BMA

Bioresources: Unlocking market growth using an advanced Digital Business Twin

Unlocking bioresource market growth using a collaborative decision support tool

DECISIO
Decision Intelligence Platform

Connected Decisions

BMA

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Data Availability can be improved

The initiative was often limited by the availability of published data, the use of public data was to allow the results to be shared openly without exposing commercially sensitive data. While the data gathered by Ofwat was useful for high level analysis more detail could provide better insight. The areas where information was most lacking was on growth projections and impact of future AMP8 WINEP schemes, asset age, wastewater treatment headroom to deal with return liquors, constraints on future plant expansion, reasons for reported reductions in capacity and landbank availability.

Optimisation of current networks has a significant benefit

The benefit is due to the optimisation within the constraints. The difference in costs is led by better utilisation of capacity, optimised logistics and no double handling of material. Planned and unplanned downtime events cannot be replicated and therefore the values published for the optimised scenario represents the best-case, which in practice can hardly be achieved due to real-life operational constraints.

There is benefit in short-term collaboration

In a scenario where no new investment is made there is a benefit from opening the company borders. This benefit is in the form of higher throughput through digestions facilities and a reduction of lime treated cake (the default assumption when there is insufficient permanent capacity) in this scenario, which represents the least desirable outlet when landbank is available.

Long-term collaboration creates more robust networks

When investments are allowed the difference between the open and closed networks becomes more significant when external challenges affect the network. The impact of a closure of agricultural landbank for product recycling, the reduction in asset availability or the increase in capital costs all show a relatively higher opportunity in an open network scenario.

The impact of regulatory changes is significant

The impact of the closure of the agricultural landbank is very significant. The emissions increase more than two-fold, while the need for capital increases by more than 6 times and the operating costs also increase.

There are different ways to stimulate the sector to achieve Net Zero

Three options were tested to stimulate the sector to achieve net zero. The carbon penalty option, the full carbon (costs and benefits) and the biomethane incentive options were tested. The carbon cost option did not reduce the carbon emissions down to zero. The full carbon scenario achieved a carbon negative state early in the future. The biomethane incentives scenario also achieved carbon negative state with a lower operating cost than the other options. However, more scenarios should be run to test impact of additional carbon accounting methodology, such as the location-based methodology.

There is benefit from wider collaboration and next steps

Extending the geographical scope of the initiative will provide further information on potential future shared investments and trading opportunities. The next phase of this initiative is to bring the innovation elements into a business-as-usual setting. This will include all English and Welsh WASCs collaborating on the shared national model.

Chapter 1: Context

Proposal summary

The initiative seeks to enable collaborative development of the bioresources market using a mature prescriptive analytics platform.

Ofwat has established a price control for bioresources, separate from wastewater, which includes collection, transport, treatment, disposal of sewage sludge and associated by-products. This aims to stimulate bioresources markets between Water and Sewerage Companies (WaSCs) and third-party service providers. The estimated benefits from greater utilisation of these markets are between £370-1,390m over 30 years. In the most recent Bioresources Market Reviews, Ofwat indicates that short-term marginal trades have limited potential to unlock the full benefits of markets and more focus should be put into inter-company optimisation, such as the development of joint capacity, and exploiting the benefits of economies of scale. This initiative aims to provide WaSCs with the support necessary to overcome existing barriers and unlock the benefits of these markets.

This will be achieved by integrating into a single decision support platform, the bioresource value chains of Anglian Water and 4 other WaSCs, equivalent to circa 50% of the total sludge production for England and Wales.

Introduction

English water companies treat sewage sludge generated as a by-product of wastewater treatment and produce bioresources, a valuable fertilizer product utilised in agriculture, and biogas, utilised to generate power. This initiative investigates the potential for collaboration between water companies to reduce cost, increase resilience, meet common environmental goals and simulate the impact of regulatory changes.

The five water companies represent 35 million customers and produce circa 900,000 dry tonnes (tDS) of raw sludge per annum.

Various scenarios have been developed using an advanced digital business twin showing potential benefits of collaboration, through cross-border movements and shared investments, to meet common goals.

The solution considers supply from circa 2,500 wastewater treatment centres, 100 sludge treatment centres, distributed over the Eastern region of England, and over 500,000 decision variables to calculate an optimal set of options. There is a view of potential savings, areas of collaboration and mapping of adaptive pathways to generate added value and meet future challenges. This initiative is based on data available in the public domain.

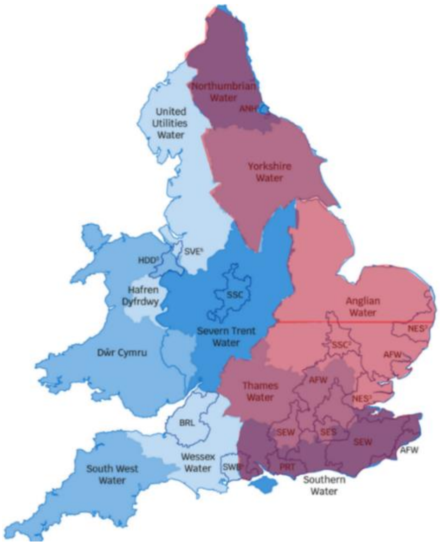


Figure 1: Map showing location of Participating Water Companies

Five UK Wastewater Companies have participated in this initial phase to explore collaborative planning. Led by Anglian Water, the other companies include Thames Water, Southern Water, Northumbrian Water and Yorkshire Water.

The initiative relies on the experience of Business Modelling Applications in building Advanced Digital Business Twins. The technology is matured over a decade of successful applications and relies on the Decision Intelligence capabilities supported by the Decisio AI-assisted, cloud-based platform.

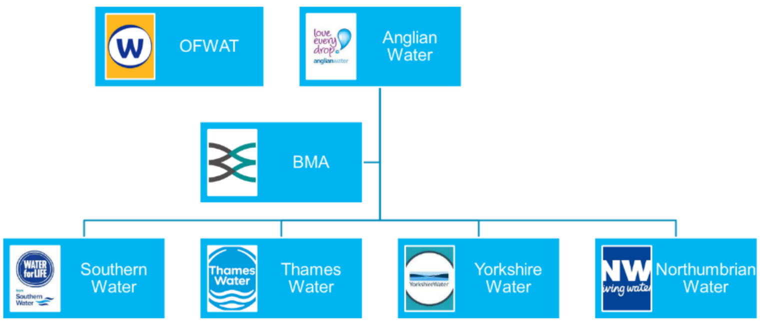


Figure 2: Initiative Participants

Since this initiative is in the public domain (it is accessible to a broad bioresources stakeholder group) all data has been taken from publicly available sources. The information published by Ofwat and the WaSCs has been validated through the initiative working group. Where data was not publicly available suggested assumptions were included from subject matter experts. The cost data in particular is a sensitive issue and results have been based on benchmark costs available in literature.

The model outcomes are based on high level assumptions and time horizons. That is the quality of the input data will have a direct impact on the direct usability of the model results. The model uses annual time horizons and excludes inter year operational impacts (such as unplanned maintenance on key assets etc.). The model can provide strategic insights and directional impacts of simulated scenarios.

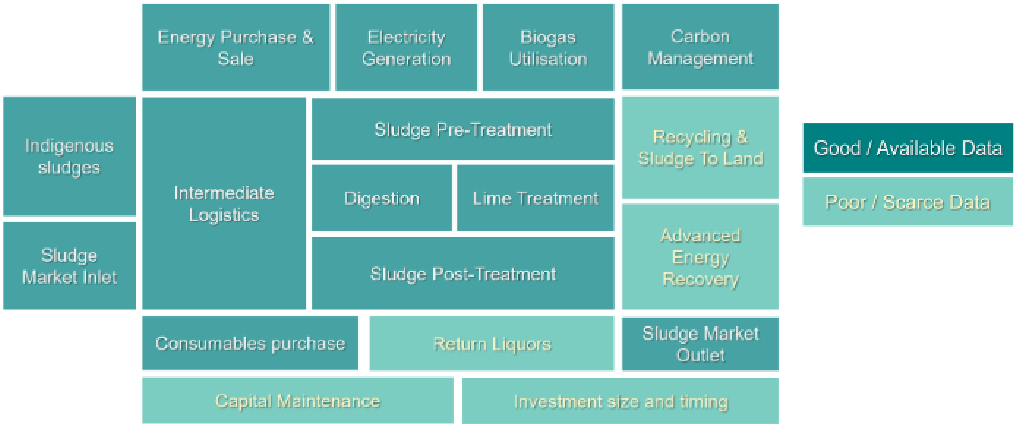


Figure 3: High level value chain and areas of data availability/scarcity

About Business Modelling Applications and Decisio™

BMA (Business Modelling Applications) is a leading UK-based technology company. Our Decision Intelligence software platform, Decisio™, helps asset-intensive businesses redefine the way they tackle the decisions that matter most.

We developed the Decisio™ Decision Processor to harness AI and other ground-breaking cloud technology advances to support organisations in making better, faster, sustainable, and more coordinated business decisions.

To do this Decisio™ encapsulates a range of technologies, analytics, methodologies, and decision science principles into a single ‘processor’ that is controlled from a single user interface and that has the security and governance built-in to support the smooth adoption of AI.

Figure 4: Decisio™ – Desicio(n) Processor

Decisio's™ capabilities cover a range of strategic, tactical and day-to-day operational decisions. Critically these decision recommendations are not made in isolation but are connected, ensuring coordination across functions and planning & execution time horizons. Capabilities can be activated individually, with each new application activation building towards comprehensive AI-assisted coverage of an organisation's key decision processes.

BMA's Decisio™ Decision Processor enables planning functions to become more connected through its AI-assisted Digital Business Twins that understand an organisation's end-to-end value chain with integrated financials, and asset & operational data across multiple nested timeframes.

Chapter 2: Objectives

This initiative, by integrating bioresources networks, will enable WaSCs to overcome critical barriers to trading, such as different pricing of activities and limited visibility of other WaSCs' strategy, challenges, and site-specific constraints. In providing WaSCs with a shared strategic 25-year view, the platform enables collaboration in identifying market opportunities. By involving Anglian Water and four WaSC partners, the outcome is expected to positively impact in the order of 50% of the population in England and Wales. Greater utilisation of these market can unlock between £370-1,390m for the wider bioresources sector over 30 years, according to Ofwat. In summary, the initiative will provide an indication of Capital Cost that can be displaced by integrated planning, and highlight the potential impact on Operational Cost savings, Carbon Reduction and increased Resilience as well as demonstrate the effect of 'cascade' sludge movements when applying systemic thinking.

The objectives will be completed by the close of the initiative with benefits resulting thereafter

- Create a level playing field for biosolids activities to identify opportunities for collaboration across multiple WaSCs.
- Identify opportunities for shared investments, to improve logistics, to improve treatment and/or manage outlets.
- Identify opportunities to offset investment by sharing existing or new capacity across multiple WaSCs.
- Identify opportunities to reduce overall TOTEX. A simulation run and previous experience from BMA indicates that the potential for cost reduction is in the range of 5%-25% for this type of strategic planning optimisation.
- Identify opportunities to rationalise sites across border to decrease Industrial Emission Directive compliance costs.
- Identify opportunities to decrease OpEx through different operational plans and through the utilisation of exiting headroom.
- Quantify the potential to mitigate operational carbon emission and support the industry journey to Net Zero.
- Demonstrate how resilience can be improved by taking a systemic approach to planning.
- Stimulation of one or more fixed term trading agreements between WaSCs and/or third parties.
- Provide a test bed for regulators, task forces and specialist working groups to test and quantify the impact of regulation before it is implemented.
- Create and demonstrate the benefit of new adaptive planning capabilities within water companies, enabling rapid, systemic scenario analysis.

The benefit from the initiative was to give the ability to WaSCs to assess their business plans against market opportunities through a systemic approach. This supports the assessment of business plans by allowing WaSCs to:

- Identify and quantify opportunities to displace or offset capital investments and to improve operational plans.
- Provide a platform to share knowledge and compare assumptions on critical factors, improving visibility and usability of data.
- Demonstrate the cost and risk implications of changing regulations and policy, for example the impact of the EA Sludge Strategy review. This is aligned to the call to action, published by United Utilities on behalf of the Water UK and EA Bioresources Strategy Task and Finish Group.
- Lower end-to-end cost through systemic modelling and optimisation. Previous applications from BMA demonstrated the potential for TOTEX reduction to be in the range of 5%-25%.
- Improve quality of the environment, by synergising WaSCs' planning around common objectives:
- Maintaining a high-quality bioresource product, as supported by the Biosolids Assurance scheme.
- Reaching Net Zero operational carbon by 2030, a target agreed by all WaSCs through a 'Public Interest Commitment' and detailed in the Water UK Carbon Roadmap.

Chapter 3: Data and Assumptions

The data used in this initiative needed to be accessible to all interested parties. These parties include all water companies in the UK, interested regulatory bodies and potential third parties who could provide capacity into the bioresources network.

Given the diversity of the audience and the sensitivity of the data required to fully cost the network the initiative only uses publicly available data and subject matter expert assumptions.

The sources of data were largely from published company data, collated by Ofwat (here). Where possible published benchmark data was used to complete process details and costs. Any missing information was completed with assumptions validated with the water company representatives.

The appendix includes list of references and the key assumptions used in the model.

Chapter 4: Model Design

The five water companies are represented by 2500 sources of sewage sludge. This demand was aggregated into geographic groups to reduce complexity. A grouping was done using a 10km radius to reduce the sludge sources down to 740 sites. The supply was aggregated to the largest centre within the 10 km radius.

