Micro-Feasibility Study

Low-Carbon Horticulture Using Waste Heat from an AD Plant in North Lincolnshire

Commissioned by the Midlands Net Zero Hub
March 2022
Jenna Barnard
District Eating Ltd

Terms and Conditions

This report is limited to the early-stage outline feasibility and scoping of potential for development of a greenhouse utilising waste heat. The numbers and additional details included in this piece of work are estimations only to be refined at later stages of project development.

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The information contained in this report is based on the best available information at the time of writing as provided by referenced sources, and selected equipment suppliers. The yield, price and cost estimates and analysis are to be used for guidance purposes only. This report is a high-level initial assessment to be followed up with the items listed in the Next Steps section.

Executive Summary

This project was commissioned by the Midlands Net Zero Hub to assess the potential for low-carbon horticulture using waste heat from an Anaerobic Digestion (AD) plant in North Lincolnshire.

Site Review and Crop Selection

The available site is 3Ha. Initial modelling showed that conventional production of fruit or vegetables would not be economically viable at this scale. Therefore, District Eating Ltd (DEL) decided to model a greenhouse growing 50% strawberries, and 50% cut flowers. Strawberries were selected based on their high demand and potential for sale into school meals. Cut flowers were selected based on their high market value and potential for high carbon savings compared with busines as usual.

Heat and Power Demand

The estimated heat and power demands for a 3Ha unlit, heated greenhouse growing 50% strawberries and 50% cut flowers were 8,694,287 and 113,055kWh per year respectively.

Financial Viability - Grower

DEL estimated capital costs, operational costs, income of the greenhouse and income to the heat producer. Assumptions are shown throughout the report and in the Appendix. Capital cost was estimated to be £6,200,700, with the cost of the glasshouse, benching and screening likely to be the biggest capital expense. Operational costs were estimated to be £1,387,417 per year, with the biggest costs coming from labour. Based on our outline techno-economic modelling, initial results indicated a positive cash flow, an attractive IRR and NPV at 20 years, and payback within 10 years.

The Financial viability of the greenhouse is summarised in the table below.

Table 1: Financial viability of greenhouse

CapEx	£6,200,700
OpEx*	£1,387,417
Income	£2,044,993
IRR	8%
Payback (years)	10
NPV @ 20 years	£6,575,551

*Assuming electricity price £0.20, primary heat source £0.03, back up heat £0.045.

Financial Viability – Heat Producer

The income to the heat producer for selling heat into the greenhouse was estimated at various heat prices. This is summarised in the table below.

Table 2: Potential income to heat producer from selling heat into greenhouse.

Sale price of heat per kWh	Potential annual income to heat seller
£0.01	£83,557

£0.02	£167,113
£0.03	£250,670
£0.04	£334,226

Sensitivity Analysis

Given the volatile prices of gas and in recent months, a sensitivity analysis was conducted to determine the sensitivity of the business case to heat and electricity price increases. As such, financial viability of the greenhouse was estimated at various heat and power prices. The results are summarised in the following tables. The analysis shows that the business case is fairly sensitive to heat prices, but not very sensitive to electricity prices. This is reassuring given the current uncertainty in the energy market.

Table 3: Sensitivity analysis of greenhouse financial KPIs at various kWh heat prices.

Waste Heat Price per kWh	£0.01	£0.02	£0.03	£0.04
IRR of greenhouse	11%	9%	8%	6%
Payback of greenhouse (years)	7.97	8.87	10	11.46
NPV @ 20 years	£9,919,816	£8,246,683	£6,575,551	£4,904,419

*Electricity price held constant at £0.20/kWh, back up heat price held constant at £0.045/kWh.

Table 4: Sensitivity analysis of greenhouse financial at various kWh electricity prices.

Electricity Price per kWh	£0.12	£0.16	£0.20	£0.24	£0.28
IRR of greenhouse	8%	8%	8%	8%	8%
Payback of greenhouse (years)	9.88	9.93	10	10.07	10.14
NPV @ 20 years	£6,756,439	£6,665,995	£6,575,551	£6,485,107	£6,394,663

*Primary heat price held constant at £0.03/kWh, back up heat price held constant at £0.045/kWh.

