A decision support tool for improving energy and environmental performance of public sector multi-energy systems

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Public sector expected to take first steps on the Net-Zero transition

- The UK is the first major economy to pass laws to bring all GHG emissions to net zero by 2050
- The public sector is expected to lead the decarbonisation agenda
  - The higher education sector has a voluntary target of a 30% reduction in GHG by 2020/21 and a 50% reduction by 2030[1]
  - The NHS has committed to a voluntary target of 34% reduction in carbon emissions by 2020 and a 50% target by 2025[2]

Net Zero
The UK's contribution to stopping global warming

Committee on Climate Change
May 2019

DECLARE A CLIMATE EMERGENCY

245 local authorities have declared a climate emergency[3].
149 of these have set a target of reaching **zero emissions by 2030** or earlier.

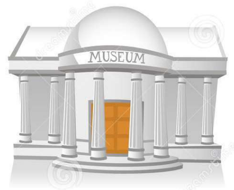
[1] *The Clean Growth Strategy: Leading the way to a low carbon future. Available at <https://www.gov.uk/government/publications/clean-growth-strategy>*
[2] *NHS Sustainable Development Unit. Available at <https://www.sduhealth.org.uk/>*
[3] *Declare a climate emergency. Available at <https://www.climateemergency.uk/>*

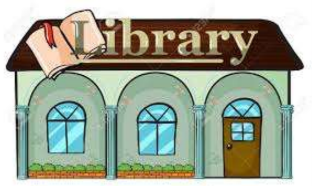
The Public Estate is the single largest consumer of gas and electricity in the UK

- Public sector is the **largest single buyer of gas and electricity** in the UK (*outside the BIG 6 Energy Suppliers*)[1]