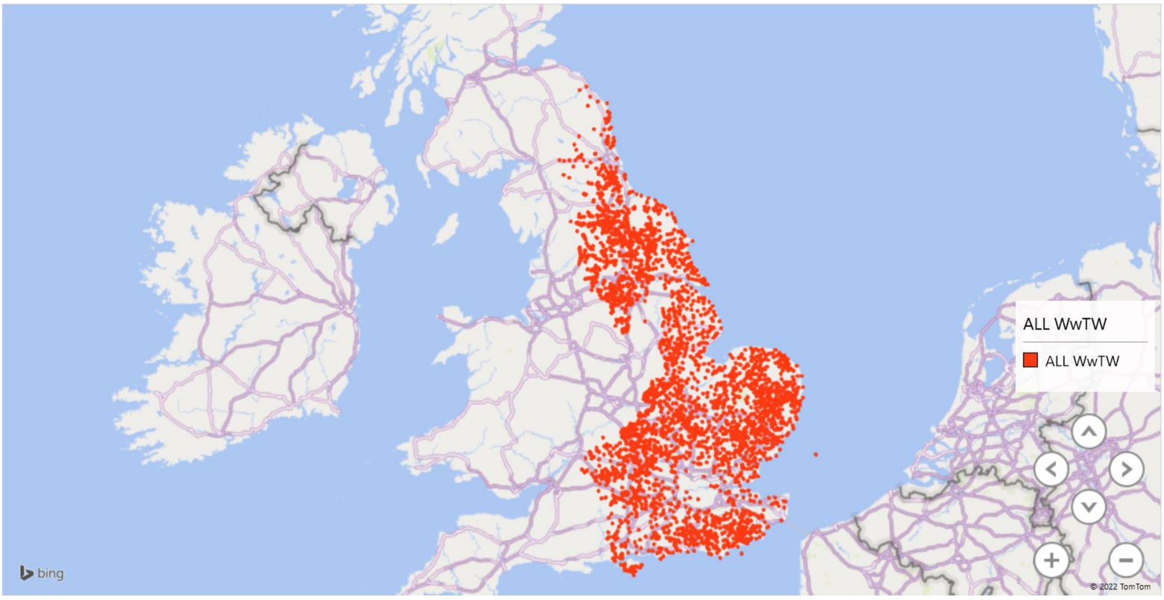


Figure 5: All WwTW and Thickening Sites

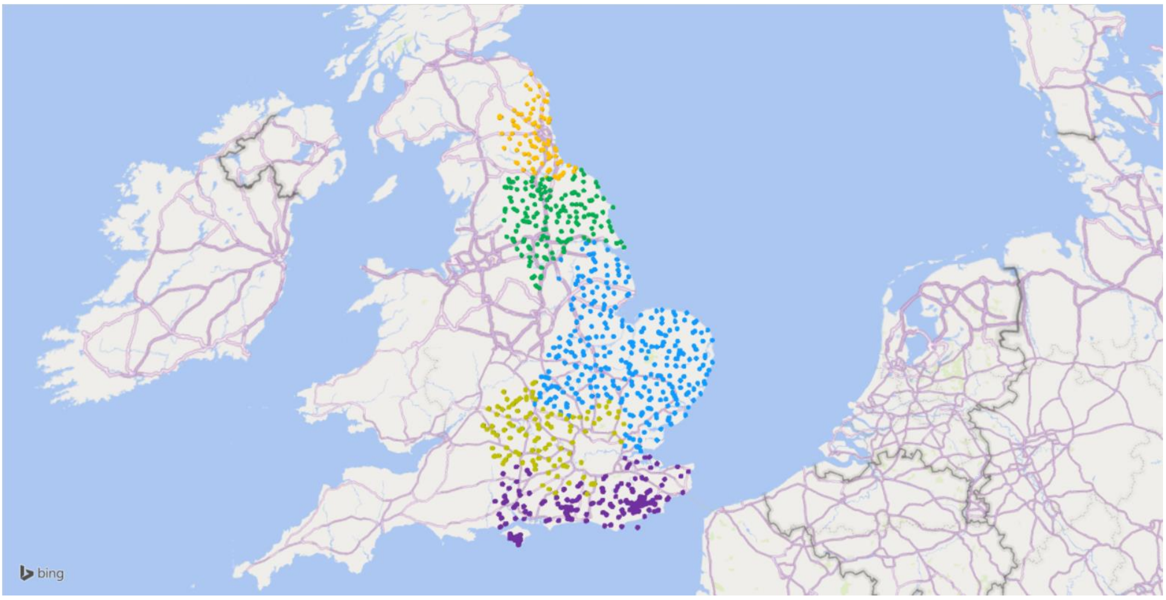


Figure 6: 10km grouping aggregation

love every drop anglianwater
NORTHUMBRIAN WATER living water
Southern Water
Thames Water
YorkshireWater

The primary treatments evaluated in this study are:

Liming (LIME): Lime powder is added to the sludge to increase pH and temperature and kill the bacteria. An established method that is not very cost effective because there is no energy recovery and no mass reduction. This is a default alternative when permanent treatment capacity is limited.

Conventional Anaerobic Digestion (CAD): Sludge is kept in an anaerobic tank (no oxygen) for a minimum of 14 days. The bacterial formation in the reactor transforms part of sludge into biogas and reduce the volatile fraction, making the output product more stable, with less pathogen and more mineralised fraction.

Hydrolysis AD (HPH AD): Similar to the process of conventional AD, but with a series of tanks upstream of the main reactor, where sludge is heated and/or pasteurised and hydrolysed to make the sludge easier for bacteria to break down and pathogens are further reduced.

Thermal Hydrolysis Process AD (THP AD): Similar to the process of conventional AD, but with a batch reactor upstream of the main reactor. Here steam is injected into the sludge to completely breakdown the organics to make them more accessible to bacteria and it kills all the pathogens. This requires higher energy input, compared to other AD process, but produces higher performance in the AD reactor compared to a conventional process and a comparable performance to other advanced AD processes (i.e. HPH).

Pasteurisation AD (PAS AD): Similar to the process of conventional AD, but with a batch reactor upstream of the main reactor, this pasteurises the sludge and kills off all the pathogens. However this does not produce the same improvement in biogas yield as other Advanced AD processes (THP or HPH).

The secondary treatments evaluated in this study are:

Incineration: this process is used to reduce the mass to its ash content and destroy all pathogens and potentially other harmful content. It comes with a high price tag, high emissions and offer little room to recover energy.

Pyrolysis: in this process sludge is heated in the absence of oxygen. This transforms the sludge into a mix of high calorific value gases (syngas), which can be used to produce heat and/or electricity. This technology has not been widely used in the sector and required more research.

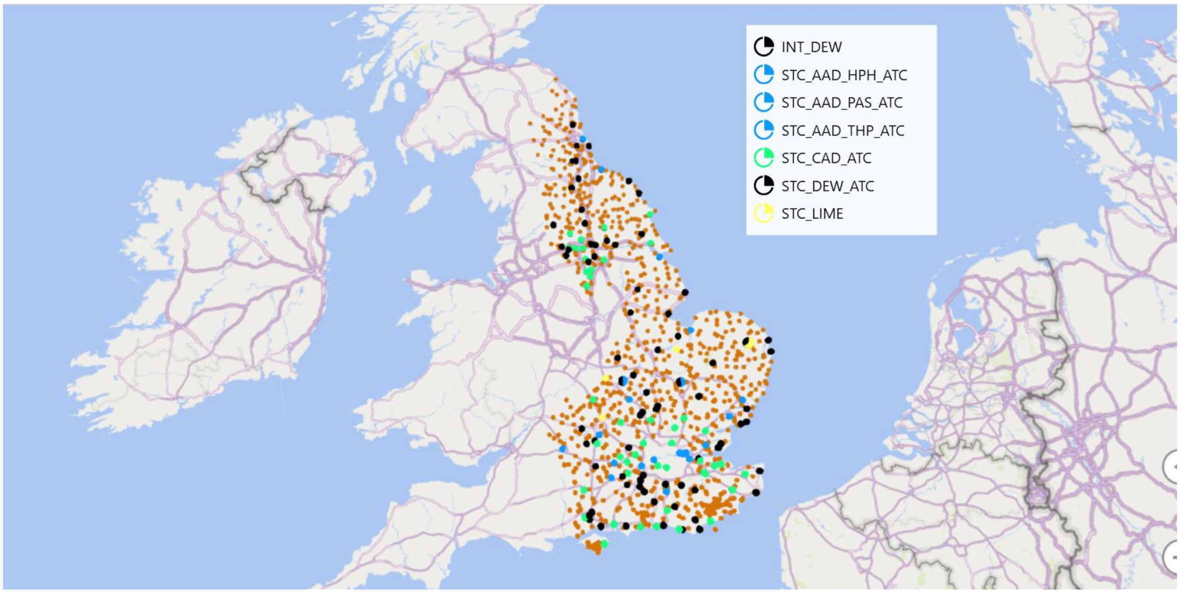


Figure 7: Location of sludge import centres

The relationship between the export centres and the import centres is given by the diagram below:

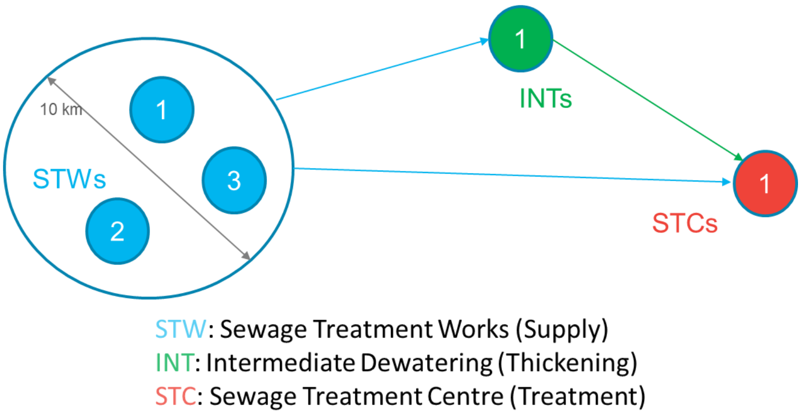


Figure 8: Supply and import centre relationships

The transport links between the sources and the treatment centres are modelled using a set fleet of vehicles. These are 15t, 20t and 27t for cake product (dewatered/treated) and 10m3, 15m3, 20m3 and 30m3 for liquid sludge. The distances between the export and import centres were calculated using the road distance based on the longitude and latitudes of each site.

The internal processing is modelled by breaking down the various activities into resources and processes which use input materials to transform the liquid sludge into the desired cake product and associated by-products. These are summarised in the following figure.

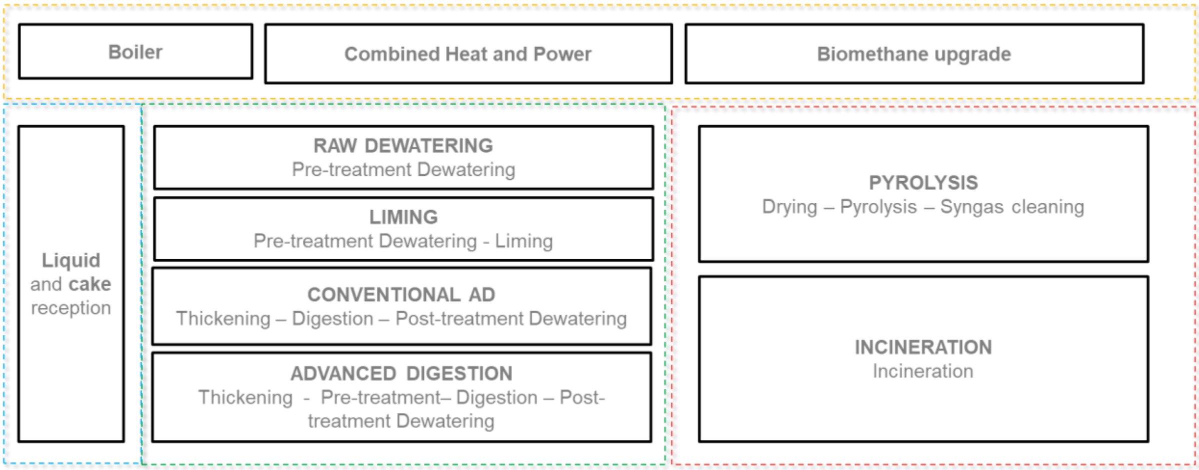


Figure 9: Model Processing Logic

The bioresources value chain is further represented in the following graphic.

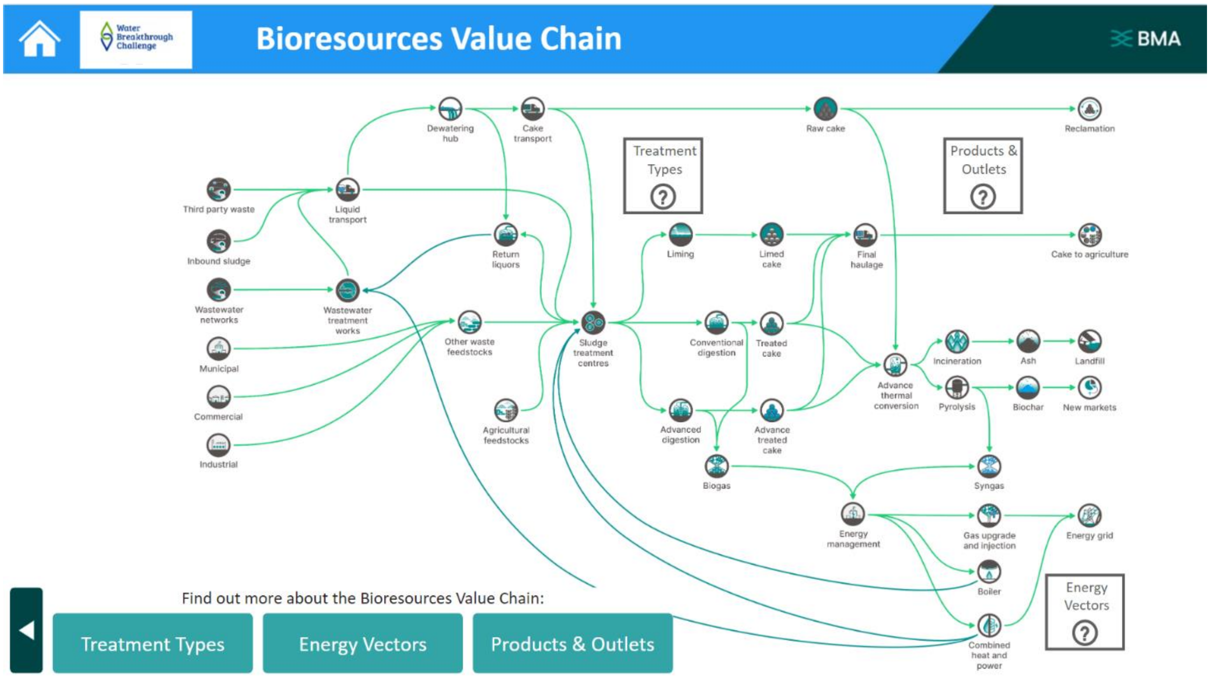
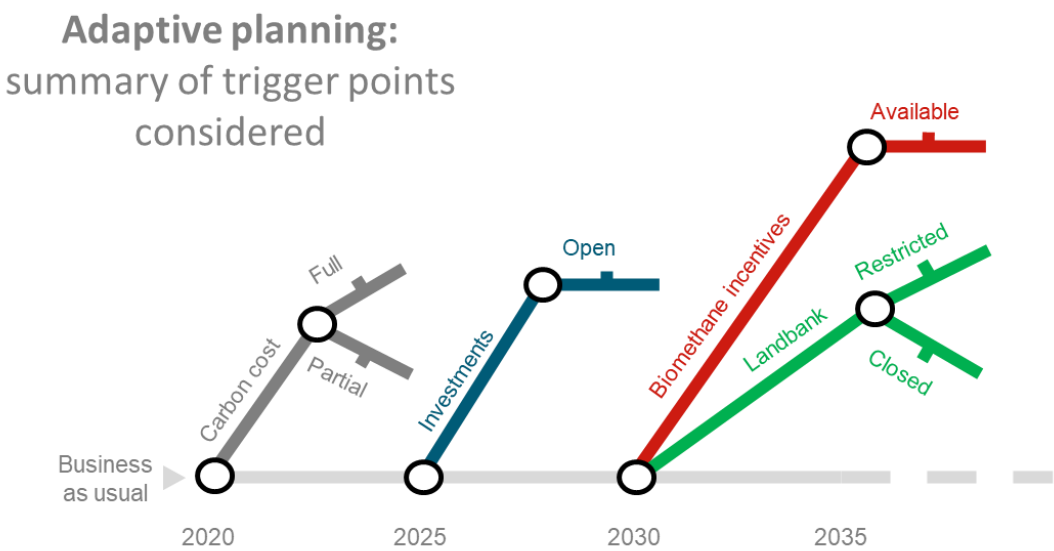