Carbon Savings

DEL estimated that growing strawberries and cut flowers in a greenhouse heated by waste heat from AD could emit less CO_2 than business as usual production using gas for heating. This is summarised in the following table:

Table 5: Estimated potential carbon savings of greenhouse.

	CO_2 emissions, tonnes/year		
	CO_2 from heat	CO_2 from electricity	Total CO_2
Scenario 1: Waste heat from AD and back up heat from kerosene.	2,300	24	2,324
Scenario 2: Business as usual – all heat from natural gas.	2,656,241	24	2,680,247

Conclusions and Recommendations

- A greenhouse at the site growing strawberries alone would not be financially viable. Converting 50% of the growing area to a cash crop such as flowers would supplement the production of local, low-carbon strawberries.
- It is essential that flowers are sold for at least their average market value, as the business case is sensitive to sale prices and selling flowers at the lower end prices makes the project financially unviable.
- If built, the greenhouse could provide a range of skilled employment opportunities, apprenticeships, and training opportunities for local people.
- The greenhouse could access cheap heat via the client's AD plant. This would benefit the client as they could make additional income by selling their excess heat and power.
- Producing flowers alongside strawberries results in a positive cash flow and attractive IRR and NPV at 20 years.
- If a proportion of CapEx were to be provided by grant funding, it could increase the IRR and reduce the payback time.
- The site requires a 300m pipeline to connect the heat source. This could be paid for by the greenhouse operator, the waste heat producer, or a third party. Our modelling showed negligible difference in financial viability of the greenhouse with or without the pipeline included in the CapEx.
- There will be months in the year where flower crops would be moved to the outdoor space, and a secondary filler crop could be grown in the indoor greenhouse space. We haven't accounted for this in this simplistic assessment.
- The client estimated that there could be 2MW heat and 3MW electricity available greenhouse. These figures need verifying by checking meters and monitoring data. Because the proposed greenhouse does not have lighting, energy demand is relatively low so it would probably not be worth the cost of connecting the client's electricity production to the greenhouse. However, this power generation could provide future opportunities for vertical farming.
- DEL assumed electricity prices of £0.20/kWh, however, volatile prices and large increases over recent months make this uncertain. The sensitivity analysis demonstrated that the financial viability of the greenhouse is not sensitive to electricity price, so further price increases may not drastically affect the business case.
- The heat generated on site will not be enough to cover the demand of the greenhouse. Supplementary heating could be provided by a back-up boiler, a heat pump, or a biomass boiler. In this report we have assumed prices based on kerosene.
- There is huge potential for carbon dioxide savings compared to similar production in a greenhouse using gas for heating.
- We have assumed a blanket temperature across the greenhouse. In reality, the flower species we have considered would require lower temperatures than strawberries, so with screening to create different climate zones the overall heat demand could be reduced, which could remove the requirement for a secondary heat source.

Next Steps

The recommended next steps if the client wishes to pursue this project are as follows:

- Share this work with key stakeholders. Meet and discuss key benefits.
- Meet with District Eating to discuss how to proceed for maximum benefit to the client and other key stakeholders.
- Decide on preferred commercial option for delivery as explained in the Work Package 2 Report.
- Review funding opportunities and apply for funding for feasibility study and capital costs, including consideration of who will pay for connection to the heat source.
- Investigate planning permission of the site and surrounding land.
- Conduct a flood risk assessment and land stability assessment of the site.
- Verify available heat and power and analyse meter data and any AD monitoring data.
- Conduct a full detailed feasibility study to include an investment grade business case (IGBC) that also includes;
  - A market research study of flowers including statement of interest from buyers and consideration of tropical and speciality species.
  - Modelling of a greenhouse with partitioning and different climatic zones to suit different crops, and revise estimated heat demand.
  - An evaluation of how best to use the land around the greenhouse.