- The public estate **consumes over 6%** of the UK's energy supply

- The UK Government spends **over £3.4billion per annum** on its energy bills



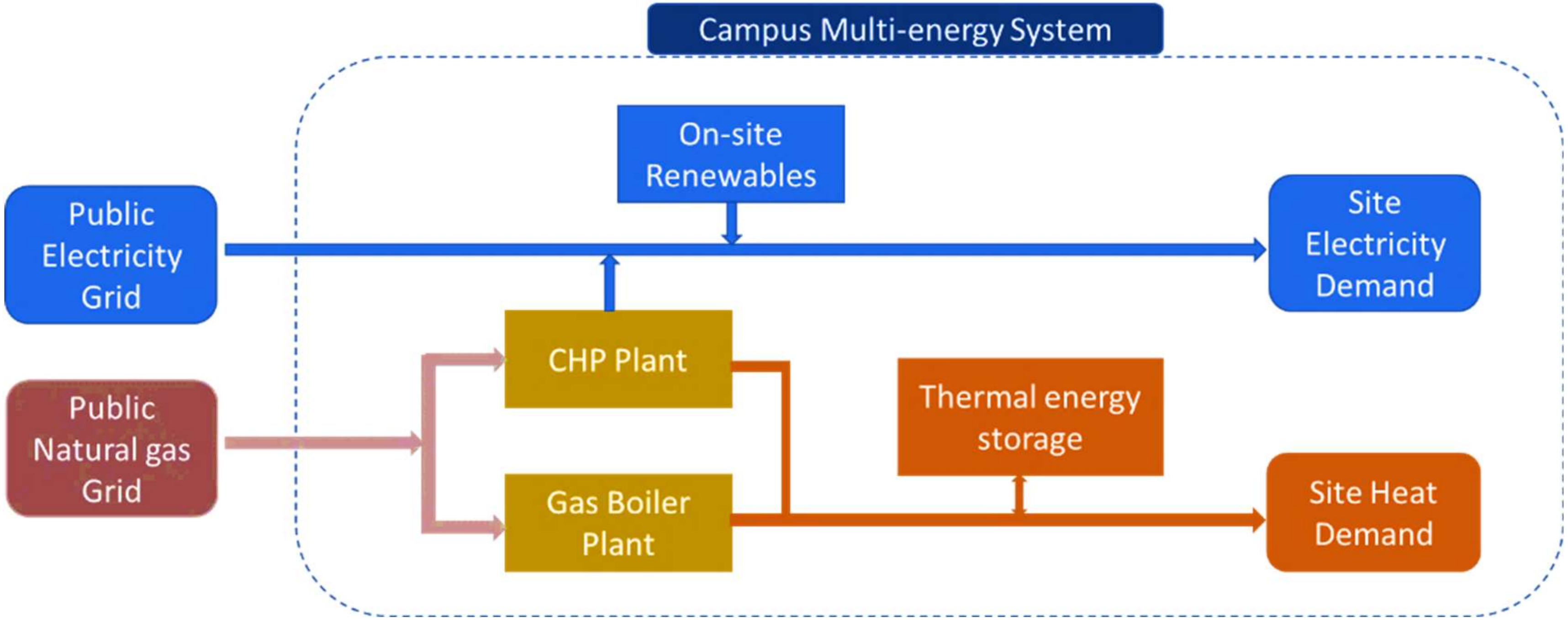


Cabinet Office