Figure 10: The bioresources value chain

Chapter 5: Scenarios

Once the baseline was built to reflect the historic operations and validate the model output, several scenarios has been run and optimised to provide visibility of the impact of certain key parameters and externalities changing. The timeline below illustrates the modelled trigger points for the adaptive pathways, future scenario runs could change these dates as the regulatory/operational landscape evolves.



Here the main parameters tested for sensitivity and the rationale for their selection is provided:

- **Carbon cost**: this was selected because the UK Government has set a target for Net Zero carbon emissions by 2050 and the Water industry has ambitions to accelerate this decarbonisation process, thus cost will be a critical element of the business plan going forward.
  - Base assumption: no cost applied to carbon (greenhouse gas emissions in carbon equivalent terms)
  - Partial: a monetary cost is applied to all Scope 1, 2 and 3 emissions
  - Full: a monetary cost is applied to all Scope 1, 2 and 3 emissions and Offsets receive an equivalent revenue
- **Investments**: this sensitivity is used to test whether the current asset base, with the existing demand forecast and future goals, is sufficient or whether additional investments will be required:
  - Base assumption: No investment allowed.
  - Open: Investment in new assets and technology is allowed
- **Biomethane incentives**: this is to explore the value that incentivisation of biomethane production could generate in terms of costs and carbon emissions:
  - Base assumption: no incentives available for biomethane production
  - Available: all biomethane generated receives a monetary incentive
- **Landbank**: this reflects the recent discussions on the implementation of the farming rules for water and potential closure of landbank to prevent potential risks associated to contaminants.
  - Base assumption: Landbank is available to recycle treated bioresources to agriculture.
  - Restricted: Cost of recycling treated bioresources to landbank increased by 5 times
  - Closed: No recycling of treated bioresources is allowed

Additional one-off scenarios (not part of the main sensitivity) have been tested:

- **Availability of assets**: this reflects downtime of assets associated with planned and unplanned interventions, which limit the overall throughput of sludge. The base assumption was that resources were limited to 90% of their nominal capacity. Additional scenarios included availability of 85%, 80%, 70% and 60%.
- **Cost of capital**: given the uncertainty on the public data collected for the capital cost of assets, an additional scenario where cost of capital was double was run.

In total, circa 50 scenarios were run to show potential adaptive planning pathways for the sector.

Chapter 6: Results

The final results of the initiative can be found on the BMA website, the Anglian Innovation Portal and other relevant online hosts. The results are displayed using a PowerBI dashboard embedded in a website. A full version of the results will be maintained on the Decisio Platform.

[BMA hosted report]

The initial landing page provides an overview of the initiative with options to navigate through the tour (Start Here button), find out more about bioresources or navigate to the home page of the report.

Figure 11: Dashboard Landing Page

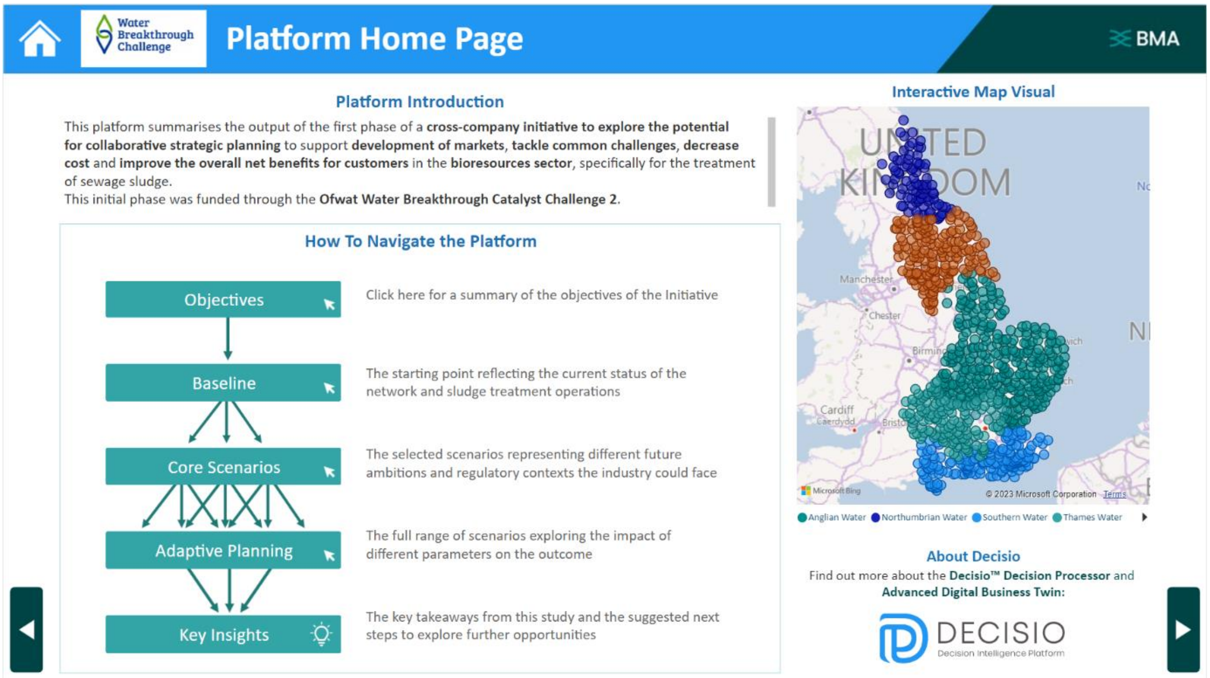
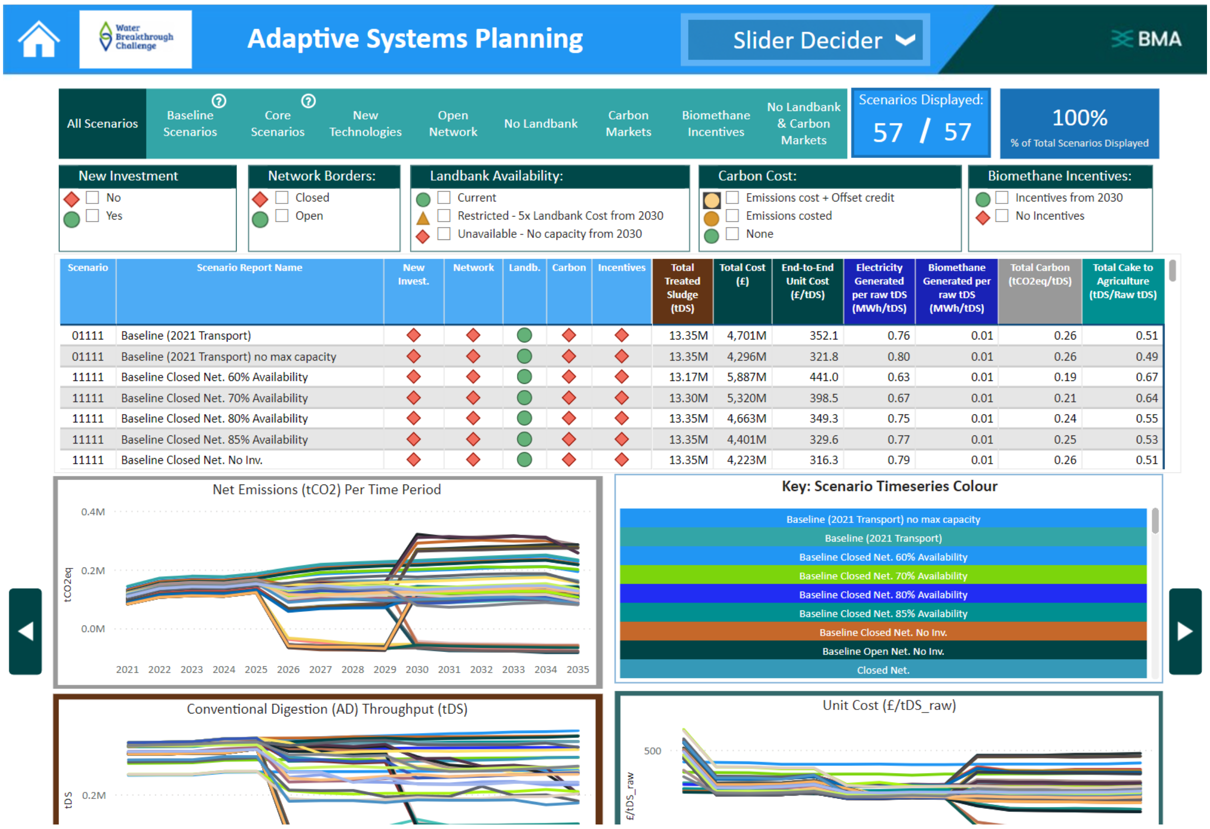


Figure 12: Dashboard Home Page

Figure 13: Dashboard Key Insights



Scenario	Scenario Report Name	Total Treated Sludge (tDS)	Total Cost (£)	End-to-End Unit Cost (£/tDS)	Electricity Generated per raw tDS (MWh/tDS)	Biomethane Generated per raw tDS (MWh/tDS)	Total Carbon (tCO2eq/tDS)	Total Cake to Agriculture (tDS/Raw tDS)
01111	Baseline (2021 Transport)	13.35M	4,701M	352.1	0.76	0.01	0.26	0.51
01111	Baseline (2021 Transport) no max capacity	13.35M	4,296M	321.8	0.80	0.01	0.26	0.49
11111	Baseline Closed Net. 60% Availability	13.17M	5,887M	441.0	0.63	0.01	0.19	0.67
11111	Baseline Closed Net. 70% Availability	13.30M	5,320M	398.5	0.67	0.01	0.21	0.64
11111	Baseline Closed Net. 80% Availability	13.35M	4,663M	349.3	0.75	0.01	0.24	0.55
11111	Baseline Closed Net. 85% Availability	13.35M	4,401M	329.6	0.77	0.01	0.25	0.53
11111	Baseline Closed Net. No Inv.	13.35M	4,223M	316.3	0.79	0.01	0.26	0.51

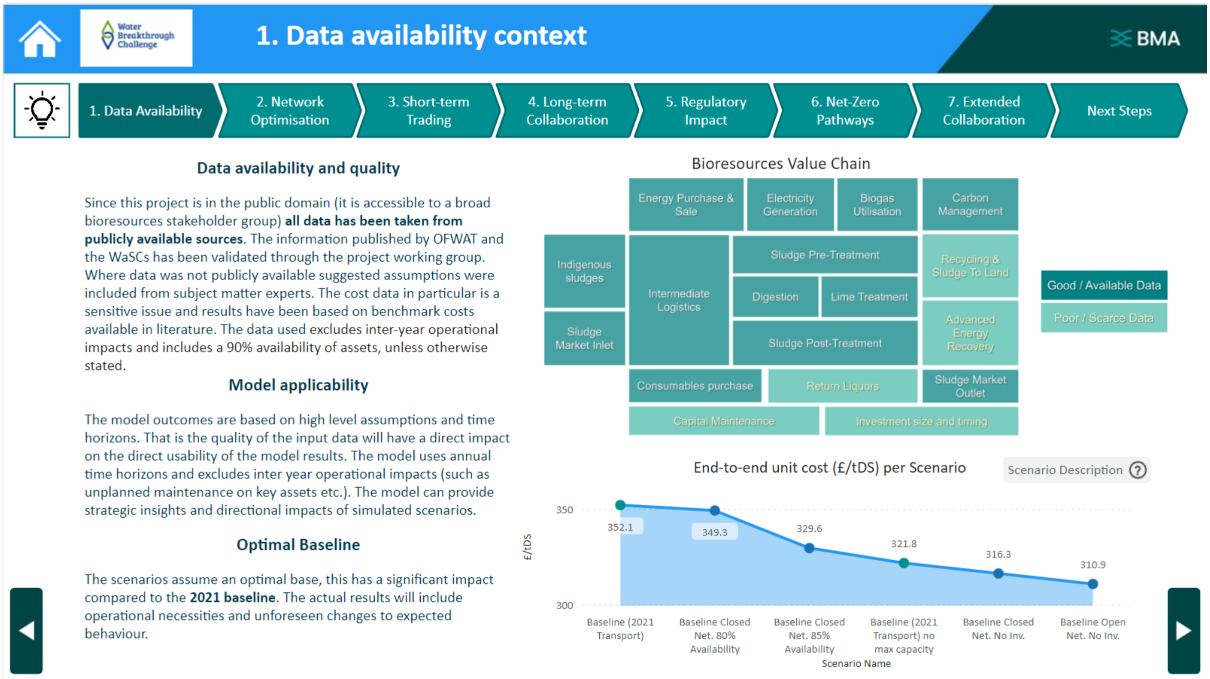
Figure 14: Dashboard Adaptive Business Planning

Chapter 7: Recommendations

The initiative has covered many aspects of the bioresources value chain and have found some key recommendations.