Consider assessing viability of a vertical farm at the site to make use of power currently being exported to the grid, as onsite use may be able to attract a higher unit price in comparison to the grid export price.

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1.0 Site Review

The proposed site is a farm and anaerobic digestion (AD) plant in rural North Lincolnshire. The site consists of 1,600 hectares of mainly arable land, used for cultivation of conventional food crops and maize to supply the AD. The land has been used for agriculture for over 100 years. The nearest usable land to the AD site is a 3-hectare field which is 300m away from the heat source. The site is accessible via narrow gravel roads. The main challenge posed by this site is the spatial constraints around the AD plant. The surrounding land is poor quality, consisting of wetlands and infilled quarries. A full flood risk assessment and land stability assessment would be key before progressing with the project. The current use of the site for cropping suggests that it may be a suitable greenhouse site.

1.1 Proposed Heat Source

A proportion of the heat arising from the AD plant is currently being used for pasteurisation. There is an additional excess 2MW of heat being generated which could potentially be sold into horticulture. The excess heat is from the running hot water circuit, which runs at 85°C. There is also electricity generation of 3MW capacity on site, most of which is exported to the grid. The farm has been generating heat and power since 2014 and has FIT tariffs for 25 years up to 2039.

2.0 Greenhouse Sizing and Crop Selection

The usable field next to the AD plant is large enough for a 3Ha greenhouse, connected to the heat source via a 300m pipeline. Commercial greenhouses generally need to be 5 hectares or larger in order to be profitable, due to the economics of scale, expensive capital costs, and the low sale price of fruit and vegetables. However, a 3-hectare greenhouse can be profitable if the income is supplemented by using a proportion or all of the growing space to produce a cash crop, such as flowers. For this project, DEL ran outline techno-economic modelling for a 3-hectare greenhouse with 50% of space used for flower production and 50% for strawberries.

Figure 1: Map showing location of site and heat source.

2.1 Strawberries

Strawberries are one of the most popular soft fruits produced in the UK. Along with blackcurrants and raspberries, they account for 90% of soft fruit production[1]. Consumers' increasing appetites for healthy, tasty, and convenient foods is leading to increasing demand for strawberries – between 1996 and 2015 their consumption rose by 150%[3]. Growing strawberries in protected hydroponic systems can increase yields by increasing the length of the season, reducing input costs.

Labour costs typically account for 50% of production cost for growers. Much seasonal picking work is provided by workers coming from the European Union. In recent years, uncertainty due to Brexit and Covid-19 has resulted in labour shortages. Hydroponic greenhouse production of strawberries on benches has the benefit of reduced labour costs as higher volumes can be produced in a smaller area. Indoor picking is more attractive to employees as staff are protected from the weather and work is done standing rather than kneeling.

Some studies have shown that growing strawberries with LED lights can improve the production, flavour, and vitamin C content of fruit[2]. However, it is also widely reported that the current cost of buying and operating LED lights outweighs the increased profit from higher yields, so it is often not a viable option, as we demonstrate in this case.

[1] https://allmanhall.co.uk/blog/overview-of-the-strawberry-industry-in-the-uk

[2] https://www.nuffieldscholar.org/sites/default/files/reports/2014_AU_Nicola-Anne-Mann_Intensive-Berry-Production-Using-Greenhouses-Substrates-And-Hydroponics-Is-This-The-Way-Forward.pdf

2.2 Cut flowers

The UK market for flowers is large and increasing. In 2018, the UK market for ornamentals and cut flowers was worth £1.4 billion[3]. Around 90% of this was imported, the majority coming from the Netherlands. In 2021, 27,363 tonnes of flowers were flown into the UK from outside of the EU, worth over £143 million[4]. This resulted in 101,267 tonnes of CO_2 emissions. Most non-EU imports of flowers come from Sub-Saharan Africa, partly due to high production in Kenya.

