Optimising energy and carbon management for an AAD plant using MILP

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Talk Outline

- What happens to our waste? (**Background**)
- The Poop Processing Plant (**Site Overview**)
- Another Tax?! (**Carbon Emissions**)
- What's the point (of the app)? (**Purpose**)
- How does it work? (**Optimisation and Modelling Techniques**)
- The App! (**Demonstration**)
- Final Comments

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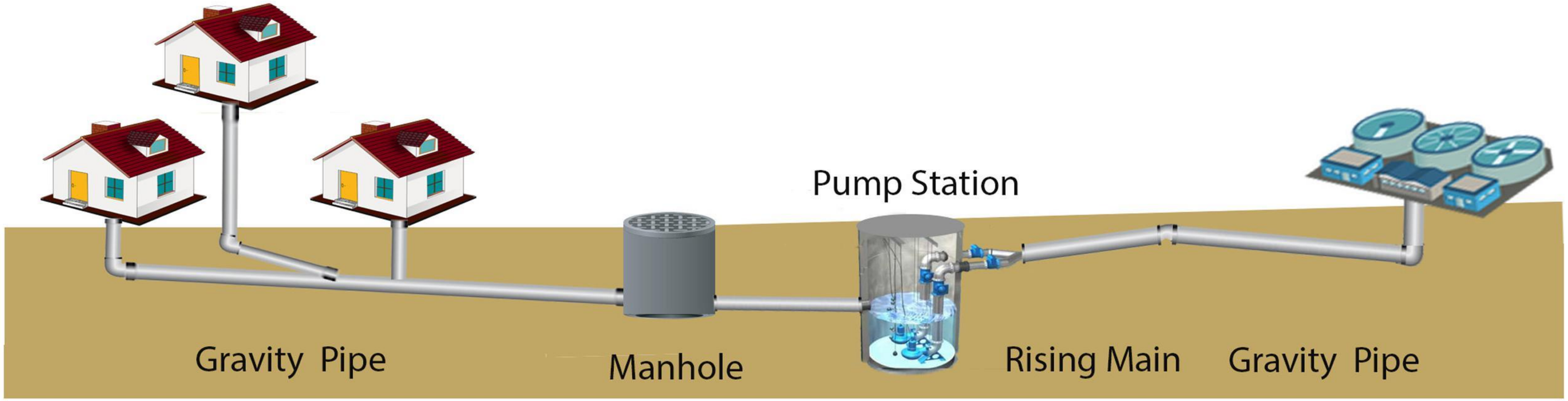
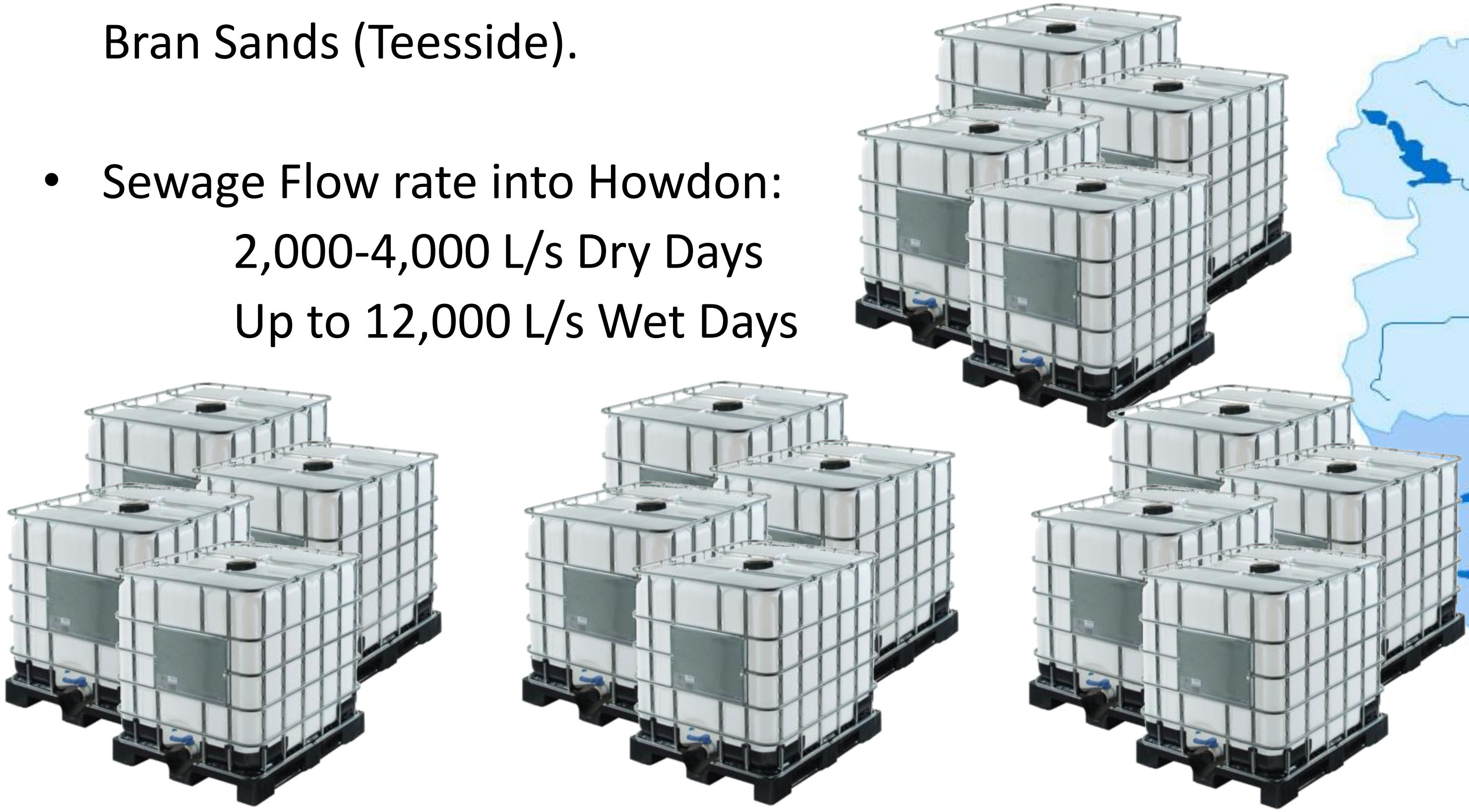
What happens to our waste?