Data Availability and quality

The initiative was, in certain cases, limited by the availability of published data. While the data gathered by Ofwat was useful for high level analysis more detail could provide better insight. The cost data for treatment methods is very limited and at a high level with little direct applicability and the low volume of cases result in limited confidence in cost values.



This table summarises the areas where published data, either through Annual returns, individual WaSCs publications or collaborative studies, the model assumptions could be improved.

Table Name	Areas for improvement
Sludge Production	No **growth data** provided by individual WaSCs. While population growth can be estimated from national and regional forecasts, there is no visibility of future environmental schemes (WINEP) impacting future sludge demand. We recommend publishing at least a 15-year projection to allow alignment of WaSC outlook to environmental schemes.
Transport Costs	A study on the transportation costs by WaSC could further improve the accuracy of the inputs. This could be expressed in overall £/m3 moved or as £/km/m3.
Transport Routes	The sludge destination provides primary and secondary destinations with a % of sludge moved. This limitation means that circa 20% of sludge movements are not accounted for in the bioresources dashboard. Further to this some sites have multiple products that are transported between sites (i.e., liquid and cake) a separation of liquid and cake movements could improve data completeness and allowances for further destinations could improve the coverage of the historic movements.
Transport Links	Standardisation of materials that can be received will avoid potential interpretation errors in the reading of the nature of material accepted in the bioresources dashboard. We suggest the following: - Liquid sludge: raw liquid sludge (<10% dry solids w/w) - Raw cake: raw cake sludge (> 10% dry solids w/w) - Treated cake: conventionally treated cake (from AD processes) - Advanced treated cake: advanced treated cake (from AAD processes) - Limed cake: advanced treated cake (from Lime processes)
Asset capital cost data	Currently an **overall MEAV** for the site is provided. Having a breakdown of MEAV by at least asset group (Sludge treatment, gas handling, liquors return for example) would improve the scope to validate data. We suggest the following breakdown as a minimum level of granularity: - Reception facility (liquid and/or cake) - Sludge treatment by treatment type (Dewatering, Conventional AD, Advance AD etc.) - Biogas handling and use - Return liquors treatment
Asset Age	**Overall MEAV and expected asset life** for the site provided. Breakdown into asset groups (see above recommended groups for Asset capital cost data) would improve accuracy of the depreciation model. Also, it is critical that a consistent approach is used by the different WaSCs to determine site MEAV and age.
Consumables and outlets rates	Currently no visibility of **landbank availability** and cost rates. More regional data on landbank availability would greatly increase the model accuracy and provide better insights on regional sludge movements. We recommend to express landbank availability as: - Maximum allowable Nitrogen applications (tN/year based on a 3-year average) - Maximum allowable Phosphorus application (tP/year based on a 3-year average) - Restriction on material type (for example advanced treated only or max allowable conventionally treated cake (tDS/y)) - Acceptance rate of farmers (to accommodate supply of other organic manures etc.)

Asset Capacity	Currently overall sludge **treatment headroom** provided. Further breakdown by asset group can improve model recommendations, particularly important for energy assets (CHPs, Gas to Grid etc). We recommend providing a breakdown using the same asset groups as per 'capital cost data' section. Where changes to nominal capacity are provided, critical to understand the cause of that change (temporary maintenance downtime, decommissioning, new addition etc).
Storage capacity	Information on available storage space will become critical to evaluate impact of Farming Rules for Water, which significantly impact the time window for land application of bioresources and therefore the storage capacity required by WaSCs. This factor, together with the compliance requirement of the Industrial Emissions Directive, could lead to significant investments required and therefore significant scope for optimisation. We recommend that available storage surface for treated, advanced treated and limed cake to be published.
Site constraints	No information available on estimated **wastewater or liquor treatment headroom**. This limits the visibility of constraints for the different sites. We recommend publishing limits on total N and/or BOD, based on treatment headroom and incoming raw sewage load.

Table 1: List of data improvement opportunities

Data applicability and interpretation

The model outcomes are based on high level assumptions and time horizons. That is the quality of the input data will have a direct impact on the usability of the model results. The model uses annual time intervals and excludes inter-year operational impacts (such as unplanned maintenance on key assets etc). The model can provide strategic insights and directional impacts of simulated scenarios.

The scenarios assume an optimal baseline, which shows a significantly improved picture compared to the 2021 Historic baseline. The actual scope for improvement is limited by operational necessities and unforeseen changes to expected behaviour. The optimised results do not necessarily represent an achievable position, but rather represent the best possible case.

As demonstrated by the image below, a critical factor to consider is the availability of assets, which is a measure to represent the downtime of assets. Some of this downtime is required for planned maintenance (for example digesters have a statutory requirement to be shut down or inspected every 10 years or Thermal Hydrolysis units have a one to two-week inspection and maintenance period every year), while others could be due to unplanned asset outage. Given the unpredictable nature of the feedstock and the presence of grit and other foreign objects in sewage sludge, it is reasonable to assume the unplanned downtime is higher compared to other industries (such as manufacturing).

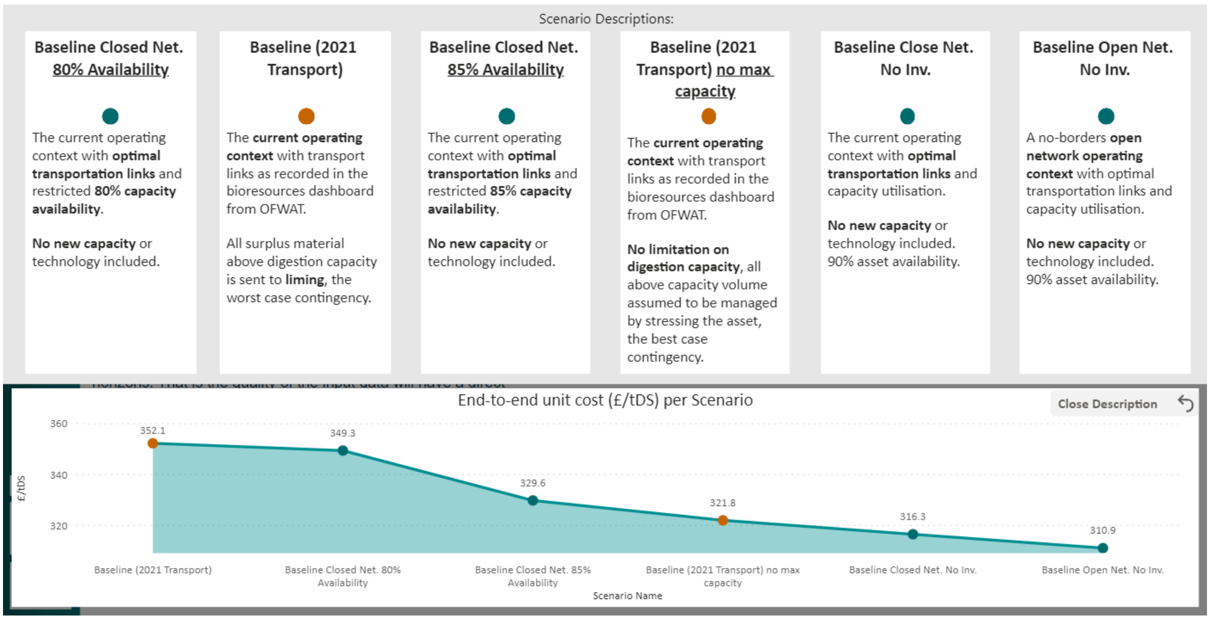


Figure 15: 1. Scope for optimisation under different assumptions

Optimisation of current networks has a significant benefit

The single biggest reduction in cost per tDS is by optimising the existing network. This has two aspects, model applicability and operational effectiveness. The optimisation nature of the model will indicate the best option within the constraints, it will not return solutions where double handling or under-utilisation would give a sub-optimal result. However, operational requirements could lead to rehandling or sub-optimal use of an asset and some of the reasons have been listed in the previous paragraph. The second aspect is a potential for improvement in current operations where the model could aid in designing transport routes and production strategies to aid in efficient treatment of sludge.

The reported fully build unit cost includes capital cost (expressed as annual depreciation), fixed costs (including labour and maintenance), disposal (liquor treatment and final cake recycle costs), transport (both liquid and raw cake) and treatment (inclusive of energy/consumable costs and net of revenue from energy export).

An important thing to note is that almost half of the cost is 'locked' in the assets. This element is important because to an extent it limits scope for optimisation, but it reinforces the need for a TOTEX model, like the one used here.

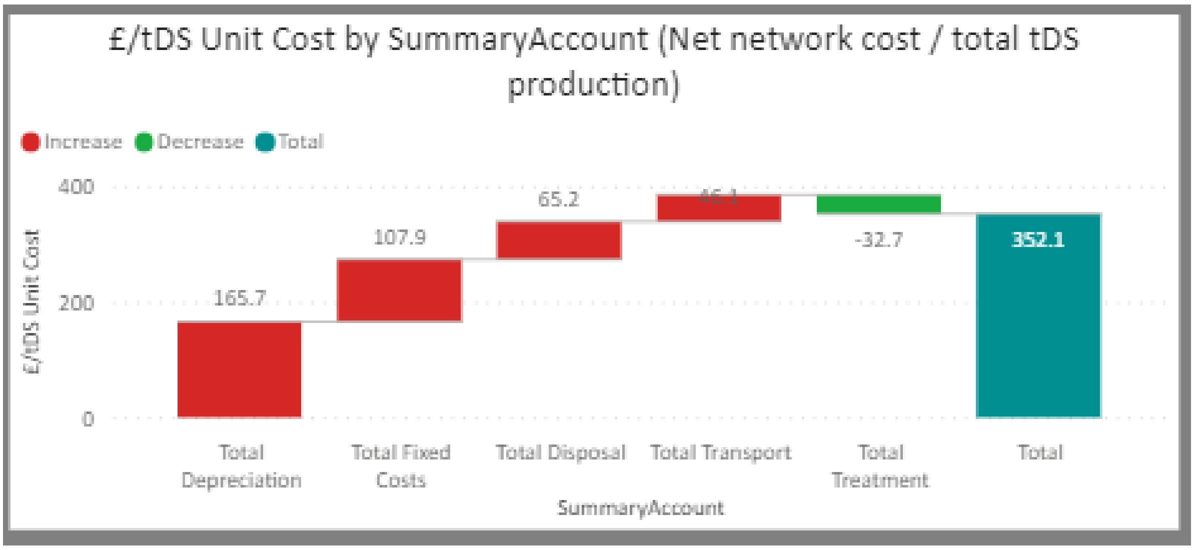


Figure 16: Unit cost for Historic Baseline 2021

The image below, extracted from the published dashboard, effectively illustrates how logistics movement have been rationalised and optimised. It also includes output from three scenarios:

- Baseline (2021 Transport): Here the logistics are forced based on the 2021 reported data. When capacity is exceeded at a destination site, excess sludge is limed.
- Baseline (2021 Transport) no max capacity: Here the logistics are forced based on the 2021 reported data. When capacity is exceeded at a destination site. Sites are allowed to over-utilised their current reported capacity.
- Baseline Closed Net. No Inv: Here logistics and use of capacity is optimised. Reported available (90%) capacity cannot be exceed and no new investments are allowed.

The reported difference in terms of end-to-end cost is significant and in annualised terms it would account for circa £26M/year. However, as indicated in the previous section, availability of assets could in reality be lower than 90%. When reducing assumed availability of assets to 85%, the optimisation opportunity reduces to cirva £14M/year.