Importing flowers by air freight is a major source of CO_2 emissions but growing them in heated greenhouses closer to home can result in an even higher carbon footprint. One life cycle analysis study found that roses grown in the Netherlands emit 2.91 kg CO_2 per stem due to the energy use of heating the greenhouse[5]. Therefore, growing flowers in the UK in a low-carbon greenhouse could cut the CO_2 emissions from air transport and fuel combustion associated with foreign production.

The large market and high import rate for cut flowers means there is a gap in the market for locally produced, low-carbon flowers. This would cut the costs and CO_2 emissions of refrigerated transport, which would appeal to environmentally conscious consumers.

For this study DEL considered *Ranunculus*, tulips, roses and *Anemone*. Flower species were chosen following extensive market research carried out for other pieces of work. The flower species considered have a high value and are typically in demand in the UK. *Ranunculus* and *Anemone* were the most profitable, so were selected to be included in the techno-economic modelling, alongside strawberries.

2.3 Heat Demand Estimate

DEL conducted modelling using local climate data and assumptions for growing temperatures required by strawberries and flowers to generate peak and annual heat demand for 1.5ha of strawberries and 1.5ha of flowers. The model used the approximate size of the heat source (2MW) to estimate how much greenhouse heating would come from the waste heat from AD, and how much would come from a secondary source. Options for secondary heating sources could include increasing the output of the AD, installing a biomass burner, a heat pump, or a natural gas boiler. The techno-economic modelling assumed that secondary heat supply is from kerosene.

Table 6: Estimated heat demand of a 3Ha greenhouse growing strawberries and flowers

	Flowers	Strawberries	Total
Peak (kW)	4,394	3,557	Up to 8,187
Heat Required (kWh/year)	4,392,582	4,301,705	8,694,287

[3] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1003935/hort-report-20jul21.pdf

[4] https://www.ons.gov.uk/datasets/trade/editions/time-series/versions/17

[5] http://www.fairflowers.de/uploads/media/Comparative_Studie_Cranfield_University.pdf

Heat from primary source (kWh/year)	2,628,492	3,098,678	5,727,170
Heat from back-up source (kWh/year)	1,764,091	1,203,026	2,967,117

2.4 Power Demand Estimate

Electricity demand was estimated based upon the following assumptions:

- Pump mechanical power was derived from the mechanical power required to deliver flow rate required to deliver heat in any given hour which was then transformed into electrical power input accounting for efficiency losses from wire to water. Overall pump–motor efficiency was assumed to be 62.6% (example from Grundfos pump selector),
- Irrigation water for flowers assumed to be 7 litres per m^2 per day. Water requirement for strawberries assumed to be 25 litres per kg.
- Air circulation fans: Horizontal distribution 10 units per hectare, 150W, costing £500 each.

Based upon these assumptions the annual electricity consumption was estimated to be approximately **113,055kWh per year**.

3.0 Outline Techno-Economic Modelling

This section details the methodology and results of the techno-economic modelling done by DEL. The methodology is summarised as follows:

1. Capital cost estimation,
2. Operational cost estimation for power, heat, water and nutrients, seedlings and bulbs, compost, labour, insurance, and repairs and maintenance,
3. Income estimation for flowers and crops,
4. Completion of 20 year cash flow (not adjusted for inflation),
5. Estimation of simple payback, NPV, IRR, and NPV @ 20 years.

3.1 Capital Costs

Capital expenditure (CapEx) was estimated. The model assumed that strawberries are grown in hydroponic systems and that flowers are grown conventionally in compost. The cost of a glasshouse together with its fixtures and fittings will almost certainly be the biggest capital expense of the project. While purchasing multi-span polytunnels may reduce capital costs, they are typically less energy efficient, do not offer the same opportunities to control the environment, have a higher heat loss coefficient than glass, RHI cannot be paid for heat sold into them, and they can be less robust than glass so may not offer the same longevity.