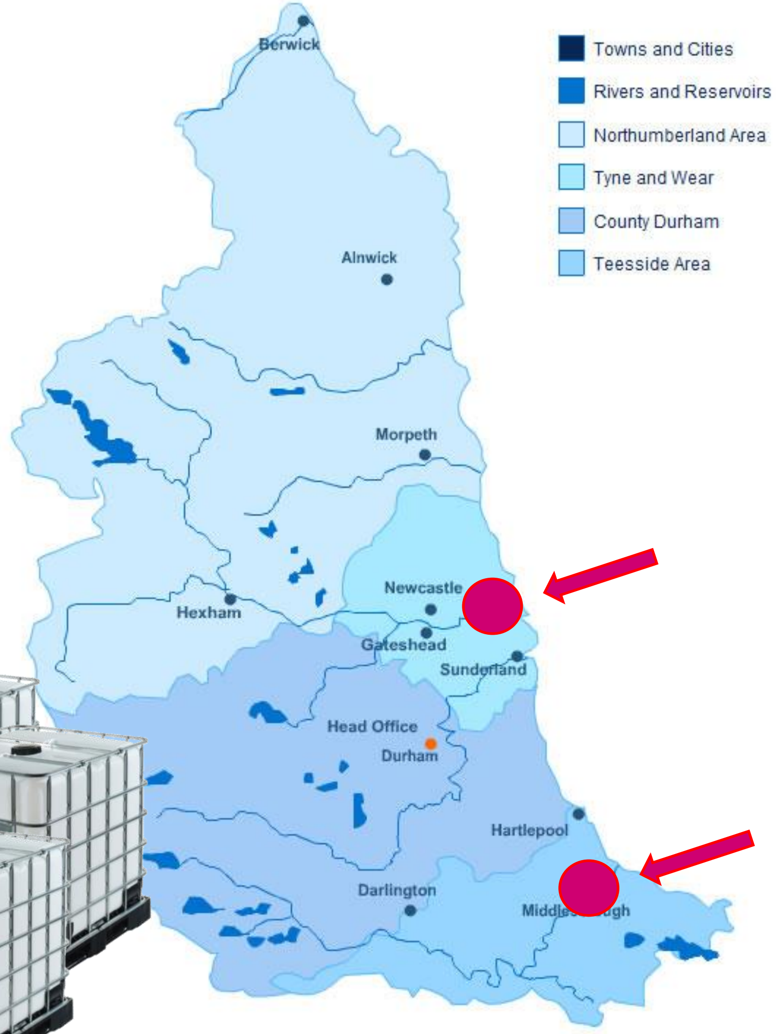
What happens when you flush?



How much?!

- Sewage from **1.3 Million Homes** treated on one of 410 sewage treatment works.
- Most of it ends up at Howdon (Newcastle) or Bran Sands (Teesside).
- Sewage Flow rate into Howdon:
  2,000-4,000 L/s Dry Days
  Up to 12,000 L/s Wet Days