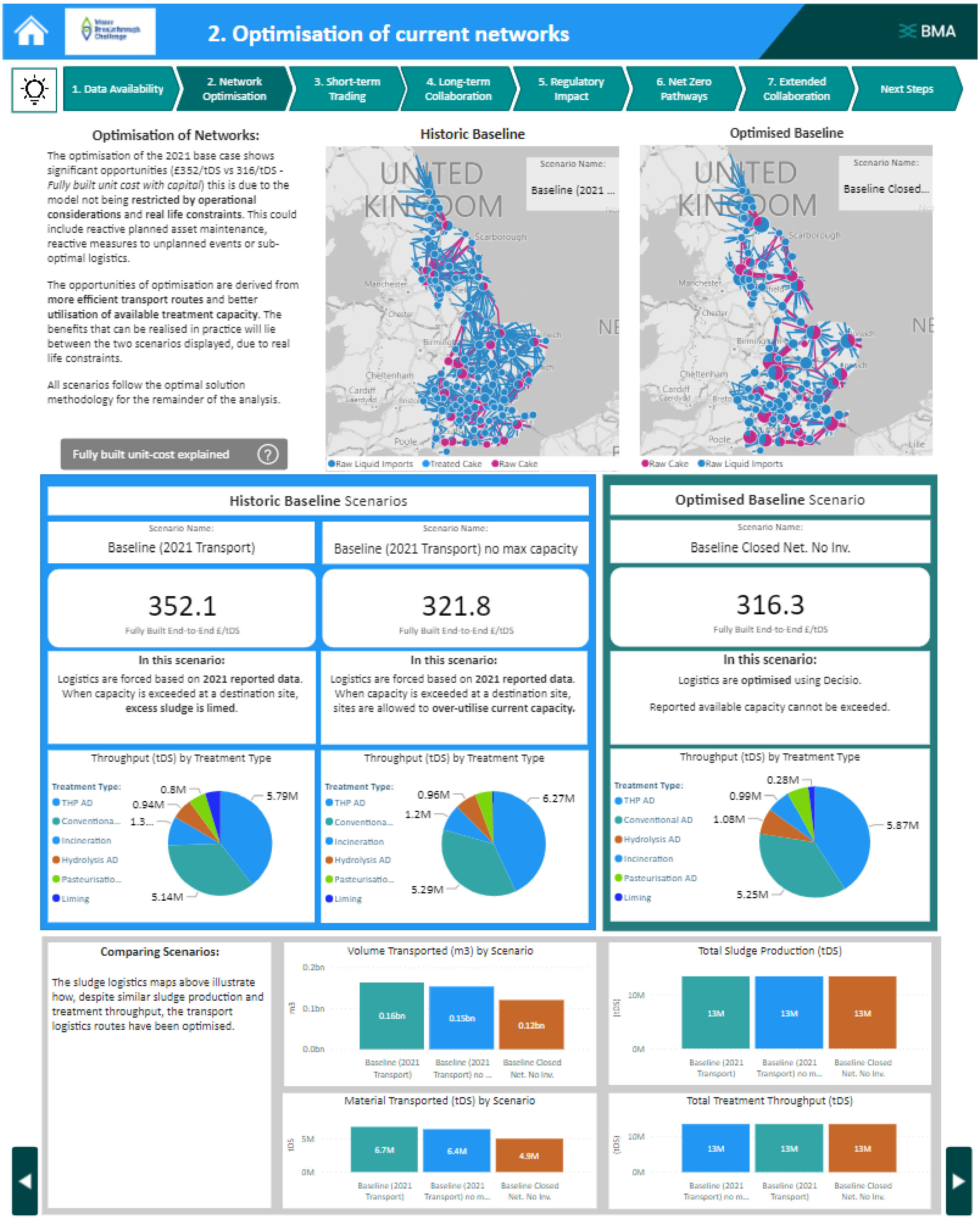


Figure 17: 2. Optimisation of current networks

There is benefit in short-term collaboration

These scenarios look at the option of opening cross-border trading without regional company borders (sludge is allowed to move across borders). In these cases no investment is assumed, as the focus in the operational cost reduction opportunities.

The key metric visualised include end-to-end unit cost, which is shown to decrease on average by 5.4 £/tDS. The opportunities arise from better utilisation of existing capacity and reduction in limed throughput, as indicated in the image below. In annualised terms this is an opportunity of circa £2.4M/y for the 5 WaSCs represented.

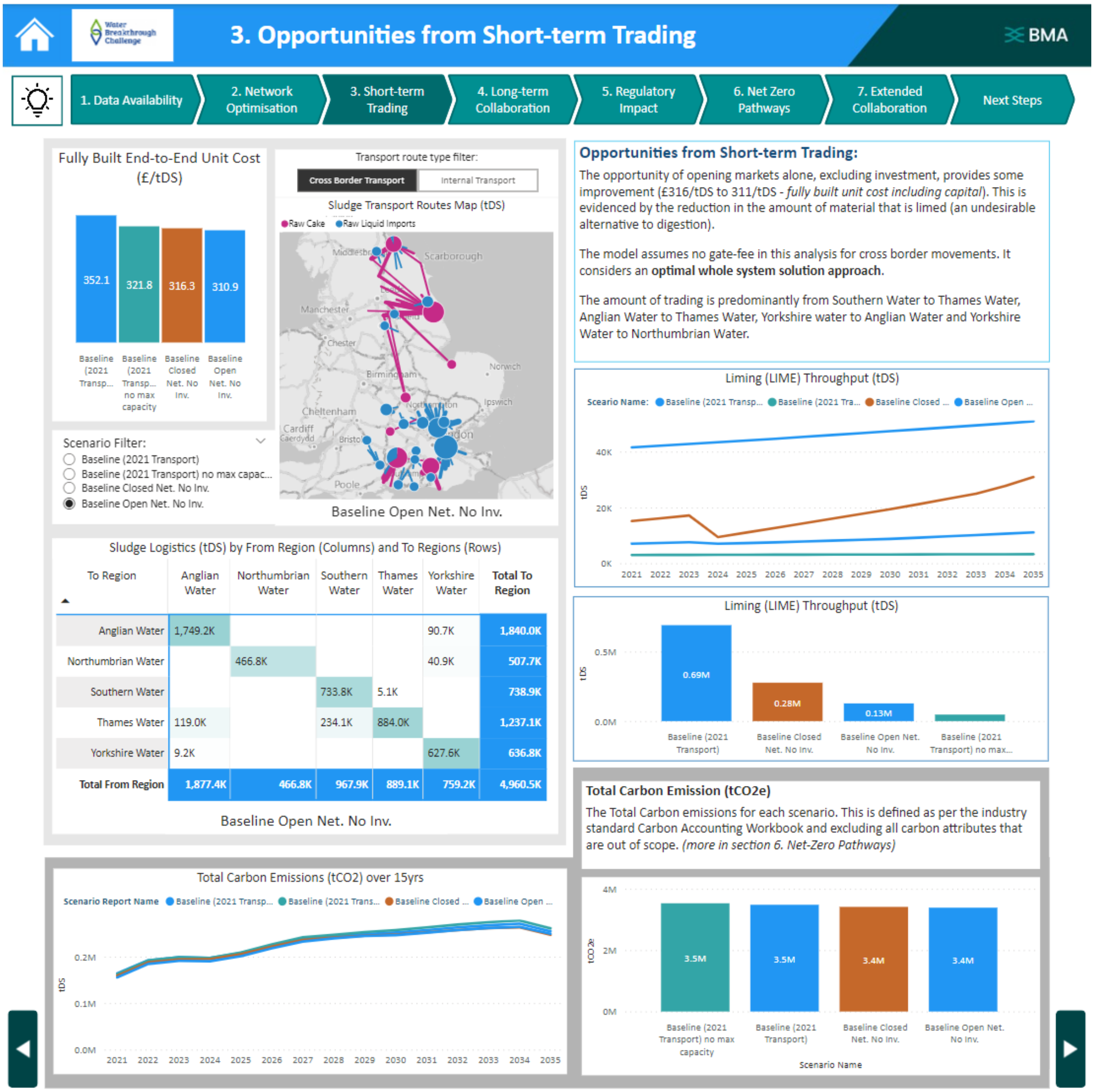
Overall, it is demonstrated that total limed sludge (the least desirable treatment, due to high cost & end product market acceptance) can be reduced significantly through cross-border trading. These are the total cross-border movements recommended (total for 15 years).

	From Region					
To Region	Anglian Water	Northumbrian Water	Southern Water	Thames Water	Yorkshire Water	**Total To Region**
Anglian Water	1,749.2K				90.7K	**1,840.0K**
Northumbrian Water		466.8K			40.9K	**507.7K**
Southern Water			733.8K	5.1K		**738.9K**
Thames Water	119.0K		234.1K	884.0K		**1,237.1K**
Yorkshire Water	9.2K				627.6K	**636.8K**
Total From Region	**1,877.4K**	**466.8K**	**967.9K**	**889.1K**	**759.2K**	**4,960.5K**

Baseline Open Net. No Inv.

It should be noted that these cross-border movements at the moment represent opportunities, but do not take into account of commercial gate fees, which the companies will apply to mitigate risks and pay for overheads to protect their customers from paying for treatment from other areas.

Another important point to note is that, even with cross-border trading, the total capacity of the network is not enough to deal with forecasted demand. This indicates that further investment in capacity will be required to ensure all the raw sludge produced in the future is treated (avoiding use of expensive liming treatment).



To Region	Anglian Water	Northumbrian Water	Southern Water	Thames Water	Yorkshire Water	Total To Region
Anglian Water	1,749.2K				90.7K	1,840.0K
Northumbrian Water		466.8K			40.9K	507.7K
Southern Water			733.8K	5.1K		738.9K
Thames Water	119.0K		234.1K	884.0K		1,237.1K
Yorkshire Water	9.2K				627.6K	636.8K
Total From Region	1,877.4K	466.8K	967.9K	889.1K	759.2K	4,960.5K

Baseline Open Net. No Inv.

Figure 18:3. Benefit of short-term trading

Long term collaboration creates more robust networks.

When investments are allowed, the model is set to identify what new capacity can be built and potentially used collaborative by two or more WaSCs. This should highlight what border areas have common requirements and could benefit from sharing capacity. This scenario was run with a number of sensitivities. Some of the key insights are presented for each.

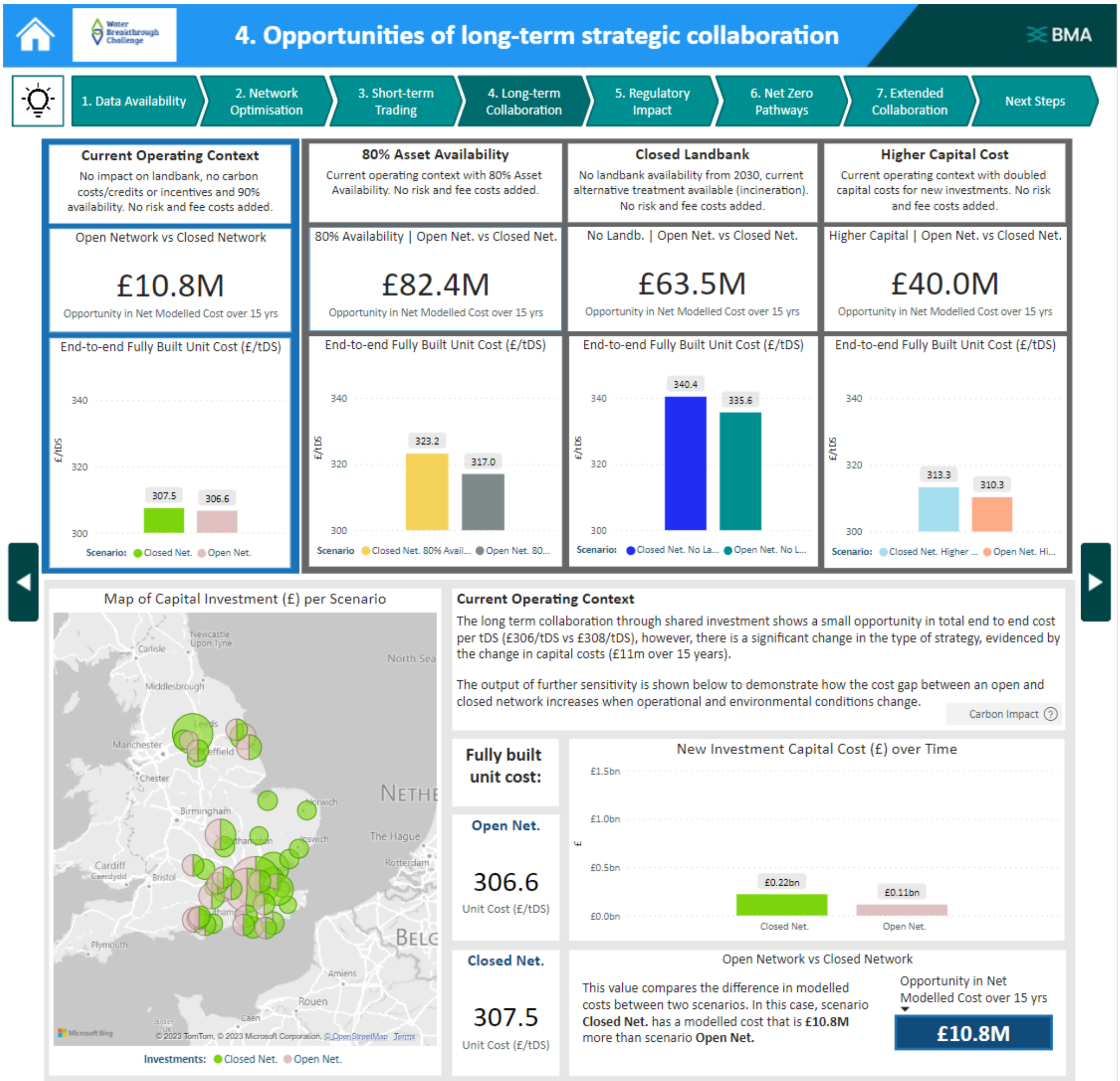
- 90% asset availability: the base case. In this case opening the borders led to circa halving the cost of capital but produced a relatively small reduction in fully built (open + capex) unit cost. Over 15 years that accounts for circa a £10M cost reduction opportunity.
-
- 80% asset availability: reduce availability due to maintenance and reactive measures. In this case the capital cost was reduced by circa 33% and the fully built unit cost reduction was larger than for the 90% availability case. Over 15 years that accounts for circa a £82M cost reduction opportunity.
-
- Doubling the cost of capital: testing for increased cost of delivery capital programmes. Increasing the cost of capital led to a smaller capital cost displacement opportunity, but overall led to a bigger gap in modelled unit cost, between a closed and an open border scenario. Over 15 years that accounts for circa a £40M cost reduction opportunity.
-
- Closing outlet to landbank: testing the scenario where recycling to landbank is no longer possible. When incineration is selected as alternative to landbank recycling, the capital cost requirement escalates by more than 6 times, compared to baseline scenario. The larger costs lead to identification of a relatively larger opportunity. Over 15 years that accounts for circa a £63M cost reduction opportunity.
-

Based on the presented results, we can conclude that:

The absolute value of the unit cost is primarily driven by other factors (such as asset availability and landbank availability), not by an open or closed border, which drive up cost significantly.

Opening the borders create a more robust network and reduces the cost impact of factors such as the ones presented in the sensitivity analysis above.

The sensitivities, here tested independently, are likely to manifest simultaneously and therefore it is reasonable to assume their effects will be compounded. It follows that the benefits of an open network, especially when extended to all WaSCs, would be relatively greater than that presented.