For this study, budget estimates for the cost of a 3Ha glasshouse structure were gathered from two reputable greenhouse supplier companies. One supplier provided an approximate price for a second-hand glasshouse. Second-hand greenhouses offer a chance to reduce capital costs and can present issues such as increase cost of maintenance. Due diligence checks must be made carefully to ensure frame quality is suitable for the location and local weather conditions. Due to the potential for lower capital costs, a second-hand greenhouse was selected over purchasing a new glasshouse in the techno-economic modelling. This decision needs evaluating in future feasibility and business case work. Based on outline quotations from greenhouse suppliers, the cost of a 3Ha second-hand greenhouse with screening and benching would be around £3,288,000 including VAT. This is a high-level estimate only that will vary depending on many variables and should be refined at a later stage in the project.

Other major capital costs included in the CapEx estimate were heating infrastructure, electrical controls, prelims, concrete slab, a gas boiler for back up heat, and 300m of pipeline connecting the greenhouse to the heat source. LED lighting was not included as it was deemed too expensive to be financially feasible. A contingency budget of 15% of the major capital costs has been included in the budget.

The total capital cost estimate was £6,200,700.

3.2 Operational Costs

Operational expenses (OpEx) were estimated. OpEx is expected to include electricity, heat, water and nutrients, seedlings and bulbs, compost, labour, insurance, and repairs and maintenance. Prices of resource inputs were estimated using benchmark costs per unit, growing space area, and crop profiles. Labour costs typically account for 50% of the cost of production for growers, with the greatest need between May – September. DEL assumed that the greenhouse would require 2 full time skilled growers (salary approximately £60,000), a fulltime greenhouse manager, 5 full time apprentices, and 30 seasonal pickers during the peak of the season.

Heat prices were assumed to be as follows:

Table 7: Assumed heat prices in techno-economic modelling

£/kWh Primary (waste heat)	0.03
£/kWh Secondary*	0.045
£/kWh Electricity	0.20

*Secondary heat source assumed to be kerosene.

IMPORTANT NOTE: This work was carried out from January 2022 – March 2022, a time of extremely volatile energy prices. At the time of writing, energy prices were rising steeply, and food prices had not yet caught up with this. Therefore, it was difficult to make realistic assumptions about electricity prices and produce sale prices that reflected these rapid changes and the changes to come over the next 6 months. The prices used here are illustrative prices that will need reviewing and updating at the next stage of the project.

Based on the above, annual OpEx was estimated at £1,396,461.

3.3 Income - Grower

Income was estimated using wholesale prices, crop yields, and area of growing space. For strawberries, wholesale prices (£/kg) were gathered from Brakes wholesalers, and for flowers from Triangle Nurseries. For flowers, the wide range in prices was accounted by calculating an average of the highest and lowest prices. Anomalies were excluded. Wholesale prices were multiplied by 0.8 to account for an assumed 20% profit margin to the wholesalers. It is important to note that wholesale prices fluctuate on a weekly, monthly and seasonal basis; figures used in this report were correct at the time of writing. A detailed feasibility study should include market research to find average wholesale prices over time for the proposed crops and model the potential impacts of seasonally fluctuating prices on the overall economics of the greenhouse, as well as to ensure a market for the produce.

IMPORTANT NOTE: For this business case to be viable, flowers must be sold for at least their average market value, or they will not generate enough income to supplement the production of strawberries.

Table 8: Estimated annual income from crops.

	Income £/year
Ranunculus	£696,150
Anemones	£1,009,613
Strawberries	£339,230
Total	**£2,044,993**

3.4 Income – Heat producer

The income to the heat producer for selling heat into the greenhouse was estimated at various heat prices. This is summarised in the table below.

Table 9: Potential income to heat producer from selling heat into greenhouse.

Sale price of heat per kWh	Potential annual income to heat seller
£0.01	£83,557
£0.02	£167,113
£0.03	£250,670
£0.04	£334,226

3.5 Financial KPIs

DEL used estimates of CapEx, OpEx and income to run a 20-year cash flow and estimate financial viability of the greenhouse. The results are shown below.