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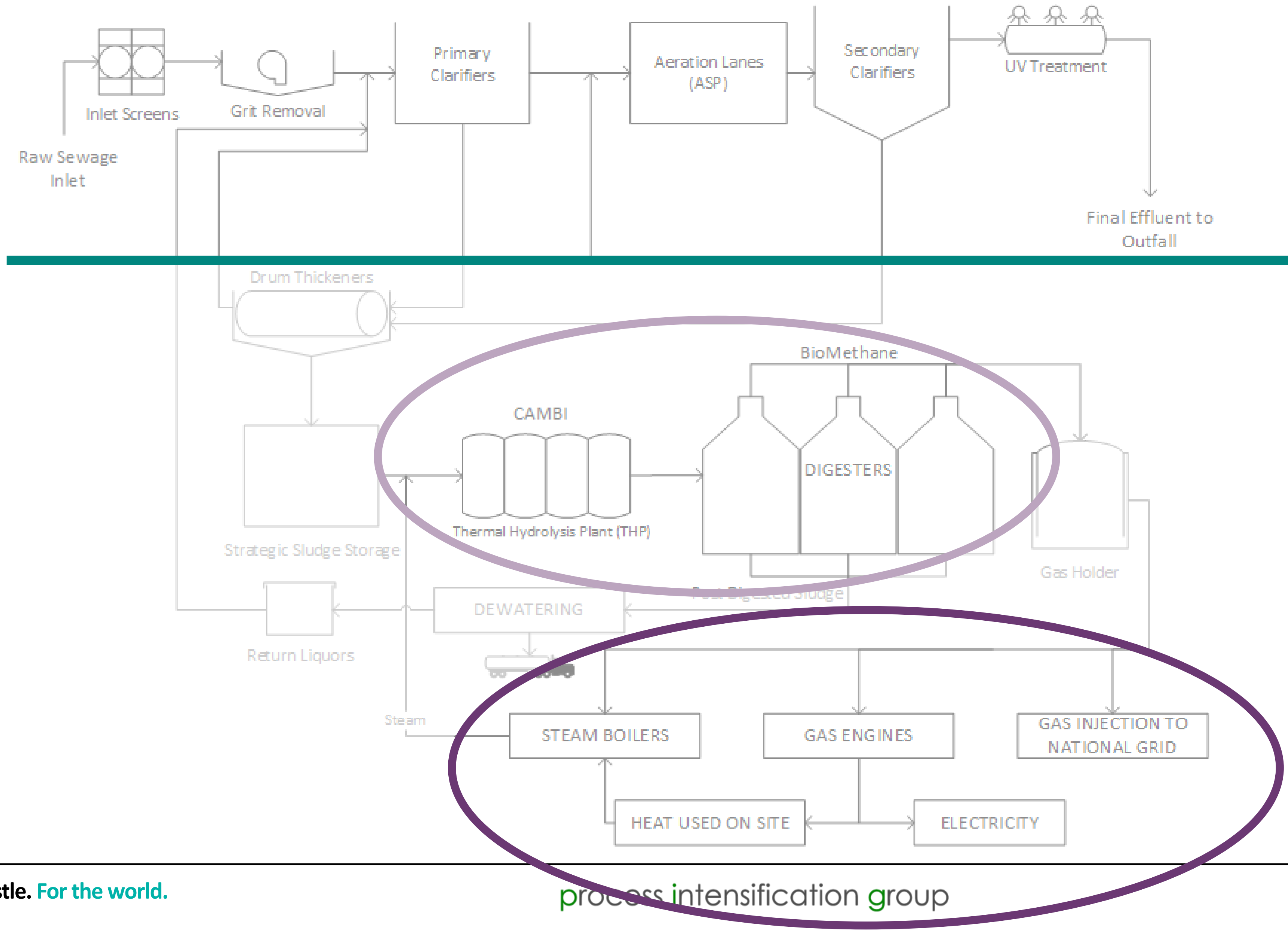
The Poop Processing Plant

Overview of the Howdon Plant



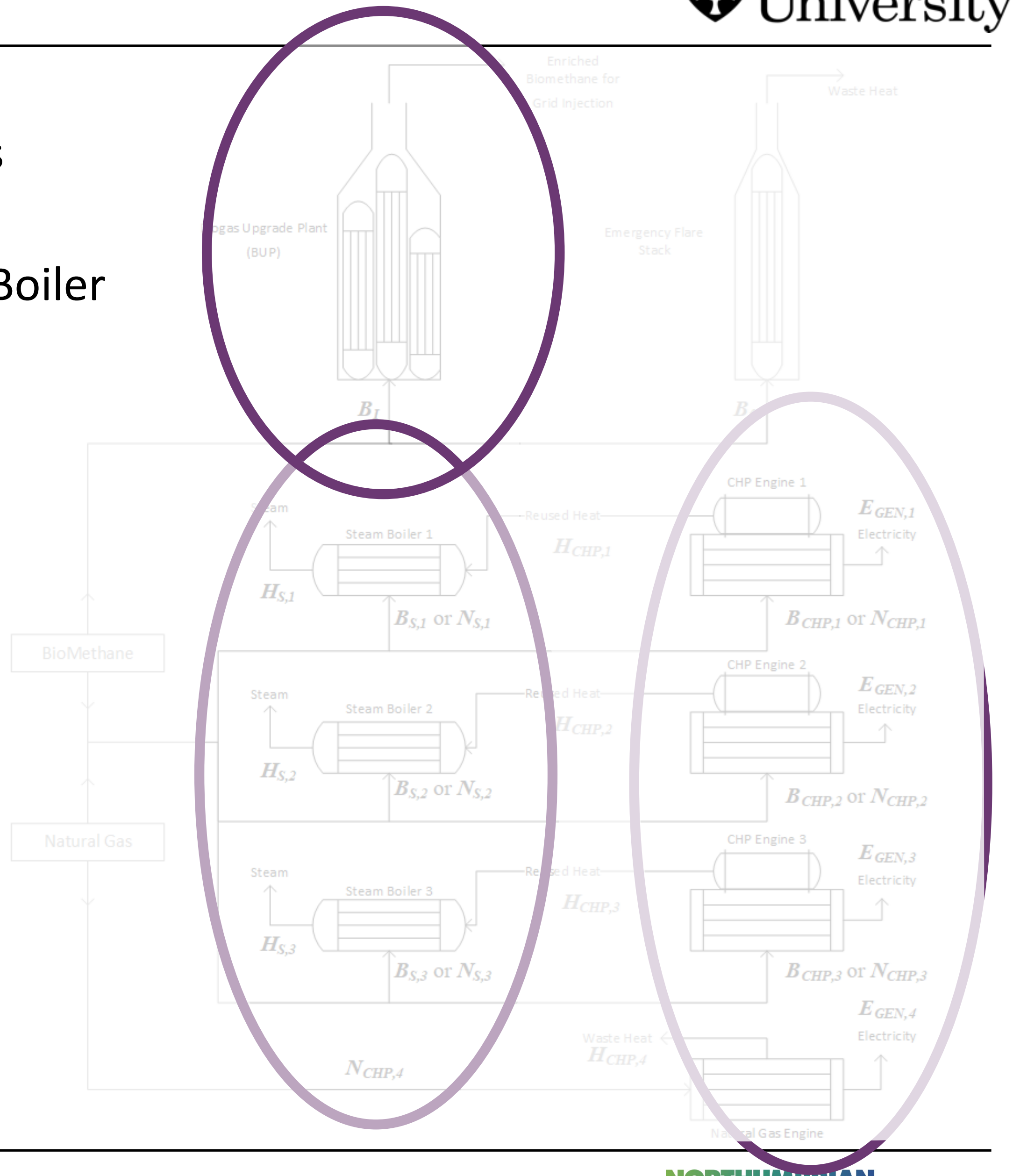
Water Treatment

Sludge Processing

Advanced Anaerobic Digestion Plant

Biomethane Processing Plant

- Biomethane (Biogas) produced form Anaerobic Digesters
- Biogas ***OR*** Natural Gas (not both) can be used in CHP or Boiler
  [CHP4 Nat Gas Only]
- Biogas can be enriched for Gas Injection
- Flare Stack available as last resort



Another Tax?!?

