWh/t feedstock	15.77	£0.05	£0.02	£0.06
	Chemicals used	Polymer	Kg/t feedstock	1.09	£0.01	£0.01	£0.02
		Ferric	Kg/t feedstock	1.82	£0.01	£0.05	£0.06
	Total £/t Feedstock for Process:				**£0.07**	**£0.08**	**£0.15**
Biological Oxidation (SBR)	Energy	Electricity	kWh/t feedstock	10.83	£0.03	£0.01	£0.04
Disposal to Sewer	Energy	Electricity	kWh/t feedstock	0	£0.00	£0.0000	£0.000
	Total £/t Feedstock for Process:				**£0.03**	**£0.01**	**£0.04**
Land Application (Fibre)	Storage emissions	CH4	kg / t feedstock	0.0002	£0.25		£0.25
		NH3	kg / t feedstock	0.01		£0.03	£0.03
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.00	£0.00	£0.00	£0.00
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**£0.22**	**-£0.07**	**£0.16**

Table A6-15: Financial Costs

Process	Cost Item		Unit	Capacity tpa		
				10,000	25,000	50,000
Dewatering (Centrifuge)	CAPEX	Main equipment item	£	72,000	106,000	179,000
		Control system	£	31,000	47,000	77,000
		Ancillaries	£	17,500	26,000	41,000
		Poly make up system	£	25,000	35,000	50,000
		Building	£	60,000	80,000	100,000
		Total	£	205,500	294,000	447,000
		Total per tonne capacity	£/t feedstock	20.55	11.76	8.94
		Total CAPEX	£/t feedstock	2.17	1.24	0.94
	OPEX	Polymer	£/t feedstock	2.29	2.29	2.29
		Ferric	£/t feedstock	0.18	0.18	0.18
		Electricity	£/t feedstock	1.42	1.04	0.78
		Labour	£/t feedstock	0.88	0.35	0.18
		Ancillary	£/t feedstock	0.18	0.07	0.04
		Maintenance	£/t feedstock	0.55	0.34	0.27
		Total OPEX	£/t feedstock	5.50	4.27	3.73
	Total £/t Feedstock for Process:			**7.67**	**5.51**	**4.67**
Biological Oxidation (SBR)	CAPEX	Main equipment item	£	328,000	525,000	820,000
		Total	£	328,000	525,000	820,000
		Total per tonne capacity	£/t feedstock	32.80	21.00	16.40
		Total CAPEX	£/t feedstock	3.47	2.22	1.73

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
	OPEX	Electricity (Aeration)	£/t feedstock	1.40	1.40	1.40
		Other costs	£/t feedstock	1.40	1.40	1.40
		Total OPEX	£/t feedstock	2.80	2.80	2.80
Disposal to Sewer	CAPEX	Pipework	£	5,000	8,000	10,000
		Total	£	5,000	8,000	10,000
		Total per tonne capacity	£/t feedstock	0.50	0.32	0.20
		Total CAPEX	£/t feedstock	0.05	0.03	0.02
	OPEX	Mogden	£/t feedstock	2.1	2.1	2.1
		Total OPEX	£/t feedstock	2.100	2.100	2.100
	Total £/t Feedstock for Process:			**8.42**	**7.15**	**6.65**
Land Application (Fibre)	CAPEX	Storage	£	60,000	140,000	270,000
		Total	£	60,000	140,000	270,000
		Total per tonne capacity	£/t feedstock	6.00	5.60	5.40
		Annualised CAPEX	£/t feedstock	0.63	0.59	0.57
	OPEX	Haulage	£/t feedstock	1.36	1.36	1.36
		Spreading	£/t feedstock	1.24	1.24	1.24
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.02	-0.02	-0.02
		Avoided synthetic fertiliser costs	£/t feedstock	-1.08	-1.08	-1.08
		Total OPEX	£/t feedstock	1.50	1.50	1.50
	Total £/t Feedstock for Process:			**2.13**	**2.09**	**2.07**

A6.6 Scenario 5: Dewatering, BO, Watercourse, Fibre to Land

Table A6-16: Outline Process

Option	Dewatering Process	Liquor Management			Fibre Management
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A6-17: Environmental Costs