It may be difficult to attract a grower to the site with the cost of the pipeline connecting the greenhouse to the heat source included in the greenhouse CapEx. A site that is already connected to the heat supply will be a much more attractive proposal to a potential grower. Therefore, there could be good reason for the heat producer or a third party to cover the cost of building the 300m pipeline required. This would also create a better IRR and payback for the greenhouse which makes it more likely to attract growers and investors.

Based on our outline techno-economic modelling, initial results indicated a positive cash flow, an attractive IRR and NPV at 20 years, and payback within 12 years for both scenarios.

Table 10: Financial viability of greenhouse, with or without pipeline included in CapEx.

	Scenario 1: Pipeline included in CapEx	Scenario 2: Pipeline outsourced
CapEx	£6,200,700	£6,028,200
OpEx*	£1,387,417	£1,378,792
Income	£2,044,993	£2,044,993
IRR	8%	8%
Payback (years)	10	9.61
NPV @ 20 years	£6,575,551	£6,920,551

*Assuming electricity price £0.20, primary heat source £0.03, back up heat £0.045.

3.6 Sensitivity Analysis

Given the volatile prices of gas and in recent months, a sensitivity analysis was conducted to determine the sensitivity of the business case to heat and electricity price increases. As such, financial viability of the greenhouse was estimated at various heat and power prices. The results are summarised in the following tables. The analysis shows that the business case is fairly sensitive to heat prices, but not very sensitive to electricity prices.

Table 11: Sensitivity analysis of greenhouse financial KPIs at various kWh heat prices.

Waste Heat Price per kWh	£0.01	£0.02	£0.03	£0.04
IRR of greenhouse	11%	9%	8%	6%
Payback of greenhouse (years)	7.97	8.87	10	11.46
NPV @ 20 years	£9,919,816	£8,246,683	£6,575,551	£4,904,419

Electricity price held constant at £0.20/kWh, back up heat price held constant at £0.045/kWh.

Table 12: Sensitivity analysis of greenhouse financial at various kWh electricity prices.

Electricity Price per kWh	£0.12	£0.16	£0.20	£0.24	£0.28
IRR of greenhouse	8%	8%	8%	8%	8%
Payback of greenhouse (years)	9.88	9.93	10	10.07	10.14
NPV @ 20 years	£6,756,439	£6,665,995	£6,575,551	£6,485,107	£6,394,663

Primary heat price held constant at £0.03/kWh, back up heat price held constant at £0.045/kWh.

4.0 Carbon Savings

The potential carbon savings for a greenhouse supplied with waste heat from AD and back up heat from kerosene was compared with business-as-usual greenhouse production, heated using gas. In both scenarios it was assumed that power was supplied from the grid and 2021 emissions factors were used. The findings below show a carbon reduction of a factor of 100.

Table 13: Carbon emissions of the proposed greenhouse compared to business as usual.

	CO_2 emissions, tonnes/year		
	CO_2 from heat	CO_2 from electricity	Total CO_2
Scenario 1: Waste heat from AD and back up heat from kerosene.	2,300	24	2,324
Scenario 2: Business as usual – all heat from natural gas.	2,656,241	24	2,680,247

5.0 Conclusions and Recommendations

- A greenhouse at the site growing strawberries alone would not be financially viable. Converting 50% of the growing area to a cash crop such as flowers would supplement the production of local, low-carbon strawberries.
- It is essential that flowers are sold for at least their average market value, as the business case is sensitive to sale prices and selling flowers at the lower end prices makes the project financially unviable.
- If built, the greenhouse could provide a range of skilled employment opportunities, apprenticeships, and training opportunities for local people.
- The greenhouse could access cheap heat via the client's AD plant. This would benefit the client as they could make additional income by selling their excess heat and power.
- Producing flowers alongside strawberries results in a positive cash flow and attractive IRR and NPV at 20 years.
- If a proportion of CapEx were to be provided by grant funding, it could increase the IRR and reduce the payback time.
- The site requires a 300m pipeline to connect the heat source. This could be paid for by the greenhouse operator, the waste heat producer, or a third party. Our modelling showed negligible difference in financial viability of the greenhouse with or without the pipeline included in the CapEx.
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- There is huge potential for carbon dioxide savings compared to similar production in a greenhouse using gas for heating.
- We have assumed a blanket temperature across the greenhouse. In reality, the flower species we have considered would require lower temperatures than strawberries, so with screening to create different climate zones the overall heat demand could be reduced, which could remove the requirement for a secondary heat source.