Local Government Association

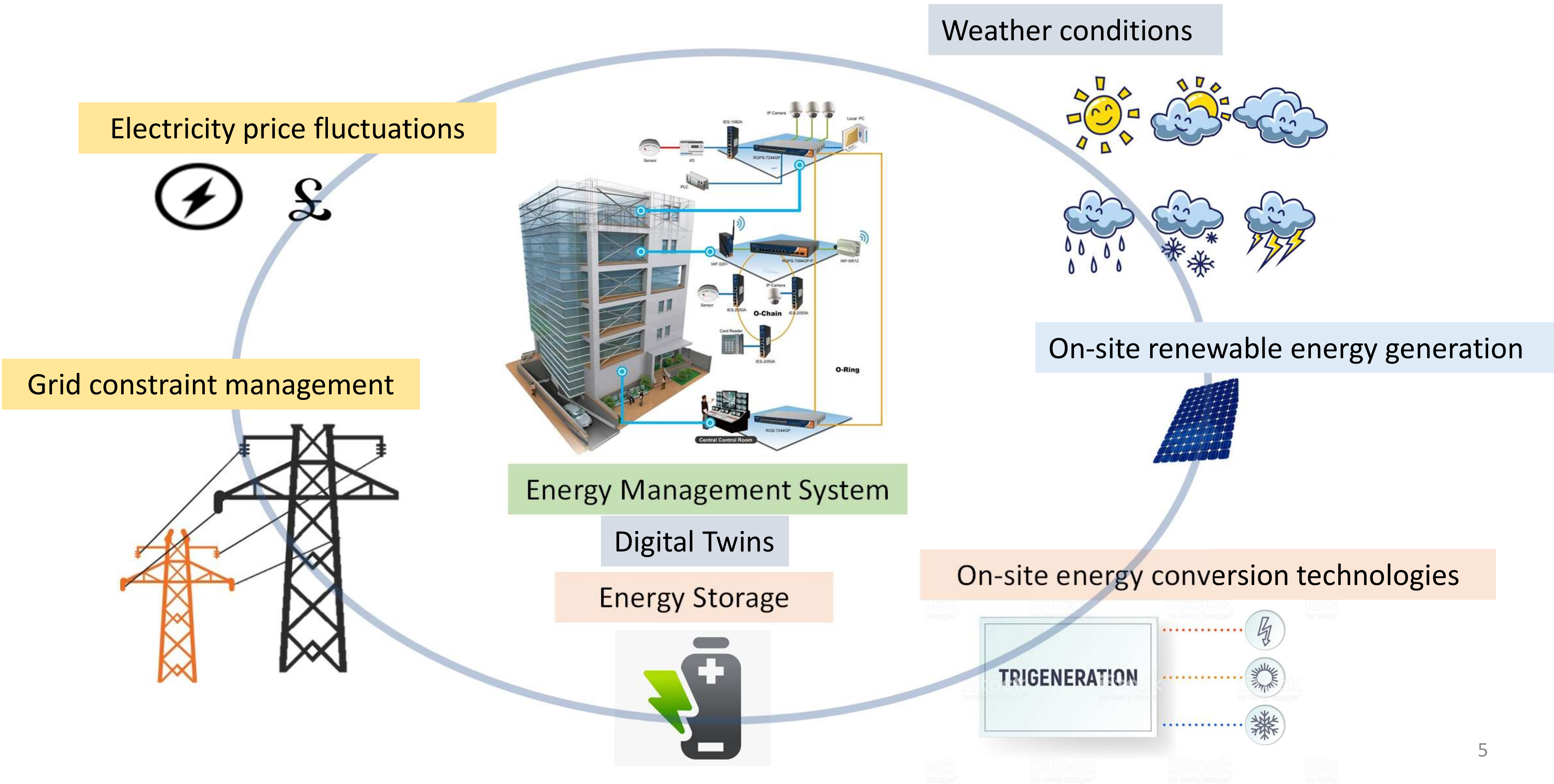
[1] *The Crown Commercial Service. Available at <https://www.crowncommercial.gov.uk/products-and-services/buildings/energy>*