Process	Environmental Aspect		Unit	Value	Damage Cost per Tonne Feedstock to Plant		
					GHG	**AQ**	**Total**
Dewatering (Centrifuge)	Energy	Electricity	kWh/t feedstock	15.77	£0.05	£0.02	£0.06
	Chemicals used	Polymer	kg/t feedstock	1.09	£0.01	£0.01	£0.02
		Ferric	kg/t feedstock	1.82	£0.01	£0.05	£0.06
	Total £/t Feedstock for Process:				**£0.07**	**£0.08**	**£0.15**
Nutrient Recovery	Energy	Electricity	kWh/t feedstock	1.23	£0.004	£0.001	£0.01
	Chemicals	Magnesium Chloride	kg/t feedstock	0.019	£0.000	£0.001	£0.002
		Sodium Hydroxide	kg/t feedstock	0.002	£0.000	£0.000	£0.000
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.57	-£0.02	-£0.06	-£0.087
		P	kg P fert / t feedstock	0.68	-£0.01	-£0.08	-£0.09
Biological Oxidation (SBR)	Energy	Electricity	kWh/t feedstock	10.83	£0.03	£0.01	£0.04
Disposal to Watercourse	Energy	Electricity	kWh/t feedstock	0	£0.00	£0.00	£0.00
	Total £/t Feedstock for Process:				**£0.01**	**-£0.13**	**-£0.12**
Land Application	Storage emissions	CH4	kg / t feedstock	0.0002	£0.25		£0.25
		NH3	kg / t feedstock	0.01		£0.03	£0.03
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.00	£0.00	£0.00	£0.00
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**£0.22**	**-£0.07**	**£0.16**

Table A6-18: Financial Costs

Process	Cost Item		Unit	Capacity tpa		
				10,000	25,000	50,000
Dewatering (Centrifuge)	CAPEX	Main equipment item	£	72,000	106,000	179,000
		Control system	£	31,000	47,000	77,000
		Ancillaries	£	17,500	26,000	41,000
		Poly make up system	£	25,000	35,000	50,000
		Building	£	60,000	80,000	100,000
		Total	£	205,500	294,000	447,000
		Total per tonne capacity	£/t feedstock	20.55	11.76	8.94
		Total CAPEX	£/t feedstock	2.17	1.24	0.94
	OPEX	Polymer	£/t feedstock	2.29	2.29	2.29
		Ferric	£/t feedstock	0.18	0.18	0.18
		Electricity	£/t feedstock	1.42	1.04	0.78
		Labour	£/t feedstock	0.88	0.35	0.18
		Ancillary	£/t feedstock	0.18	0.07	0.04
		Maintenance	£/t feedstock	0.55	0.34	0.27
		Total OPEX	£/t feedstock	5.50	4.27	3.73
	Total £/t Feedstock for Process:			**7.67**	**5.51**	**4.67**
Biological Oxidation (SBR)	CAPEX	Main equipment item	£	328,000	525,000	820,000
		Total	£	328,000	525,000	820,000
		Total per tonne capacity	£/t feedstock	32.80	21.00	16.40
		Total CAPEX	£/t feedstock	3.47	2.22	1.73

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
	OPEX	Electricity (Aeration)	£/t feedstock	1.40	1.40	1.40
		Other costs	£/t feedstock	1.40	1.40	1.40
		Total OPEX	£/t feedstock	2.80	2.80	2.80
Disposal to Watercourse	CAPEX	-	£	0.00	0.00	0.00
		Total	£	0.00	0.00	0.00
		Total per tonne capacity	£/t feedstock	0.00	0.00	0.00
		Total CAPEX	£/t feedstock	0.00	0.00	0.00
	OPEX	Ferric	£/t feedstock	0.21	0.21	0.21
		Total OPEX	£/t feedstock	0.210	0.210	0.210
	Total £/t Feedstock for Process:			**6.47**	**5.23**	**4.74**
Land Application (Fibre)	CAPEX	Storage	£	60,000	140,000	270,000
		Total	£	60,000	140,000	270,000
		Total per tonne capacity	£/t feedstock	6.00	5.60	5.40
		Annualised CAPEX	£/t feedstock	0.63	0.59	0.57
	OPEX	Haulage	£/t feedstock	1.36	1.36	1.36
		Spreading	£/t feedstock	1.24	1.24	1.24
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.02	-0.02	-0.02
		Avoided synthetic fertiliser costs	£/t feedstock	-1.08	-1.08	-1.08
		Total OPEX	£/t feedstock	1.50	1.50	1.50
	Total £/t Feedstock for Process:			**2.13**	**2.09**	**2.07**

