Optimisation of the Gas Distribution of a wastewater treatment plant: A Mixed Integer Linear Programming approach

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1. Introduction

- Northumbrian Water (NW) anaerobically digests up to 40,000 tonnes of sewage sludge (dry solids) annually at the Advanced Anaerobic Digestion (AAD) plant [Fig.1] at Tyneside, producing renewable 'Biomethane' (Biogas)

Figure 1 – Areal Photograph of sludge processing area of Tyneside Wastewater Treatment Facility

- **Aim**: To investigate and develop operational strategies in order to improve process understanding, operation and site robustness of gas (and energy) distribution across the AAD plant

2. Problem Statement: Gas and Energy Distribution

- CHP Engines use a gas fuel to create electricity and heat for on site use
- Steam Boilers must be utilised to provide steam for the AAD plant
- Units have either Biogas OR Natural Gas as a fuel source - not both at once [Fig.2]
- If a CHP Engine is not used, electricity from the national grid makes up the deficit

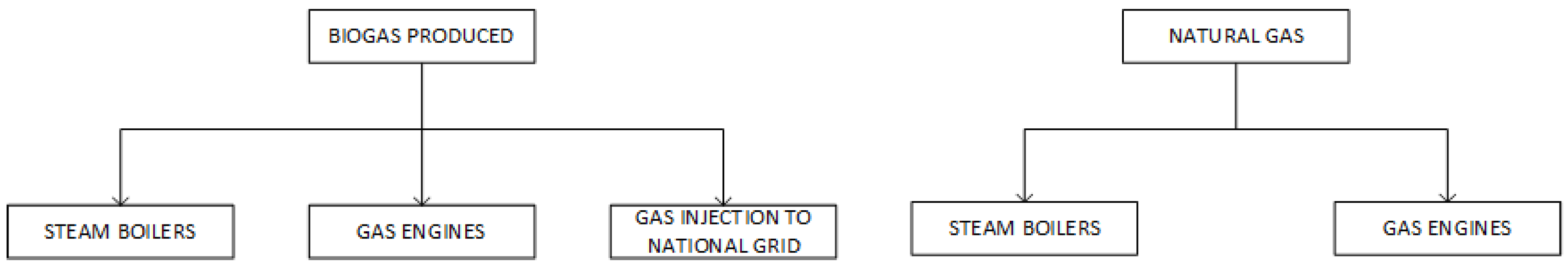

Figure 2 – Gas Distribution on Site

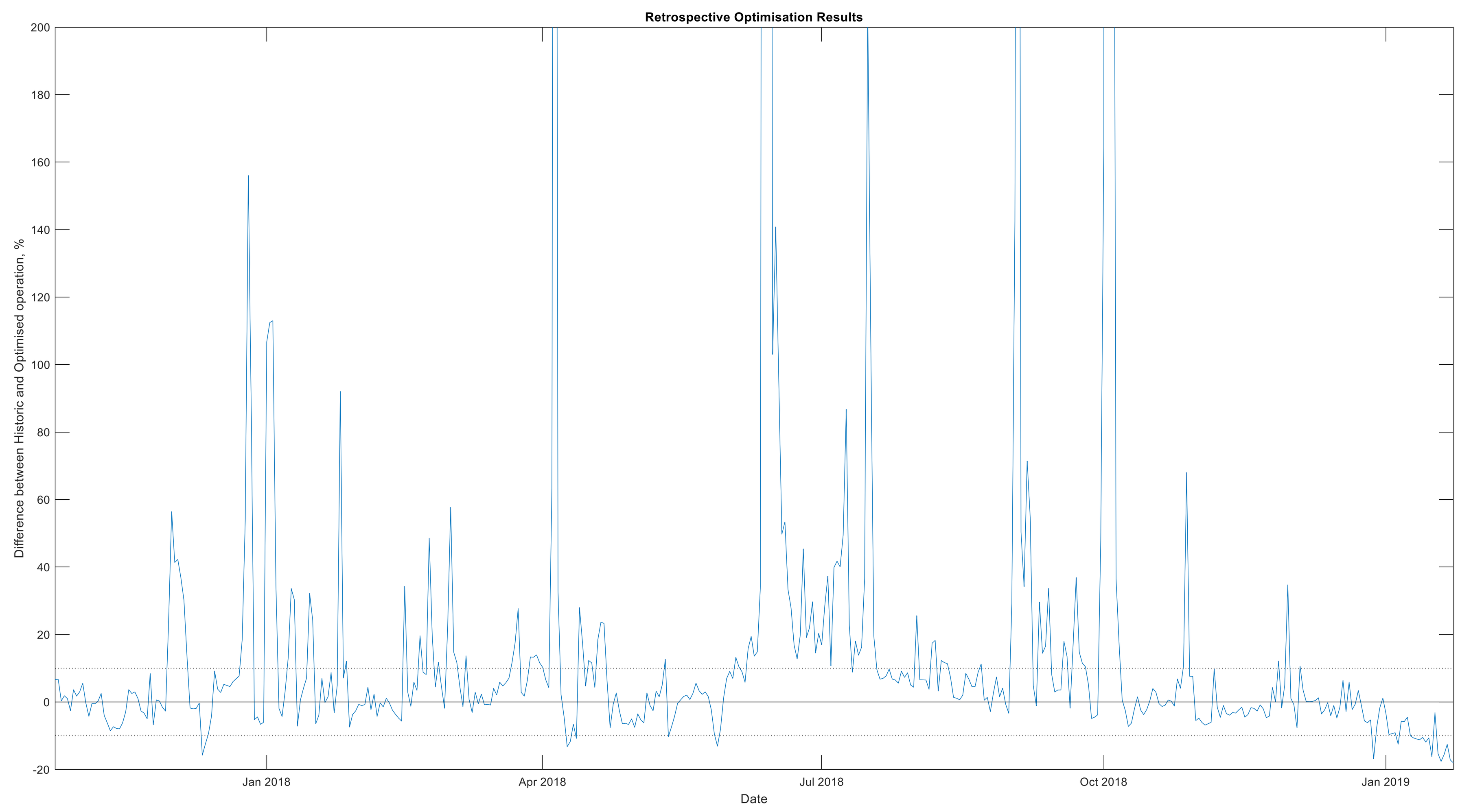

Figure 3 – Percentage change in Daily Optimised cost to the Actual Operational cost - a negative percentage shows plant performed better than expected

3. MILP Approach

- Adapting MILP (Mixed Integer Linear Programming) modelling work by *Cummings et al.* [1], a MILP model for the cost of Energy Distribution on site can be written as:

$$T_c = \sum_{t=1}^{N_t} (C_b\, B_{t,CHP}\, z_i) + \left(C_n N_{t,CHP}(1-z_i)\right) + \cdots \quad \textit{CHP Engines}$$

$$\sum_{t=1}^{N_t} (C_b\, B_{t,Boil}\, z_i) + \left(C_n N_{t,Boil}(1-z_i)\right) + \cdots \quad \textit{Steam Boilers}$$

$$\sum_{t=1}^{N_t} (C_I\, B_{t,Inject}) + \cdots \quad \textit{Grid Injection}$$

$$\sum_{t=1}^{N_t} (C_f\, P_{t,Flare}) + \cdots \quad \textit{Waste Burner}$$

$$\sum_{t=1}^{N_t} (C_E\, P_E) \quad \textit{Electricity Import}$$

Key:
C_b = Cost of burning Biogas
C_n = Cost of burning Natural Gas
C_I = Cost of injecting biogas
C_f = Cost of flaring biogas
C_E = Cost of Electricity