Carbon Neutrality Pledge and Tax

- Northumbrian Water Ltd pledges to be Carbon Neutral by 2027
- To aid/incentivise the move, NWL will incur a 'Carbon Tax' (subject to a Carbon Emissions Performance Criteria)
- Cost: **£187 per tonne CO2e**

Variable	Factor	Units
Import Electricity	0 **or** 0.31	$kgCO_2e/kWh$
Export Electricity	-0.28307	$kgCO_2e/kWh$
Import Natural Gas	0.18396	$kgCO_2e/kg$
Export Biomethane	-2.04652	$kgCO_2e/m^3$
Propane	1.51906	$kgCO_2e/L$
Diesel	2.9705	$kgCO_2e/m^3$
Biogas CHP	0.0175	$kgCO_2e/m^3$
Biogas residual	0.16	$kgCO_2e/m^3$

IMPROVING THE ENVIRONMENT

Our ambitious goals in this area are to:

- Be leading in the sustainable use of natural resources, through achieving zero avoidable waste by 2025 and being carbon neutral by 2027
- Demonstrate leadership in catchment management to enhance natural capital and deliver net gain for biodiversity
- Have the best rivers and beaches in the country
- Have zero pollutions as a result of our assets and operations

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What's the point (of the App)?

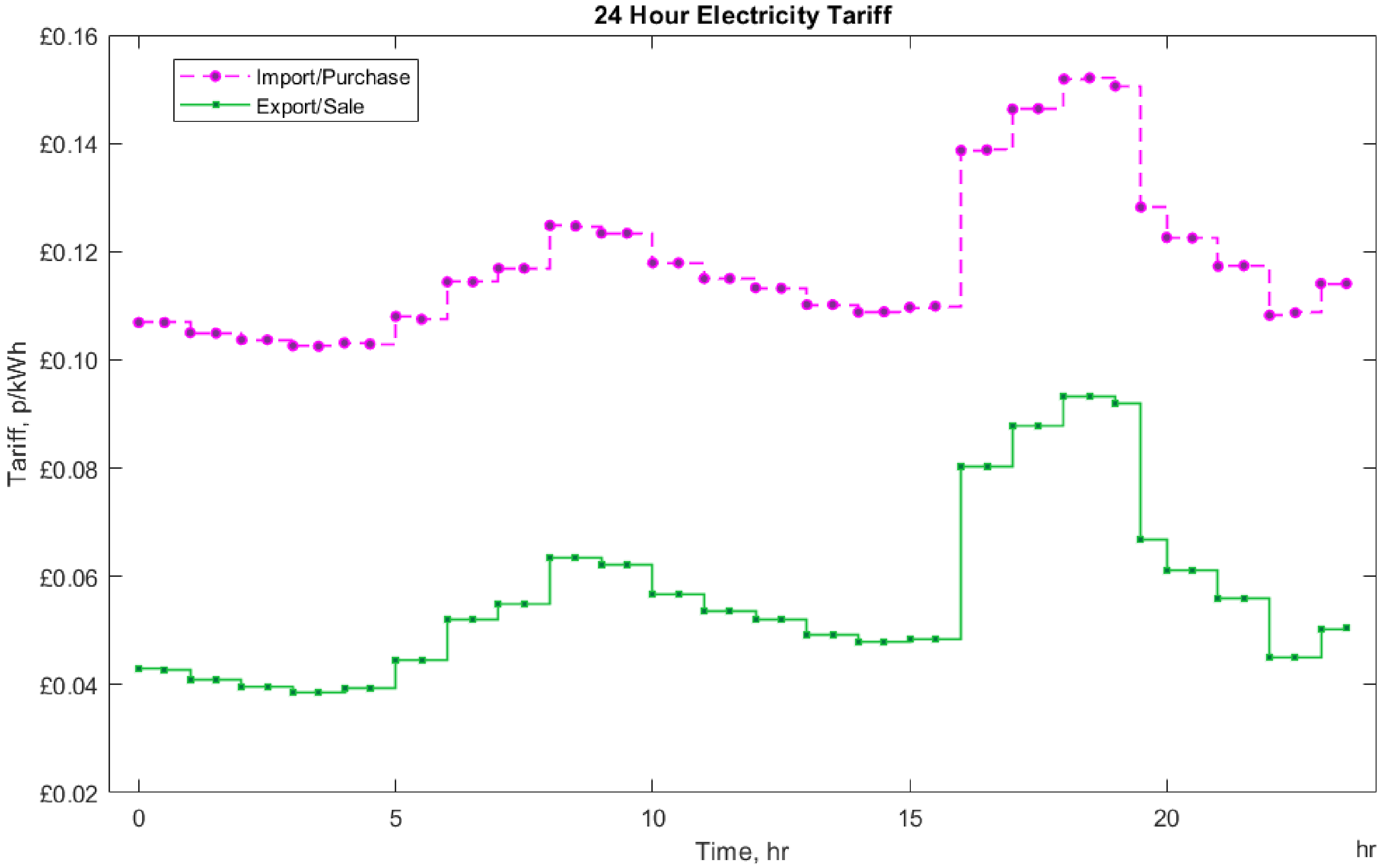
Purpose of the App

- Operators have no way of validating their current operational strategy
- Daily Biogas production levels change based on sludge processing demands
- Electricity prices change daily ("fixed variable")
- Natural Gas prices can change seasonally