Typical arrangement of a campus energy system



The public estate includes many campus scale energy systems that are typically large users of power and heat and own and operate an on-site multi-vector energy supply system

Net-zero public sector campuses will be complex energy systems



Significant challenges for public sector energy managers to deliver Net-Zero

Common challenges

- Energy system is one of many priorities
- System resilience more important than efficiency
- Aged infrastructure and obsolete equipment
- Financial constraints and lack of engagement with the energy system → Lack of investment
- Lack of an energy strategy

Other more technical challenges

- Carbon savings not anymore aligned with gas CHP
- Plethora of low carbon technology options
- Reluctance of designers and contractors to deviate from traditional technologies
- Conflicting systems as new infrastructure added on to site
- Local DNO constraints
- Complexities and uncertainties in the energy sector delay decisions

Insight: Decision support tools essential to support public sector energy managers

There is a gap between sophisticated academic research and the simple approaches/tools required by practicing site managers

A clear need for accessible, user friendly decision support tools that

- Capture multiple site objectives (resilience, cost, emissions) and provide evidence on key performance indicators
- Capture internal and external factors that influence decisions
- Does not have onerous Initial data requirements

Research Projects investigating the development of Decision Support Tools

Research Grants funded by EPSRC – Centre for Energy Systems Integration

National Centre for Energy Systems Integration (CESI)

Funder

Cabinet Office

Crown Commercial Service

Government

Building Controls Maintenance Ltd

ICS Integrated Control Solutions

Control solution supplier

WARWICK THE UNIVERSITY OF WARWICK

NHS The Queen Elizabeth Hospital King's Lynn NHS Foundation Trust

Case study sites

UK Power Networks

Electricity Distribution Network Operator

Cardiff University Prifysgol Caerdydd

Catapult Energy Systems

Research Organisations

Phase 1: Decision support tool for <u>operation planning</u> in public sector multi-energy systems (Project value : £60,000)

Phase 2: Decision support tool for <u>real-time</u> operation improvements in public sector multi-energy systems (Project Value : £87,000)