B_t = Biogas Volume
N_t = Natural Gas Volume

z_i = binary variable, to ensure only one gas type is used

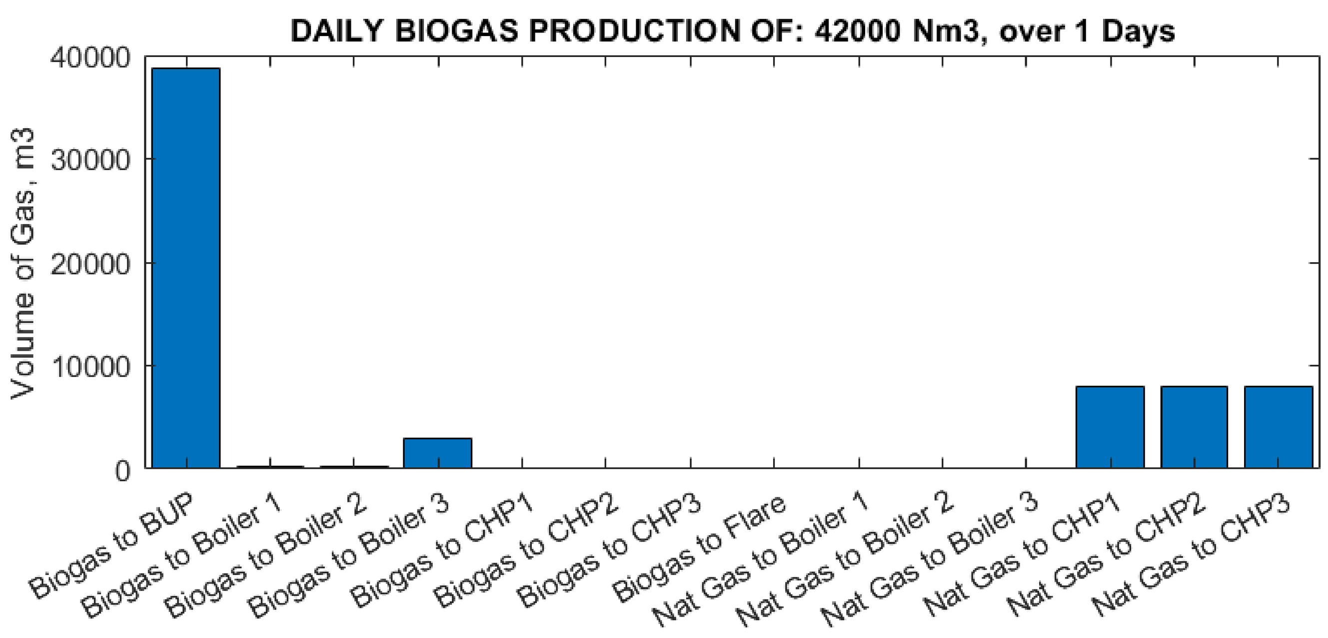

Figure 4 – Example daily optimised gas distribution on site, for a daily biogas production of 42,000 normalised cubic meters of biomethane

4. Results

- Historic daily operational data was gathered for November 2017 to Jan 2019, allowing for Retrospective Optimisation (RO) of the plant operation
- 70% of the time the plant was operated optimally (to within a 10% boundary) [Fig.3]. Optimised daily gas distribution is provided in graphical form [Fig.4]
- Fluctuating electricity costs [Fig.5] show it is sometimes more cost effective to use energy from the national grid rather than generate it on site [Fig.6]