4. Opportunities of long-term strategic collaboration
BMA
1. Data Availability
2. Network Optimisation
3. Short-term Trading
4. Long-term Collaboration
5. Regulatory Impact
6. Net Zero Pathways
7. Extended Collaboration
Next Steps
Current Operating Context
No impact on landbank, no carbon costs/credits or incentives and 90% availability. No risk and fee costs added.
80% Asset Availability
Current operating context with 80% Asset Availability. No risk and fee costs added.
Closed Landbank
No landbank availability from 2030, current alternative treatment available (incineration). No risk and fee costs added.
Higher Capital Cost
Current operating context with doubled capital costs for new investments. No risk and fee costs added.
Open Network vs Closed Network
£10.8M
Opportunity in Net Modelled Cost over 15 yrs
80% Availability | Open Net. vs Closed Net.
£82.4M
Opportunity in Net Modelled Cost over 15 yrs
No Landb. | Open Net. vs Closed Net.
£63.5M
Opportunity in Net Modelled Cost over 15 yrs
Higher Capital | Open Net. vs Closed Net.
£40.0M
Opportunity in Net Modelled Cost over 15 yrs
End-to-end Fully Built Unit Cost (£/tDS)
307.5
306.6
Scenario: Closed Net. Open Net.
323.2
317.0
Scenario Closed Net. 80% Avail... Open Net. 80...
340.4
335.6
Scenario: Closed Net. No La... Open Net. No L...
313.3
310.3
Scenario: Closed Net. Higher ... Open Net. Hi...
Map of Capital Investment (£) per Scenario
Investments: Closed Net. Open Net.
Current Operating Context
The long term collaboration through shared investment shows a small opportunity in total end to end cost per tDS (£306/tDS vs £308/tDS), however, there is a significant change in the type of strategy, evidenced by the change in capital costs (£11m over 15 years).
The output of further sensitivity is shown below to demonstrate how the cost gap between an open and closed network increases when operational and environmental conditions change.
Carbon Impact
Fully built unit cost:
Open Net.
306.6
Unit Cost (£/tDS)
Closed Net.
307.5
Unit Cost (£/tDS)
New Investment Capital Cost (£) over Time
£0.22bn
£0.11bn
Closed Net.
Open Net.
Open Network vs Closed Network
This value compares the difference in modelled costs between two scenarios. In this case, scenario Closed Net. has a modelled cost that is £10.8M more than scenario Open Net.
Opportunity in Net Modelled Cost over 15 yrs
£10.8M

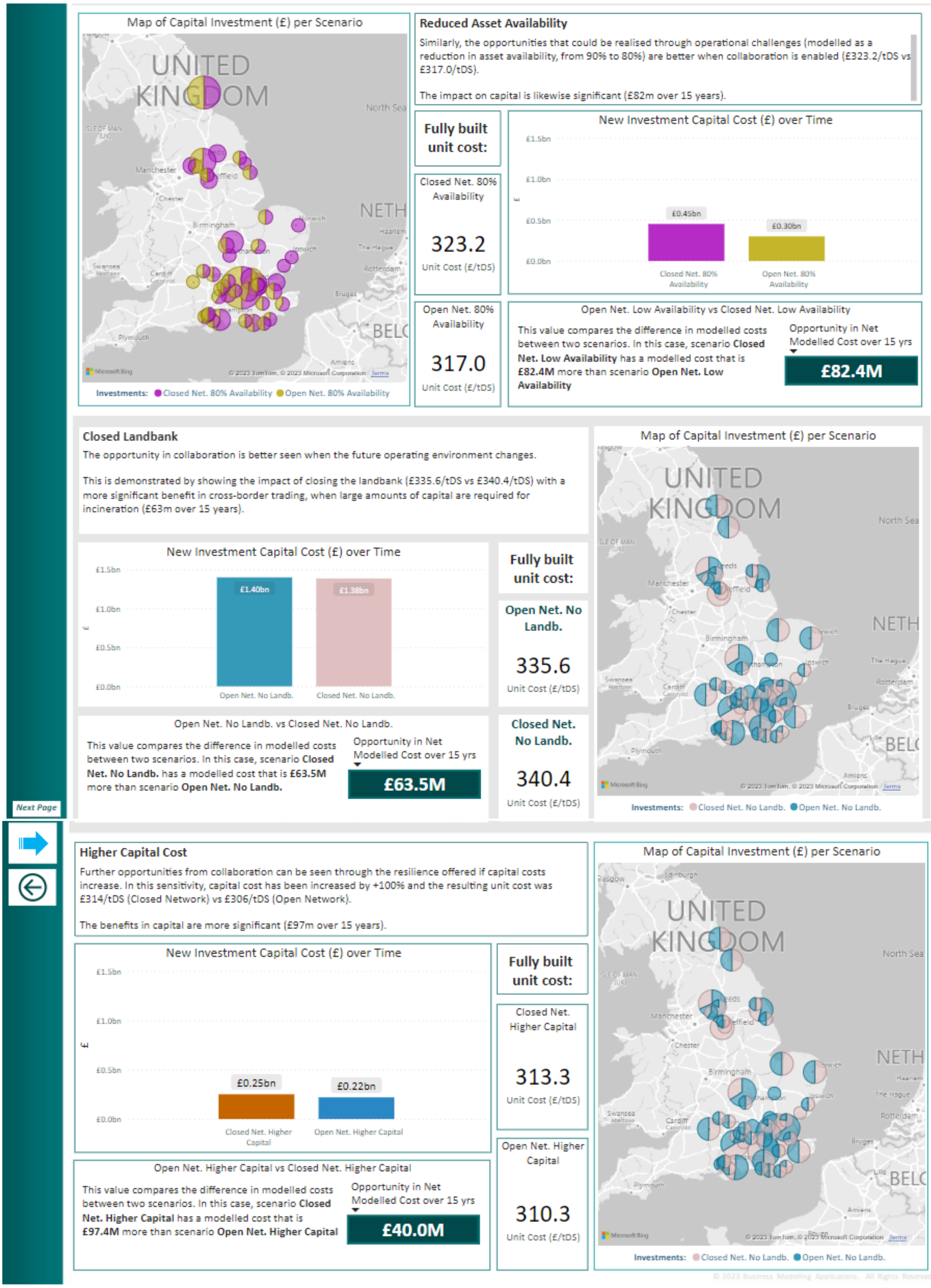


Figure 19: 4. Benefit of long-term collaboration

The impact of regulatory changes is significant.

Use of incineration

In this scenario where recycling to landbank was closed, the only alternative available was incineration, as this is the only tried and tested thermal destruction method in the UK bioresources sector.

Use of incineration instead of recycling to landbank was shown having a significant impact on both projected costs and emissions. Capital requirements increased by circa 6 times and was in excess of £1.3B for the 5 WaSCs. Operational emissions also more than doubled, compared to current activities. Based on the current assumptions the model still recommended investment in advanced digestion and biomethane upgrade when landbank was closed, to minimise mass to incineration and generate revenue from biogas.

Use of pyrolysis

In another scenario, use of pyrolysis was tested to replace incineration. This scenario still generated a similar capital cost to the incineration one, but overall produced a significantly lower fully built unit cost (circa 10% cost reduction opportunity) and lower emissions. This was primarily driven using syngas to produce additional renewable electricity.

It is important to note that several uncertainties currently limit the ability of the sector to adopt pyrolysis:

- No full-scale application for sewage sludge in the UK
- Product yield closely linked to operational conditions of pyrolysis reactor.
- Undeveloped biochar market, limiting application of the end product (here a cost of disposal was assumed, but biochar has potential to generate revenue). Note that there is no current regulatory framework for recycling of sewage sludge from BioChar products.
- Unclear carbon sequestration potential of biochar (here no carbon sequestration benefit was assumed).

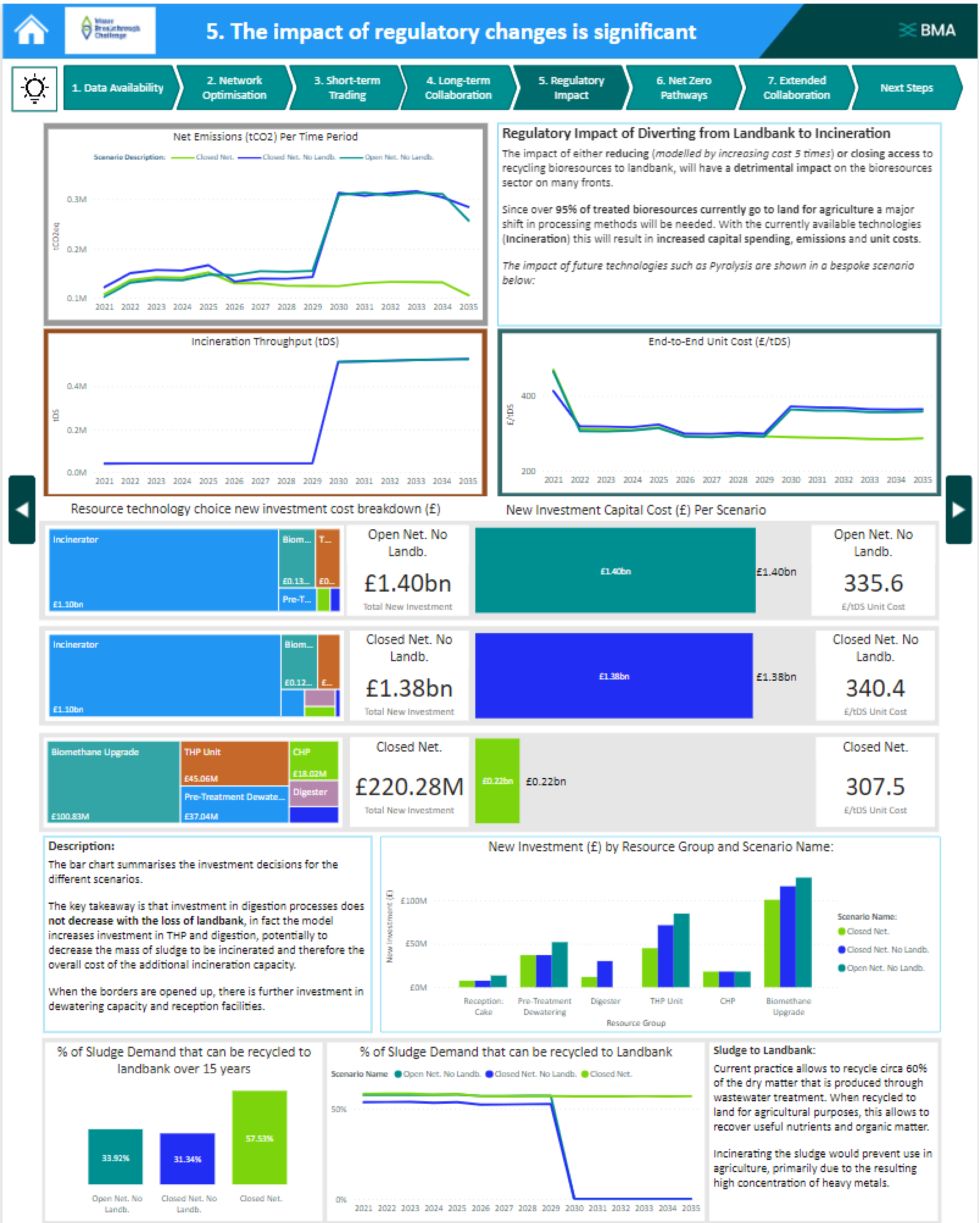


Figure 20: 5. A) The impact of regulatory changes is significant

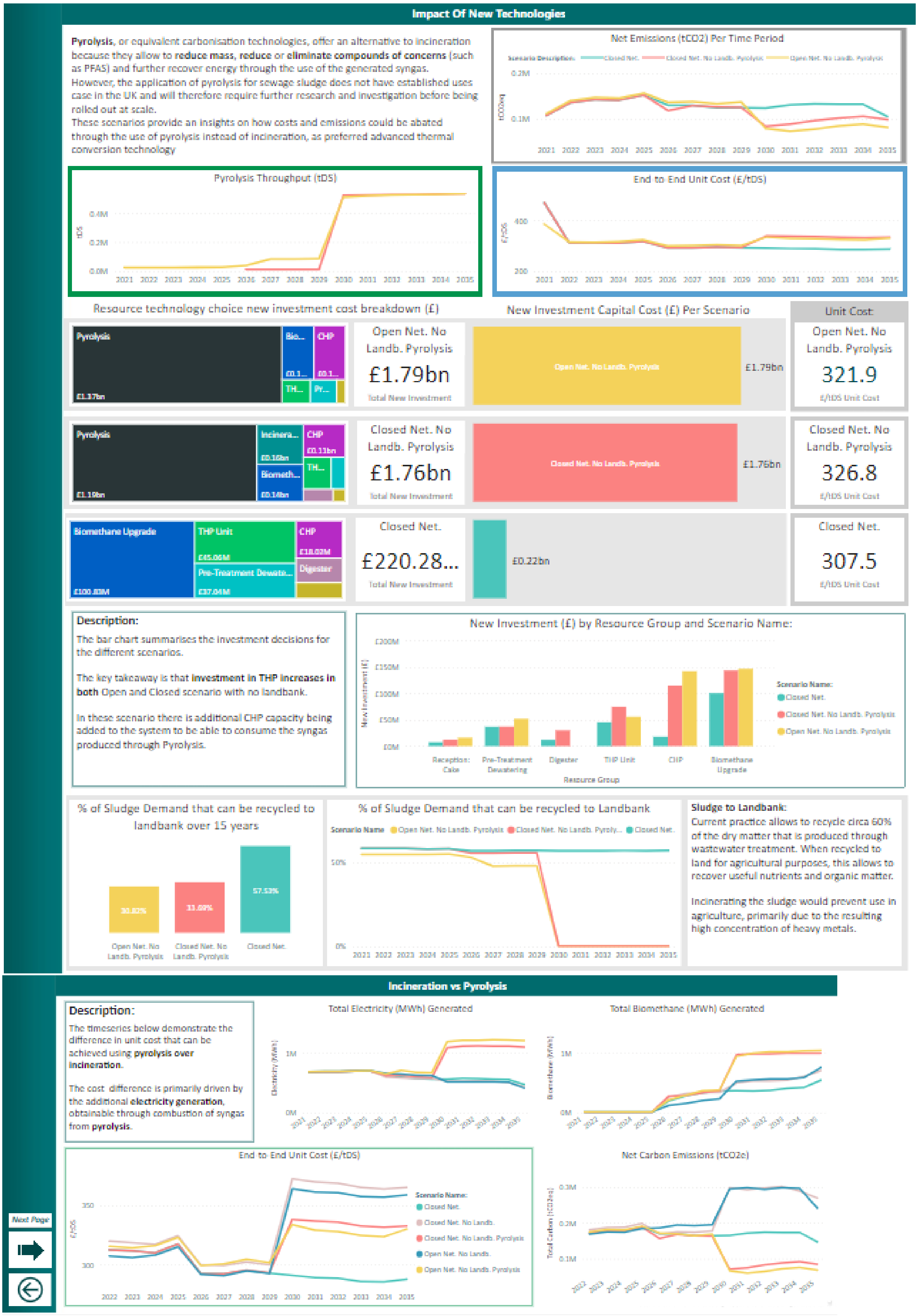


Figure 21: 5. B) Impact of New Technology (Pyrolysis vs Incineration)

There are different ways to stimulate the sector to achieve Net Zero

In line with the UK Government commitment to decarbonise all sectors by 2050, the water industry aspires to achieve Net Zero Carbon operations ahead of that date. However, there are still a number of uncertainties in the sector that have to be considered:

- Accounting methodology. Here 3 different options are presented (See *Scenarios chapter*), but other could also be adopted (location-based).
- Cost of carbon, to be used as a refence from the industry to define cost of residual carbon emissions.
- Emission factors associated with activities and processes. Certain factors are still subject to research and might change in the future, an example of this is N2O emissions associated with liquor treatment.
- Availability of incentives to produce renewable energy (electricity or gas). This could move the sector towards utilisation of certain technologies over others.