A6.7 Scenario 6: Dewatering, Sewer, Fibre to Land

Table A6-19: Outline Process

Option	Dewatering Process	Liquor Management			Fibre Management
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A6-20: Environmental Costs

Process	**Environmental Aspect**		**Unit**	**Value**	**Damage Cost per Tonne Feedstock to Plant**		
					GHG	**AQ**	**Total**
Dewatering (Centrifuge)	Energy	Electricity	kWh/t feedstock	15.77	£0.05	£0.02	£0.06
	Chemicals used	Polymer	Kg/t feedstock	1.09	£0.01	£0.01	£0.02
		Ferric	Kg/t feedstock	1.82	£0.01	£0.05	£0.06
	Total £/t Feedstock for Process:				**£0.07**	**£0.08**	**£0.15**
Direct Disposal to Sewer	Energy	Electricity	kWh/t feedstock	0	£0.00	£0.00	£0.00
	Total £/t Feedstock for Process:				£0.00	£0.00	**£0.00**
Land Application (Fibre)	Storage emissions	CH4	kg / t feedstock	0.0002	£0.25		£0.25
		NH3	kg / t feedstock	0.01		£0.03	£0.03
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.00	£0.00	£0.00	£0.00
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**£0.22**	**-£0.07**	**£0.16**

Table A6-21: Financial Costs

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
Dewatering (Centrifuge)	CAPEX	Main equipment item	£	72,000	106,000	179,000
		Control system	£	31,000	47,000	77,000
		Ancillaries	£	17,500	26,000	41,000
		Poly make up system	£	25,000	35,000	50,000
		Building	£	60,000	80,000	100,000
		Total	£	205,500	294,000	447,000
		Total per tonne capacity	£/t feedstock	20.55	11.76	8.94
		Total CAPEX	£/t feedstock	2.17	1.24	0.94
	OPEX	Polymer	£/t feedstock	2.29	2.29	2.29
		Ferric	£/t feedstock	0.18	0.18	0.18
		Electricity	£/t feedstock	1.42	1.04	0.78
		Labour	£/t feedstock	0.88	0.35	0.18
		Ancillary	£/t feedstock	0.18	0.07	0.04
		Maintenance	£/t feedstock	0.55	0.34	0.27
		Total OPEX	£/t feedstock	5.50	4.27	3.73
	Total £/t Feedstock for Process:			**7.67**	**5.51**	**4.67**
Disposal to Sewer	CAPEX	Pipework	£	5,000	8,000	10,000
		Total	£	5,000	8,000	10,000
		Total per tonne capacity	£/t feedstock	0.50	0.32	0.20
		Annualised CAPEX	£/t feedstock	0.05	0.03	0.02

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
	OPEX	Mogden	£/t feedstock	13.92	13.92	13.92
		Total OPEX	£/t feedstock	13.92	13.92	13.92
	Total £/t Feedstock for Process:			**13.98**	**13.96**	**13.94**
Land Application (Fibre)	CAPEX	Storage	£	60,000	140,000	270,000
		Total	£	60,000	140,000	270,000
		Total per tonne capacity	£/t feedstock	6.00	5.60	5.40
		Annualised CAPEX	£/t feedstock	0.63	0.59	0.57
	OPEX	Haulage	£/t feedstock	1.36	1.36	1.36
		Spreading	£/t feedstock	1.24	1.24	1.24
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.02	-0.02	-0.02
		Avoided synthetic fertiliser costs	£/t feedstock	-1.08	-1.08	-1.08
		Total OPEX	£/t feedstock	1.50	1.50	1.50
	Total £/t Feedstock for Process:			**2.13**	**2.09**	**2.07**

A6.8 Scenario 7: Dewatering, Liquor to Land, Fibre to Land

Table A6-22 Outline Process

Option	**Dewatering Process**	**Liquor Management**			**Fibre Management**
1	Centrifuge	Nutrient recovery	Biological oxidation	Sewer	Direct application to Land
2				Watercourse	
3			Sewer		
4		Biological oxidation	Sewer		
5			Watercourse		
6		Disposal to sewer			
7		Direct to land			
Baseline	Direct application of whole digestate to land				