- **Aim**: To provide operators/managers with a quick tool to validate operational decisions, based on up to date pricing, biogas production and carbon emissions

E.g. Varying Electrical Costs

- Electrical Import and Export costs vary every half hour, but are fixed one day ahead for 24 hours

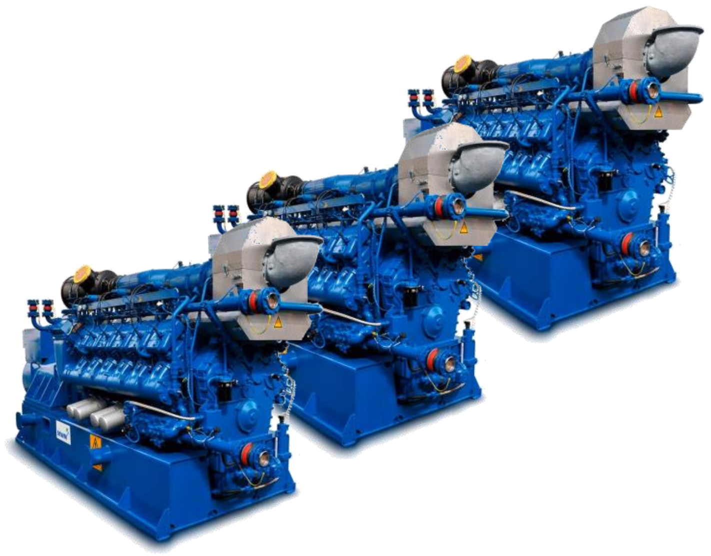


How does it work?

How can we define the plant model?

- All flow rates and process limits can be defined as a series of linear equations

- For example: CHP Engine gas flows
  - Gas flow to a CHP engine can be either Biogas ($\boldsymbol{B_{CHP,i,t}}$) or Natural Gas ($\boldsymbol{N_{CHP,i,t}}$)
  - Each unit has a maximum capable gas flow
  - Minimum gas flow is half the maximum for operation



$$B_{CHP,min} \leq \boldsymbol{B_{CHP,i,t}} \leq B_{CHP,max}$$

$$N_{CHP,min} \leq \boldsymbol{N_{CHP,i,t}} \leq N_{CHP,max}$$

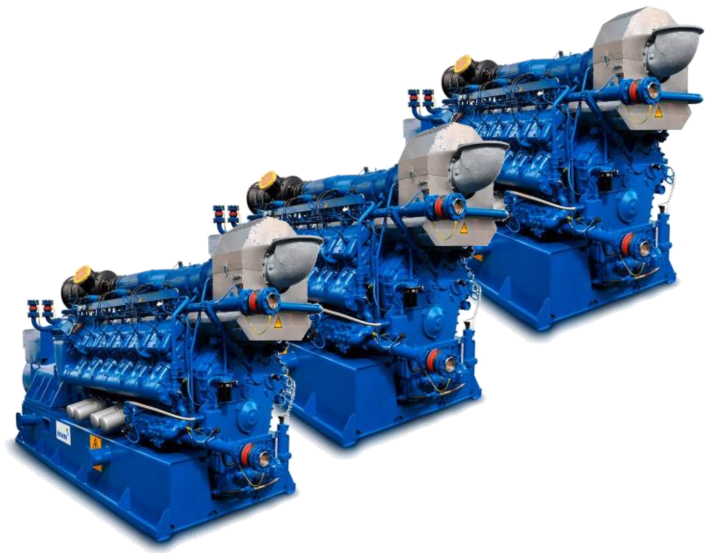
Linear Programming Model - CHP Example

- Gas flow must be either Biogas **OR** Natural Gas

- Use a binary variable, $\boldsymbol{z_{i,t}}$ (= 1 or 0), to force this choice

$$B_{CHP,min} \cdot \mathbf{z_{i,t}} \leq \boldsymbol{B_{CHP,i,t}} \leq B_{CHP,max} \cdot \mathbf{z_{i,t}} \qquad \boldsymbol{z_{i,t} = 1}$$

$$N_{CHP,min} \cdot (1 - \mathbf{z_{i,t}}) \leq \boldsymbol{N_{CHP,i,t}} \leq N_{CHP,max} \cdot (1 - \mathbf{z_{i,t}}) \qquad \boldsymbol{z_{i,t} = 0}$$



Linear Programming Model - CHP Example

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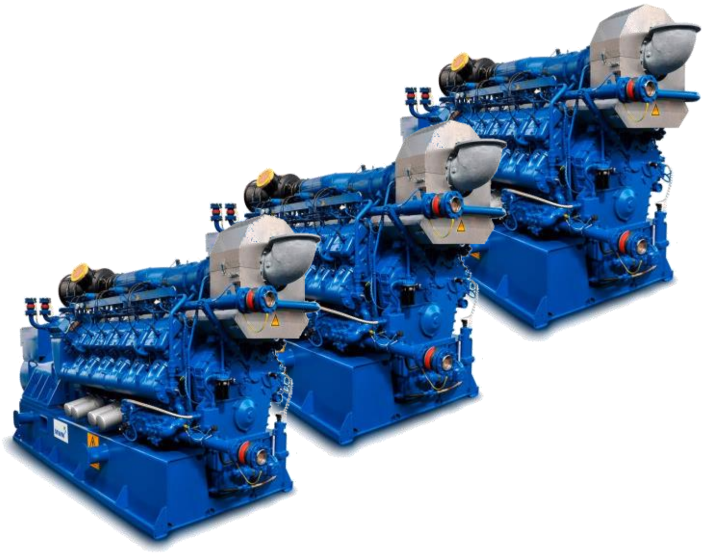
- In addition, the engines can either be **On** or **Off**