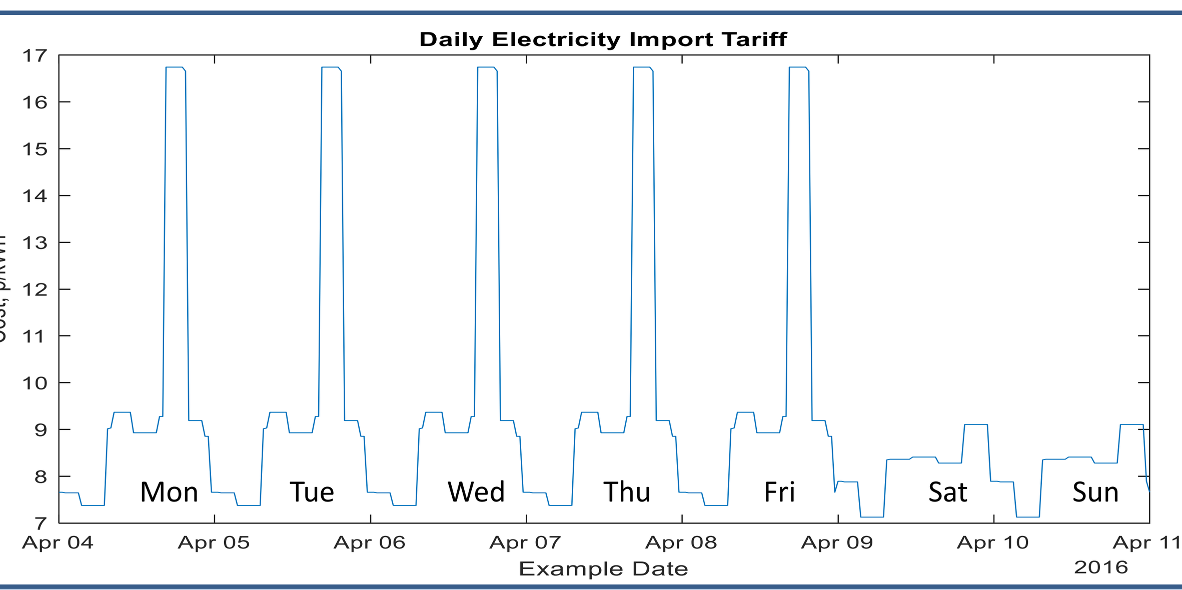

Figure 5 – Historic daily fixed electricity import price fluctuations

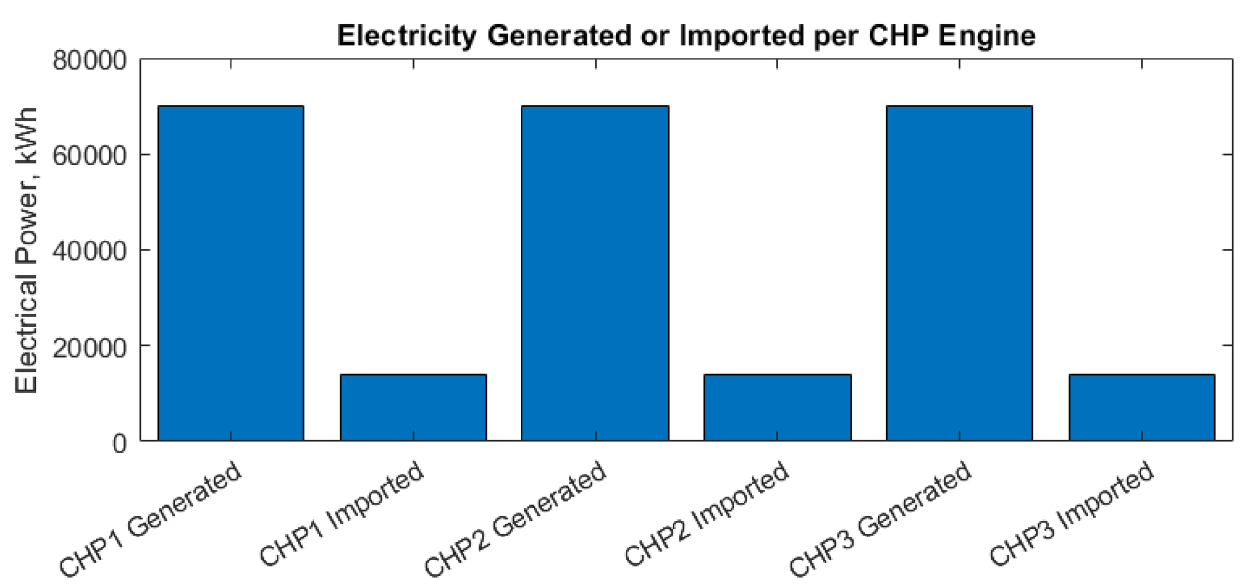

Figure 6 – Example daily optimised electrical energy usage on site, based on the same optimisation performed in Fig.5

5. Discussion and Future Work

- Non-optimal performance is likely to be lower once maintenance downtime has been accounted for
- Developing a Biogas Prediction Model (modelling the anaerobic digesters) will transform the current model from RO to a predictor
- Northumbrian Water has a strategic objective of being carbon neutral by 2027; the Biogas Optimiser does not currently consider the carbon impacts of optimisation, however in future the optimiser will allocate a financial value to the resultant carbon emissions which will affect current optimisation results

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References

1. Cummings, T., Adamson, R., Sugden, A., Willis, M. J. (2017), Retrospective and predictive optimal scheduling of nitrogen liquefier units and the effect of renewable generation - *Applied Energy 208* 158–170

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