This table allows to compare the various scenarios presented in this section.

Scenario Report Name	New Investment	Network	Carbon	Incent.	End-to-End Unit Cost (£/tDS)	Electricity Generated per raw tDS (MWh/tDS)	Biomethane Generated per raw tDS (MWh/tDS)	Total Carbon (tCO2eq/tDS)
Baseline Closed Net. No Inv.	No	Closed	None	No Incentives	316.3	0.79	0.01	0.26
Open Net.	Yes	Open	None	No Incentives	306.6	0.75	0.12	0.22
Open Net. With Incentives	Yes	Open	None	Incentives from 2030	258.1	0.46	1.08	0.11
Open Net. Carbon Cost	Yes	Open	Emissions costed	No Incentives	367.9	0.75	0.06	0.15
Open Net. Full Carbon Cost	Yes	Open	Emissions cost + Offset credit	No Incentives	323.9	0.29	1.01	0.03

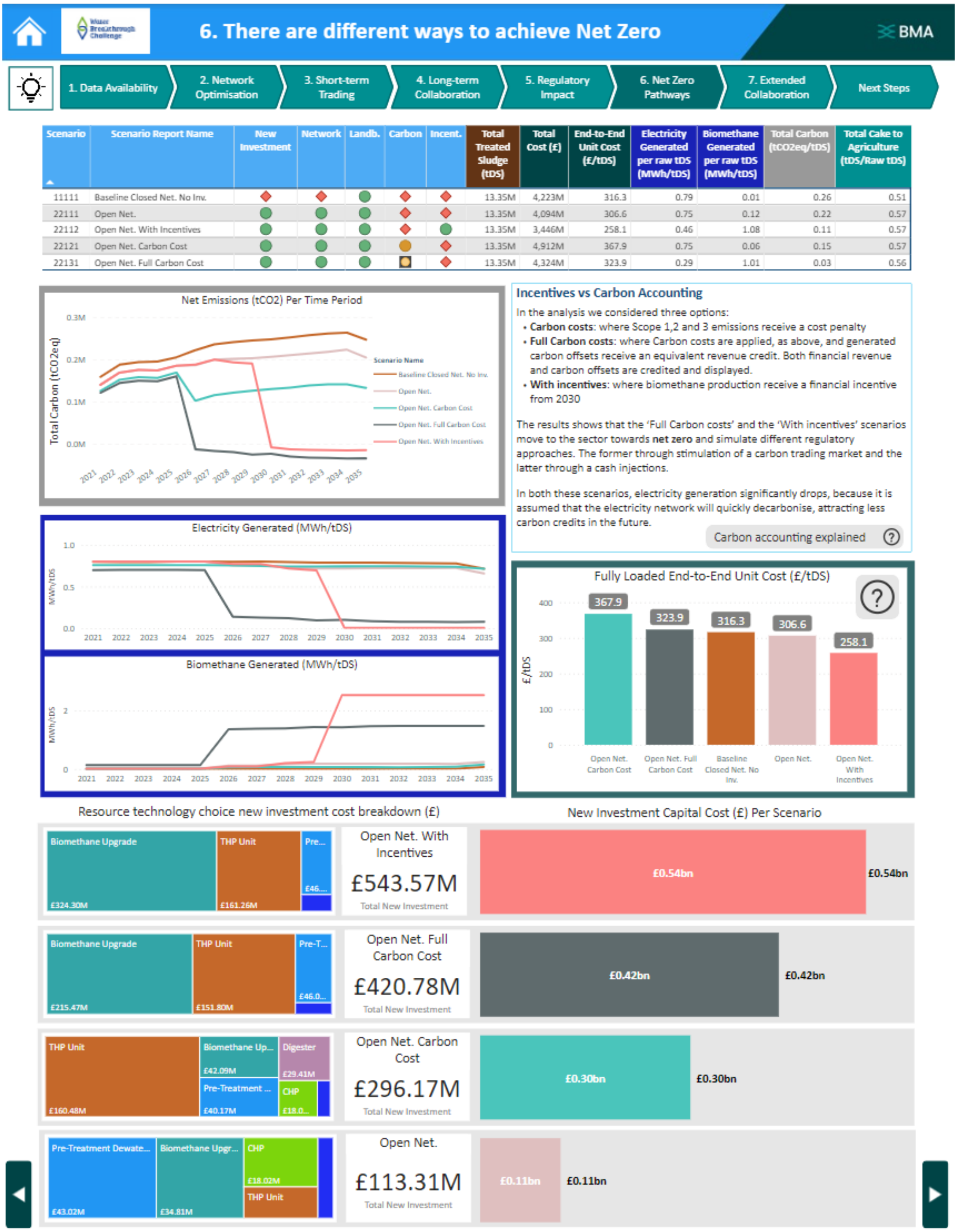
Table 2: Selected scenario comparison.

The lowest value obtained was for the scenario with incentives. This is not surprising because the incentives represented a cash injection into the sector and thus represented a large revenue opportunity. However, these incentives must be funded externally, so this might not represent the most favourable scenario for end users.

In terms of energy generation. The two scenarios that see a big swing towards biomethane generation are those were there are incentives available for biomethane and those where biomethane can be traded for their carbon offset potential. Two key things should be noted for this scenario (full carbon):

- It is assumed that the average carbon intensity of the national gas grid remains unvaried.
- It is assumed that companies can claim both the carbon accounting offset benefits and the monetary value of offsets. Under location-based accounting, they would be able to only claim one of the two (more likely the latter, as there is not enough demand for biomethane on site)

Two scenarios achieve carbon neutrality or better, under the stated assumptions. Indicating that overall, the sector has potential to decarbonise their operations.



Scenario	Scenario Report Name	New Investment	Network	Landb.	Carbon	Incent.	Total Treated Sludge (tDS)	Total Cost (£)	End-to-End Unit Cost (£/tDS)	Electricity Generated per raw tDS (MWh/tDS)	Biomethane Generated per raw tDS (MWh/tDS)	Total Carbon (tCO2eq/tDS)	Total Cake to Agriculture (tDS/Raw tDS)
11111	Baseline Closed Net. No Inv.	◆	◆	●	◆	◆	13.35M	4,223M	316.3	0.79	0.01	0.26	0.51
22111	Open Net.	●	●	●	◆	◆	13.35M	4,094M	306.6	0.75	0.12	0.22	0.57
22112	Open Net. With Incentives	●	●	●	◆	●	13.35M	3,446M	258.1	0.46	1.08	0.11	0.57
22121	Open Net. Carbon Cost	●	●	●	●	◆	13.35M	4,912M	367.9	0.75	0.06	0.15	0.57
22131	Open Net. Full Carbon Cost	●	●	●	■	◆	13.35M	4,324M	323.9	0.29	1.01	0.03	0.56

Incentives vs Carbon Accounting

In the analysis we considered three options:

- **Carbon costs**: where Scope 1,2 and 3 emissions receive a cost penalty
- **Full Carbon costs**: where Carbon costs are applied, as above, and generated carbon offsets receive an equivalent revenue credit. Both financial revenue and carbon offsets are credited and displayed.
- **With incentives**: where biomethane production receive a financial incentive from 2030

The results shows that the 'Full Carbon costs' and the 'With incentives' scenarios move to the sector towards **net zero** and simulate different regulatory approaches. The former through stimulation of a carbon trading market and the latter through a cash injections.

In both these scenarios, electricity generation significantly drops, because it is assumed that the electricity network will quickly decarbonise, attracting less carbon credits in the future.

Carbon accounting explained

Figure 22:6. There are different ways to achieve Net Zero

There is benefit from wider collaboration.

The benefits for all stakeholders of the next phase and the potential beyond are:

- More evidence-based positioning with Regulators
- Clearer pathways to shared investment.
- More accurate simulation of impacts in policy on the national network
- National pathway to net zero strategy options.
- Maximised utilisation of national network
- New insights from modelling impact of various advanced thermal conversion technologies
- Identification of future outperformance opportunities
- Coordination and continued development of the National Strategy

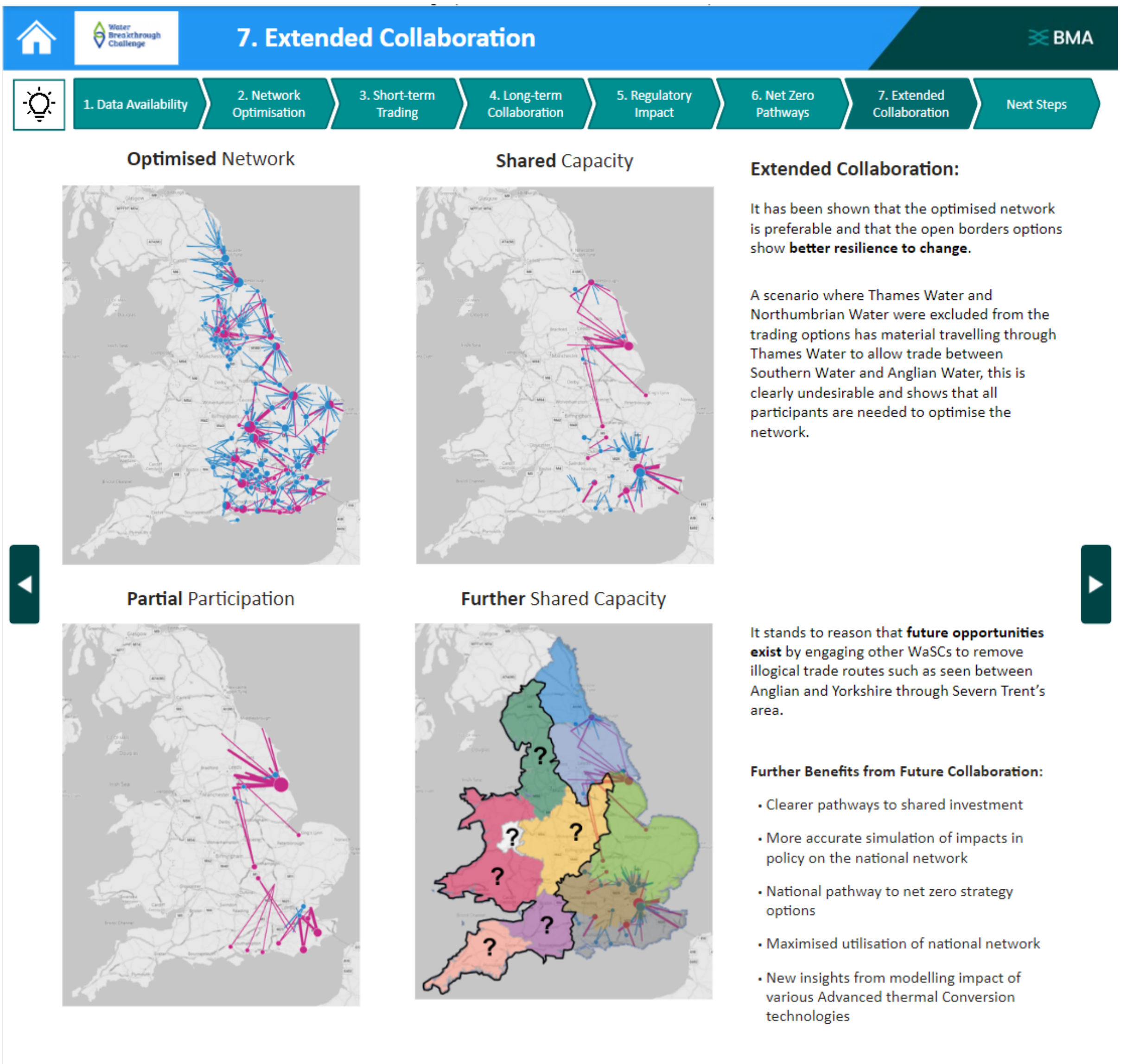


Figure 23: 7. Further Collaboration

Next Steps

Following dissemination of the above results to all WASC's, and through consultation during this process, the proposal for the next steps can be summarised as follows:

- Represent the entire bioresources asset base of Ofwat-regulated WaSCs, using publicly available data and assuming a level-playing field, as per the initial phase.
- Evaluate strategic drivers and the pathways to achieve designated goals within the context of the current available asset base and operating context.
- Link regional landbank availability to investment decision-making and quantify impact on the whole system and for individual WaSCs, to understand if these restrictions have a disproportionate effect on individual companies.
- Link and quantify compounded effect of different environmental policies, such as Farming Rules for Water, EA sludge strategy and the Industrial Emissions Directive.
- Quantify capital and operational costs, greenhouse gas emissions and resource recovery opportunities for the scenarios generated to evaluate strategic options.
- Recommend size and type of investment and geographical centres of gravity for investments. This includes further and more detailed representation of advanced thermal destruction technologies and other resource recovery processes.
- Test multiple carbon accounting and trading strategy, for example location-based vs market-based for different decarbonisation target dates.
- Explore impact of different commercial trading models, ie. apply different levels of gate fees for cross-border movements.
- Identify tipping points for investment decisions and commercial opportunities, for key parameters such as carbon offset cost.
- Run additional sensitivity analysis for parameters deemed highly uncertain or of particular significance.