- Use two more binary variables, $w_{i,t,1}$ and $w_{i,t,2}$, to force this choice



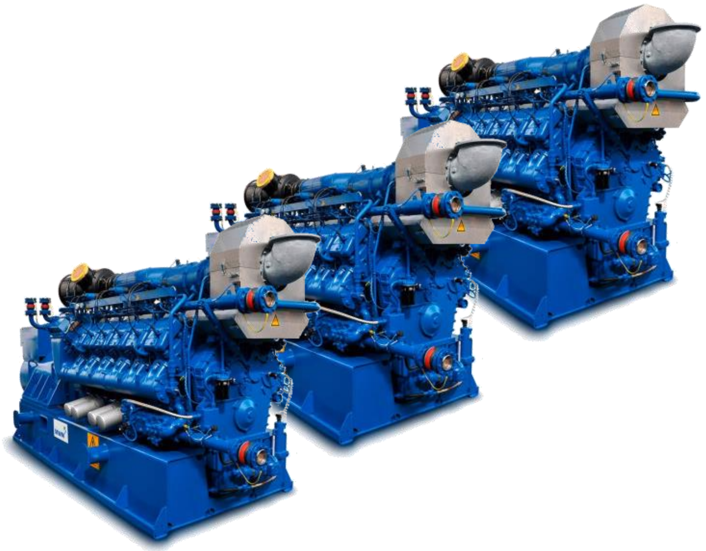
$$B_{CHP,min} \cdot z_{i,t} - B_{CHP,min} \cdot \boldsymbol{w}_{\mathbf{i,t,1}} \leq \boldsymbol{B_{CHP,i,t}} \leq B_{CHP,max} \cdot z_{i,t} - B_{CHP,max} \cdot \boldsymbol{w}_{\mathbf{i,t,1}}$$

$$N_{CHP,min} \cdot (1 - z_{i,t}) - N_{CHP,min} \cdot \boldsymbol{w}_{\mathbf{i,t,2}} \leq \boldsymbol{N_{CHP,i,t}} \leq N_{CHP,max} \cdot (1 - z_{i,t}) - N_{CHP,max} \cdot \boldsymbol{w}_{\mathbf{i,t,2}}$$

Linear Programming Model - CHP Example

- Further, must now consider engine start-up, shutdown and minimum operating time once switched on

- Use four more binary variables, $\boldsymbol{su}_{i,t,1}$, $\boldsymbol{su}_{i,t,2}$, $\boldsymbol{sd}_{i,t,1}$ and $\boldsymbol{sd}_{i,t,\mathbf{2}}$



$$B_{CHP,min}\, z_{i,t} - B_{CHP,min}\, w_{i,t,1} - 0.5B_{CHP,min}\, \boldsymbol{su}_{\mathbf{i,t,1}} - 0.5B_{CHP,min}\, \boldsymbol{sd}_{\mathbf{i,t,1}} \leq \boldsymbol{B}_{\boldsymbol{CHP,i,t}}$$

$$\boldsymbol{B}_{\boldsymbol{CHP,i,t}} \leq B_{CHP,max}\, z_{i,t} - B_{CHP,max}\, w_{i,t,1} - 0.5B_{CHP,max}\, \boldsymbol{su}_{\mathbf{i,t,1}} - 0.5B_{CHP,max}\, \boldsymbol{sd}_{\mathbf{i,t,1}}$$

$$N_{CHP,min}(1 - z_{i,t}) - N_{CHP,min}\, w_{i,t,2} - 0.5N_{CHP,min}\, su_{i,t,2} - 0.5N_{CHP,min}\, \boldsymbol{sd}_{\mathbf{i,t,2}} \leq \boldsymbol{N}_{\boldsymbol{CHP,i,t}}$$

$$\boldsymbol{N}_{\boldsymbol{CHP,i,t}} \leq N_{CHP,max}(1 - z_{i,t}) - N_{CHP,max}\, w_{i,t,2} - 0.5N_{CHP,max}\, su_{i,t,2} - 0.5B_{CHP,max}\, \boldsymbol{sd}_{\mathbf{i,t,2}}$$

Mixed Integer Linear Programming (MILP)

- MILP takes a series of linear statements (equalities and inequalities) and aims to minimise a cost function.

$$\min_{x} f^T(x) \text{ subject to } \begin{cases} x(intcon) \\ A \cdot x \leq b \\ Aeq \cdot x = beq \\ lb \leq x \leq ub \end{cases}$$

- **Aim**: to minimise expenditure (maximise potential profits) of our plant based on energy, gas and carbon use/distribution

Mixed Integer Linear Programming (MILP)

- For a single 24 hour optimisation (48 half hourly time periods):

$$\min_{x} f^{T}(x) \ \text{subject to} \begin{cases} x(intcon) \\ A \cdot x \leq b \\ Aeq \cdot x = beq \\ lb \leq x \leq ub \end{cases}$$