6.0 Next Steps

The recommended next steps if the client wishes to pursue this project are as follows:

- Share this work with key stakeholders. Meet and discuss key benefits.
- Meet with District Eating to discuss how to proceed for maximum benefit to the client and other key stakeholders.
- Decide on preferred commercial option for delivery as explained in the Work Package 2 Report.
- Review funding opportunities and apply for funding for feasibility study and capital costs, including consideration of who will pay for connection to the heat source.
- Investigate planning permission of the site and surrounding land.
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- Conduct a full detailed feasibility study to include an investment grade business case (IGBC) that also includes;
    - A market research study of flowers including statement of interest from buyers and consideration of tropical and speciality species.
    - Modelling of a greenhouse with partitioning and different climatic zones to suit different crops, and revise estimated heat demand.
    - An evaluation of how best to use the land around the greenhouse.
- Consider assessing viability of a vertical farm at the site to make use of power currently being exported to the grid, as onsite use may be able to attract a higher unit price in comparison to the grid export price.

Appendix 1: Assumptions

Due to the broad scope of this initial micro-feasibility study, various assumptions were made in the techno-economic modelling. These serve as outline figures only and will need refining if the client proceeds with the project.

Strawberries

Figure	Value	Justification/Source
Yield	7.41 kg/m^2	Research has found yields between 0.37-2.1kg per plant[6]. We calculated an average per m^2 using these figures.
Cropping density	6 plants/m2	6 plants per m^2 recommended by Grow Wales[7].
Wholesale price	£4.36/kg	Average of 2021 DEFRA weekly wholesale prices[8]
Cost per seedling	£0.30 per plant	Reported by a contact at Johnsons of Whixley plant nursery, 17/11/21.

Ranunculus

Figure	Value	Justification/Source
Yield	187.5 stems/m^2.yr	Plants per m^2 figure from here. Stems per plant is the mid - range value taken from here.
Wholesale price	£1.77/stem	Price from Triangle Nurseries. DEL have identified a range of suppliers and prices-this price is within the middle range of prices identified.
Cost per corn	£0.06 - £0.08	Dutch Bulbs - Ranunculus
Assumed crop success rate	80%	Figure gained from a horticultural expert.

Anemone

Figure	Value	Justification/Source
Yield	384 stems/m^2.yr	Tubers spaced 6cm apart in a row and rows 10cm apart = 160 tubers per m^2. Assumes 2x stems per plant (resulting from tubers)
Wholesale price	£1.25/stem	Price from Triangle Nurseries. DEL have identified a range of suppliers and prices-this price is within the middle range of prices identified.
Cost per seedling	£0.08-£0.22	Dutch Bulbs - Anemone

[6] https://www.tandfonline.com/doi/pdf/10.1080/15538362.2017.1305941?src=getftr
[7] https://www.tyfucymru.co.uk/media/1350/strawberry-soiless-toolkit-eng-3.pdf
[8] https://www.gov.uk/government/statistical-data-sets/wholesale-fruit-and-vegetable-prices-weekly-average

Assumed crop success rate	80%	Figure gained from a horticultural expert.

Carbon Factors

Carbon Factor	Unit	Value
Waste Heat from AD	Kg CO_2e/kWh	0.000111
Fuel Oil (Kerosene)	Kg CO_2e/kWh	0.29
Natural Gas	Kg CO_2e/kWh	0.20297
Grid Electricity	Kg CO_2e/kWh	0.21

Source: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2021