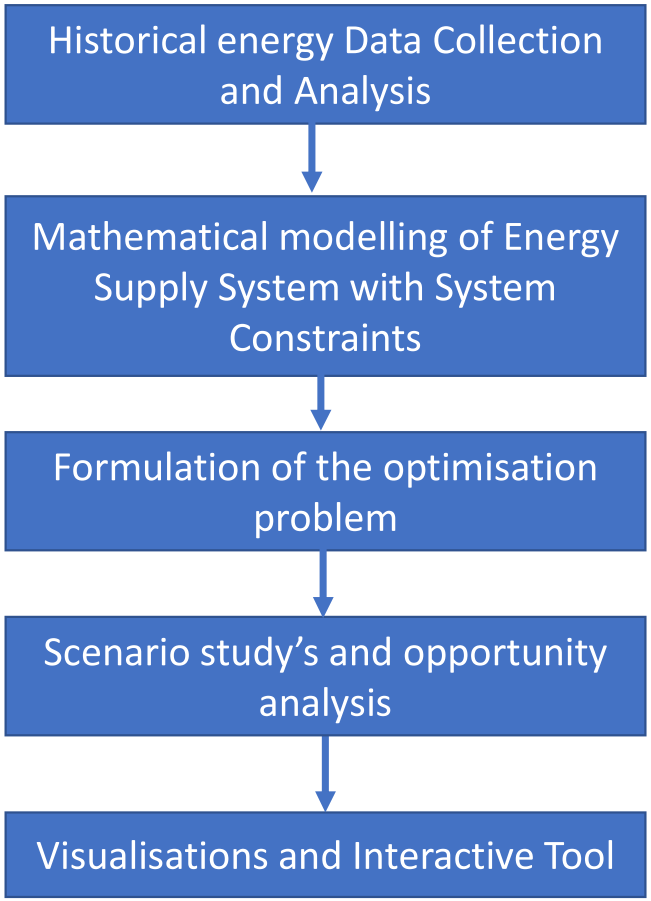
Project website:

Phase 1: https://www.ncl.ac.uk/cesi/cesiflexfund/firstcesiflexfundprojects/abey/;

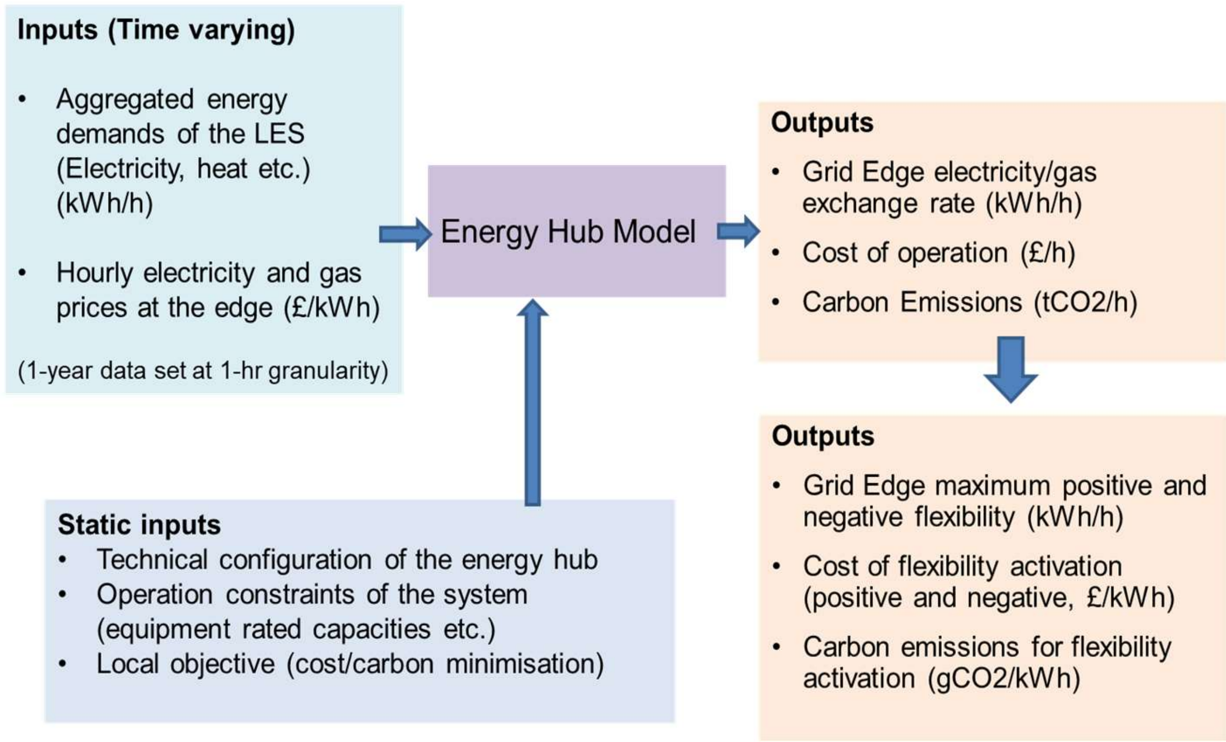
Phase 2: https://www.ncl.ac.uk/cesi/cesiflexfund/thirdcesiflexfundprojects/abey/