1491 Integers

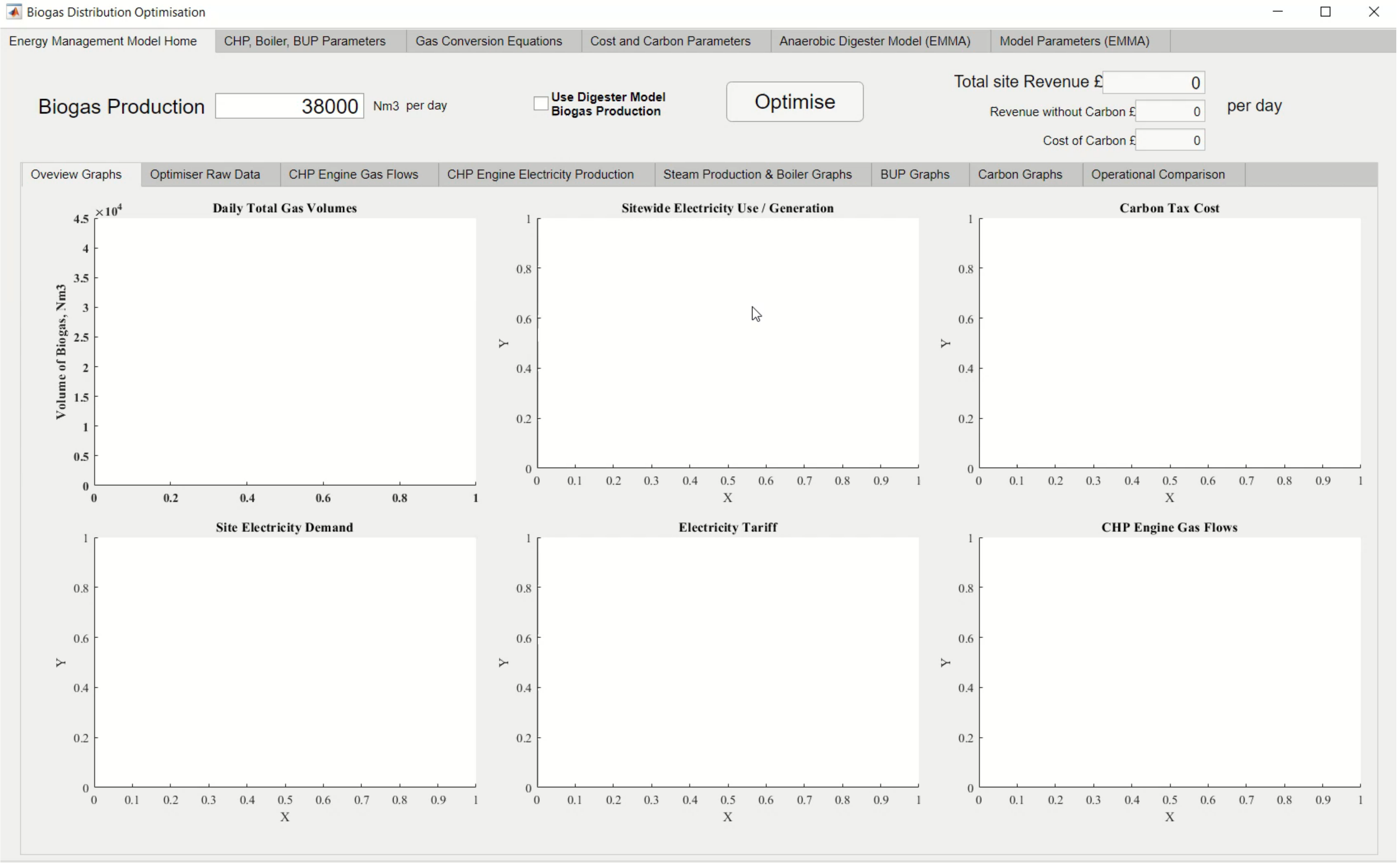
1872 Inequalities

768 Equalities

2355 Variables

The App!

The App! General Use



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Comparison to Current operation

Key Variables:

- 38,000 Nm^3 Biogas / Day
- Nat Gas 65 p/therm

	Current Operation	Optimal Operation
Total Revenue	**£ 8350**	**£ 9270**
Revenue Excluding Carbon	£ 12390	£ 7927
Cost of Carbon	£ 4040	£ -1343

<u>Carbon Tax Payable in two years time</u>

Comparison to Current operation

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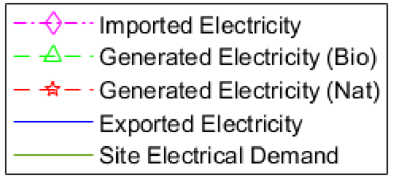