Table A6-23: Environmental Costs

Process	**Environmental Aspect**		**Unit**	**Value**	**Damage Cost per Tonne Feedstock to Plant**		
					GHG	**AQ**	**Total**
Dewatering (Centrifuge)	Energy	Electricity	kWh/t feedstock	15.77	£0.05	£0.02	£0.06
	Chemicals used	Polymer	Kg/t feedstock	1.09	£0.01	£0.01	£0.02
		Ferric	Kg/t feedstock	1.82	£0.01	£0.05	£0.06
	Total £/t Feedstock for Process:				**£0.07**	**£0.08**	**£0.15**
Land Application (Liquor)	Storage emissions	CH4	kg / t feedstock	0.0000	£0.04		£0.04
		NH3	kg / t feedstock	0.0290		£0.11	£0.11
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	9.52	-£0.40	-£1.06	-£1.46
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**-£0.38**	**-£1.05**	**-£1.43**
Land Application (Fibre)	Storage emissions	CH4	kg / t feedstock	0.0002	£0.25		£0.25
		NH3	kg / t feedstock	0.01		£0.03	£0.03
	Avoided synthetic fertiliser use	N	kg N fert / t feedstock	0.00	£0.00	£0.00	£0.00
		P	kg P fert / t feedstock	0.75	-£0.01	-£0.09	-£0.10
		K	kg K fert / t feedstock	2.61	-£0.01	-£0.01	-£0.02
	Total £/t Feedstock for Process:				**£0.22**	**-£0.07**	**£0.16**

Table A6-24: Financial Costs

Process	**Cost Item**		**Unit**	**Capacity tpa**		
				10,000	**25,000**	**50,000**
Dewatering (Centrifuge)	CAPEX	Main equipment item	£	72,000	106,000	179,000
		Control system	£	31,000	47,000	77,000
		Ancillaries	£	17,500	26,000	41,000
		Poly make up system	£	25,000	35,000	50,000
		Building	£	60,000	80,000	100,000
		Total	£	205,500	294,000	447,000
		Total per tonne capacity	£/t feedstock	20.55	11.76	8.94
		Total CAPEX	£/t feedstock	2.17	1.24	0.94
	OPEX	Polymer	£/t feedstock	2.29	2.29	2.29
		Ferric	£/t feedstock	0.18	0.18	0.18
		Electricity	£/t feedstock	1.42	1.04	0.78
		Labour	£/t feedstock	0.88	0.35	0.18
		Ancillary	£/t feedstock	0.18	0.07	0.04
		Maintenance	£/t feedstock	0.55	0.34	0.27
		Total OPEX	£/t feedstock	5.50	4.27	3.73
		Total £/t Feedstock for Process:		**7.67**	**5.51**	**4.67**
Land Application (Liquor)	CAPEX	Storage	£	310,000	640,000	1,150,000
		Total	£	310,000	640,000	1,150,000
		Total per tonne capacity	£/t feedstock	31.00	25.60	23.00
		Annualised CAPEX	£/t feedstock	3.28	2.71	2.43

Process	Cost Item		Unit	Capacity tpa		
				10,000	25,000	50,000
	OPEX	Haulage	£/t feedstock	14.39	14.39	14.39
		Spreading	£/t feedstock	13.04	13.04	13.04
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.22	-0.22	-0.22
		Avoided synthetic fertiliser costs	£/t feedstock	-3.95	-3.95	-3.95
		Total OPEX	£/t feedstock	23.26	23.26	23.26
		Total £/t Feedstock for Process:		**26.54**	**25.97**	**25.69**
Land Application (Fibre)	CAPEX	Storage	£	60,000	140,000	270,000
		Total	£	60,000	140,000	270,000
		Total per tonne capacity	£/t feedstock	6.00	5.60	5.40
		Annualised CAPEX	£/t feedstock	0.63	0.59	0.57
	OPEX	Haulage	£/t feedstock	1.36	1.36	1.36
		Spreading	£/t feedstock	1.24	1.24	1.24
		Avoided synthetic fertiliser spreading	£/t feedstock	-0.02	-0.02	-0.02
		Avoided synthetic fertiliser costs	£/t feedstock	-1.08	-1.08	-1.08
		Total OPEX	£/t feedstock	1.50	1.50	1.50
		Total £/t Feedstock for Process:		**2.13**	**2.09**	**2.07**

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