The common theme in all the above is to identify and quantify opportunities where greater value for can be delivered for all stakeholders through collaboration than through individual company plans.

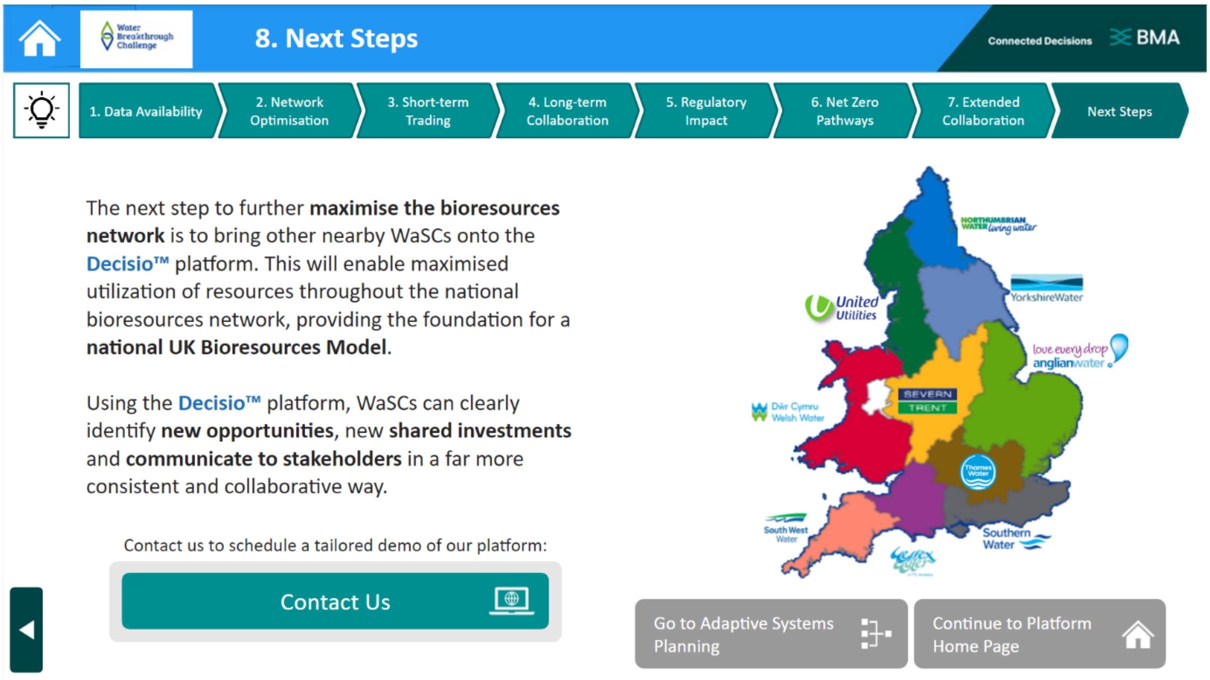


Figure 24: 8. Next Steps

Appendices

Appendix 1: List of Data Sources and Assumptions

Item	Data Label	Source
1	Bioresources Dashboard	**Ofwat website** • Consolidated Bioresources market information dashboard 2021-22 • https://www.ofwat.gov.uk/regulated-companies/markets/bioresources-market/bioresources-market-information/
2	Asset value and Age Data	**Anglian Water** • http://www.ofwat.gov.uk/publication/depreciation-and-net-modern-equivalent-asset-value-anglian-water/ **Northumbrian Water** • https://www.ofwat.gov.uk/publication/depreciation-and-net-modern-equivalent-asset-value-northumbrian-water/ **Southern Water** • https://www.ofwat.gov.uk/publication/new-depreciation-and-net-modern-equivalent-asset-value-southern-water/ **Thames Water** • https://www.ofwat.gov.uk/publication/new-depreciation-and-net-modern-equivalent-asset-value-thames-water/ **Yorkshire Water** • https://www.ofwat.gov.uk/publication/new-depreciation-and-net-modern-equivalent-asset-value-yorkshire-water/
3	Operational performance and capital Cost Data	• Preparing For The Future – Ni Water's Sludge Strategy (Auty, D and McArthur J) • Environmental & Economic Life Cycle Assessment Of Current & Future Sewage Sludge To Energy Technologies (N. Mills, P. Pearce, J. Farrow, R.B. Thorpe, N.F. Kirkby) • Green Gas Support Scheme Guidance (Matthew Hall, Andrew Muir) • Life Cycle Costs Of Advanced Treatment Techniques For Wastewater Reuse And Resource Recovery From Sewage Sludge (Raphael Ricardo Zepon Tarpani and Adisa Azapagic) • An Analysis of Electricity Consumption Patterns in the Water and Wastewater Sectors in South East England, UK – Majid • Thames Water Study on WWTW site demand ○ https://www.mdpi.com/2073-4441/12/1/225
4	Transport Cost Data	• Anglian Water Pr19 Sludge Transport Cost Adjustment Claim (Anglian Water Company)
5	Carbon Emissions and cost	• UKWIR – Carbon Accounting Workbook • IWC Carbon Credits synthetic fertilizer displacement • UK Department for Business, Energy & Industrial Strategy, 2022
6	Miscellaneous	**Average speed on roads in Great Britain** • https://www.statista.com/statistics/303443/average-speed-on-different-roads-in-great-britain-by-vehicle-type/ **Office of National Statistics** • https://www.ons.gov.uk/generator?uri=/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/nationalpopulationprojections/2020basedinterim/0b5f896e&format=csv

Table 3: List of data sources

Table Name	Data Source Used	Assumptions	Comment
Site information and vehicles	Bioresources Dashboard	Vehicle types limited to 15t, 20t, 27t, 10m3, 15m3, 20m3 and 30m3.	See summary **Error! Reference source not found.**
Transport and Logistics	Bioresources Dashboard	Max travel distance set to 200km and 140 km for raw cake and raw liquid transport respectively.	Higher distance tolerance needed to allow for outlying sites.
Transport Costs	Transport Cost Data	Analysis for AW appropriate for all WASCs Load and unload times assumed at 1 min / m3	Cake load/unload time assumed half of liquid time
Transport Routes	Bioresources Dashboard	Distance between sites based on shortest road distance	The 2021 baseline transport links were used in the base
Import/Export Transport Links	Bioresources Dashboard	Island site limited from moving on mainland. Pipeline sites limited to move only to 1 destination. London sites (Beckton, Crossness, London) limited inbound liquid to Baseline values.	Existing limitations on liquid and cake imports assumed as base line with options to invest in cake import facilities, but not liquid import facilities, where it did not previously exist
Asset capital data	Bioresources Dashboard Operational performance and capital Cost Data	Costs of assets are calculated bottom-up on a technology level. i.e., AAD, CAD, INC etc. CAD assumed the same as AAD without benefit of by-products.	The current capital value aligned with GMEAV without land cost so calculated RCV and published NMEAV matched. No investments allowed until 2026. See**Error! Reference source not found.**
Consumables and outlets rates	Bioresources Dashboard Process Cost Data Carbon Emissions		*See Table 7: Unit Rates*
Sludge Production	Bioresources Dashboard Office of National Statistics	WINEP increase in demand assumed to be 50% of population growth forecast	Population growth based on regional growth estimates

Dry Solids	Bioresources Dashboard	Published data or assumed values where no data available	See Table 8: Dry Solids
Transport Routes	Bioresources Dashboard	Any unallocated cake transport was left to the optimisation tool to allocate. No sludge movements allowed in or out of the Isle of man.	The model optimised transport where historic reported movements didn't match treatment throughputs (the dashboard lists the first 2 transport links only).
Asset Capacity	Bioresources Dashboard	90% availability assumed unless indigenous supply exceeded the available capacity.	
Process Assumptions	Bioresources Dashboard Process Cost Data		See Table 7: Process Assumptions
Site constraints	Process Cost Data	Electricity demand for WwTW limited to 1.1MW per indigenous tDS. No return liquors constraints data	
Fixed Costs	Process Cost Data	75% of cost (excluding asset depreciation) is assumed to be fixed cost on a £/tDS basis. Aligned with Ofwat fixed cost report.	Fixed cost refers to labour and operational maintenance
Asset Age	Age Data	Assume average mechanical life of 25 years, civil life of 60 years and ICA life of 10 years	Pro-rata split of asset age to relevant asset type (civil, mechanical or ICA) based on average life assumption.
Carbon Emissions	Carbon Emissions	Carbon intensity of electricity from grid assumed to be decreasing with time	Default CAW values used
Carbon Costs	Carbon Emissions	UK government central assumption (BEIS 2022)	

Table 4: List of data application and assumptions

Site type	Description
STW_Liquid	Liquid Sludge Export
INT_DEW	Intermediate Dewatering Centre
INT_DEW_LIQ	Intermediate Dewatering Centre - can import/export liquid
STC_AAD_HPH	Sludge Treatment Centre with Advanced digestion: Pasteurisation and/or Hydrolysis + Mesophilic AD
STC_AAD_PAS	Sludge Treatment Centre with Advanced digestion Pasteurisation + Mesophilic AD
STC_AAD_THP	Sludge Treatment Centre with Advanced digestion Thermal Hydrolysis Plant + Mesophiilic AD
STC_CAD	Sludge Treatment Centre with Conventional Mesophilic Digestion
STC_LIME	Sludge Treatment Centre with Powder Liming

Table 5: Site Types

Sludge Treatment			
Asset Type	**Size**	**Unit**	**Capital Cost £**
Digestion	1,000	tDS/yr	8,900,000
	5,000	tDS/yr	13,500,000
	10,000	tDS/yr	19,250,000
HPH Unit	1,000	tDS/yr	2,525,000
	5,000	tDS/yr	3,825,000
	10,000	tDS/yr	5,450,000
PAS Unit	1,000	tDS/yr	2,525,000
	5,000	tDS/yr	3,825,000
	10,000	tDS/yr	5,450,000
THP Unit	1,000	tDS/yr	2,525,000
	5,000	tDS/yr	3,825,000
	10,000	tDS/yr	5,450,000
Liming	1,000	tDS/yr	1,494,465
	5,000	tDS/yr	2,432,325
	10,000	tDS/yr	3,604,650
Dewatering	1,000	tDS/yr	2,988,930
	5,000	tDS/yr	4,864,650
	10,000	tDS/yr	7,209,300

Biogas Utilisation			
Asset Type	**Size**	**Unit**	**Capital Cost £**
CHP	1,000	1000Nm3/yr	3,134,820
	5,000	1000Nm3/yr	6,860,420
	10,000	1000Nm3/yr	11,517,420
Gas to grid	1,000	1000Nm3/yr	2,616,790
	5,000	1000Nm3/yr	5,726,750
	10,000	1000Nm3/yr	9,614,200

Advanced Thermal Conversion			
Asset Type	**Size**	**Unit**	**Capital Cost £**
Incineration	10,000	tDS/yr	19,979,700
	20,000	tDS/yr	39,959,400
	50,000	tDS/yr	99,898,500
Pyrolysis	10,000	tDS/yr	28,894,500
	20,000	tDS/yr	57,789,000
	50,000	tDS/yr	144,472,500

Table 6: Capital Costs

Opex rate	ValuePerUnit	Units
Chemicals	1.6	£/kg
Natural gas	65.0	£/MWh
Electricity From Grid	125.0	£/MWh
Ash disposal	150.0	£/tDS
Char disposal	150.0	£/tDS
Tar disposal	500.0	£/kg
Return Liquors treatment	0.5	£/m3
Advanced Treated Cake recycling	66.7	£/tDS
Limed Treated Cake recycling	50.0	£/tDS
Treated Cake recycling	80.0	£/tDS

Revenue rate	Value	Units
Biomethane incentives	55.1	£/GGSS
Electricity incentives	45.0	£/ROC
Electricity for WWTW Demand	125.0	£/MWh
Electricity to Grid	67.5	£/MWh
Biomethane to Grid	65.0	£/MWh

Table 7: Unit Rates

Material type	Value	Units
Raw liquid	2%	DS% (w/w)
Raw cake	25%	DS% (w/w)
Treated cake	25%	DS% (w/w)
Advanced treated cake	30%	DS% (w/w)

Table 8: Dry Solids

Site type	Description	Value	Units
Conventional AD	Chemicals	6.6	kg/tDS
	Electricity	0.2	MWh/tDS
	Heat - Low Grade	0.4	MWh/tDS
	Biogas yield	300.0	m3/tDS
	Solids reduction	40%	%
Pasteurisation AD	Chemicals	6.3	kg/tDS
	Electricity	0.2	MWh/tDS
	Heat - Low Grade	0.4	MWh/tDS
	Biogas yield	350.0	m3/tDS
	Solids reduction	40%	%
Hydrolysis AD	Chemicals	8.6	kg/tDS
	Electricity	0.2	MWh/tDS
	Heat	0.9	MWh/tDS
	Biogas yield	420.0	m3/tDS
	Solids reduction	45%	%
THP AD	Chemicals	8.6	kg/tDS
	Electricity	0.2	MWh/tDS
	Heat - High Grade	0.9	MWh/tDS
	Biogas yield	420.0	m3/tDS
	Solids reduction	45%	%
LIME	Chemicals	200	kg/tDS
	Electricity	0.3	MWh/tDS
Incineration	Chemicals	20	kg/tDS
	Electricity	0.062	MWh/tDS
	Solids reduction	64%	%
	Electricity yield	0.2	MWh/tDS
	Heat yield	0.15	MWh/tDS
Pyrolysis	Chemicals	16	kg/tDS
	Electricity	0.4	MWh/tDS
	Heat	1.6	MWh/tDS
	Syngas yield	1.2	1000m3/tDS
	Tar yield	20	kg
	Solids reduction	54%	tDS

Table 7: Process Assumptions