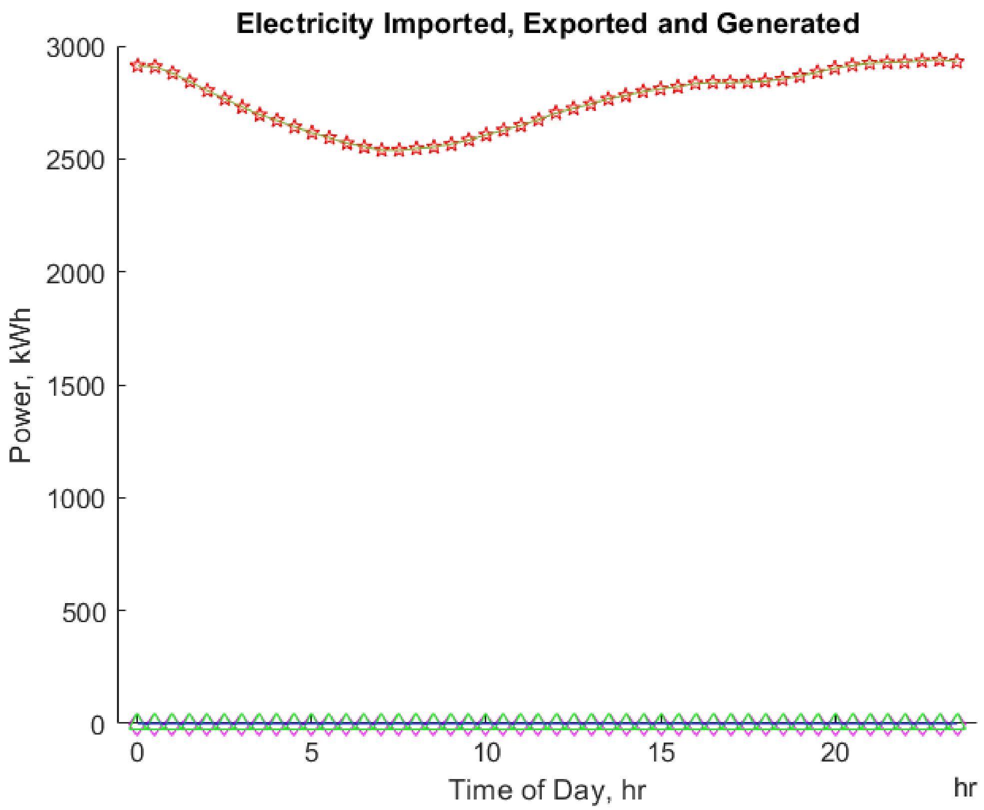

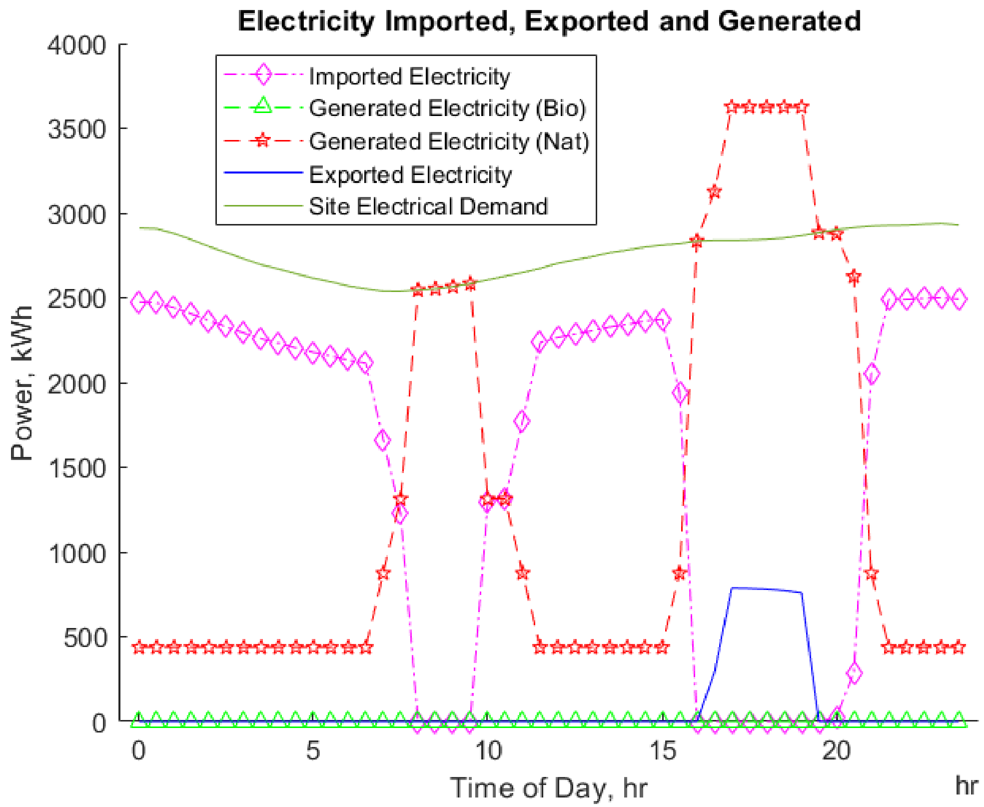

Comparison to Current operation

Key Variables:

- 38,000 Nm^3 Biogas / Day
- Nat Gas 65 p/therm

	Current Operation	Optimal Operation	Current Annual	Optimal Annual
Total Revenue	**£ 8350**	**£ 9270**	**£ 3.05 M**	**£ 3.38 M**
Revenue Excluding Carbon	£ 12390	£ 7927	£ 4.52 M	£ 2.89 M
Cost of Carbon	£ 4040	£ -1343	£ 1.47 M	£ -0.49 M

Carbon Tax Payable in two years time

Final Comments

What benefits does this app provide?

- Provides quick optimisations
- Validates operational decisions
- Allows operators/managers to investigate scenarios easily
- Highlights the importance of new legislation (Carbon Tax)
- Demonstrates impactful changes could be made to operational strategy, especially with respect to daily revenues

Current/future use of the Model

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- Retrospective Analysis
  - Investigate unprecedented energy prices

- Investigation into CHPQA and it's impact on annual operations
  - CHPQA can be considered a tax relief based on the usage on CHP Engines

- With some adaptations, model could be **applied to similar sites** (Such as the Bran Sands site at NWG)
  - Funding secured to implement and deploy models within NWL

Acknowledgments

NORTHUMBRIAN WATER living water

Stream
The Industrial Doctorate Centre for the Water Sector
Shaping careers, delivering innovation

UKRI Engineering and Physical Sciences Research Council

Thank you for listening

Any Questions?

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