Methods: Decision tool to evaluate operation improvement opportunities

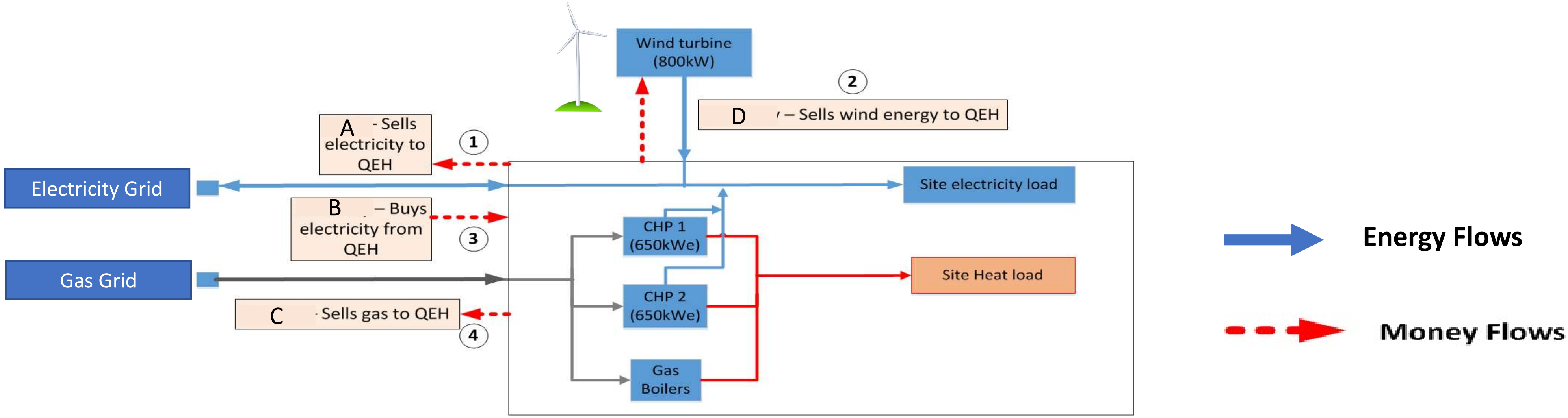
Process of decision tool development



Mathematical Model structure



Case study: Hospital site



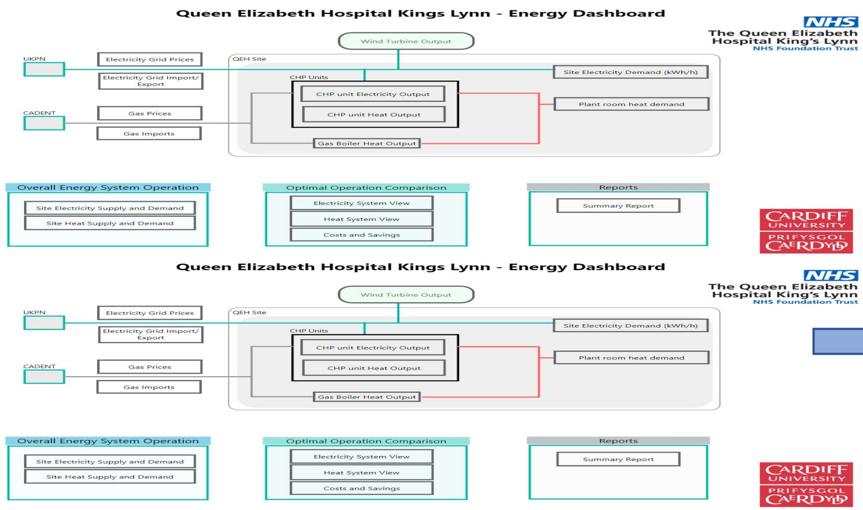
- On-site electricity generation
  - ✓ 800kWe Wind turbine generator
  - ✓ 2 x 650kWe CHP units
- Heat supplied by 4 Gas Boilers + CHP units
- 11kV electricity ring circuit
- Hot water ring circuit operating between 90ºC/50ºC
- Electricity Export capacity constraint of 200kW

Overview of Decision support tool for operation planning

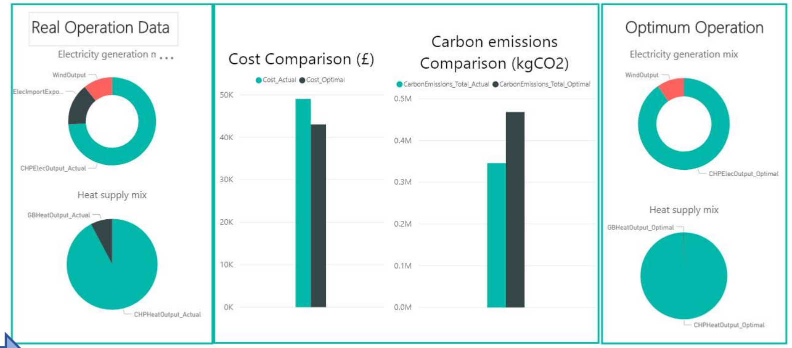
Data base

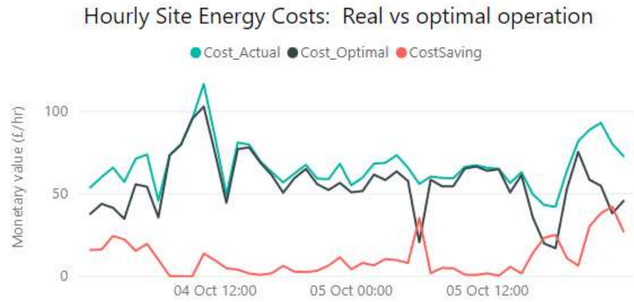
- Electricity Import/Export
- Wind turbine output
- CHP unit(s) operation data
- Electricity demand
- Gas demand
- Heat Demand
- Electricity Import Price
- Electricity Export Price
- Gas Price

Decision tool dashboard



Analysis results

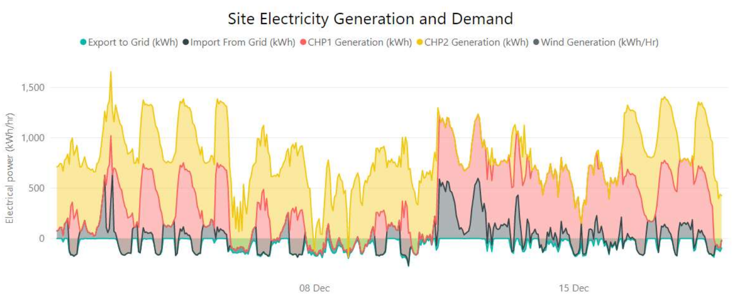


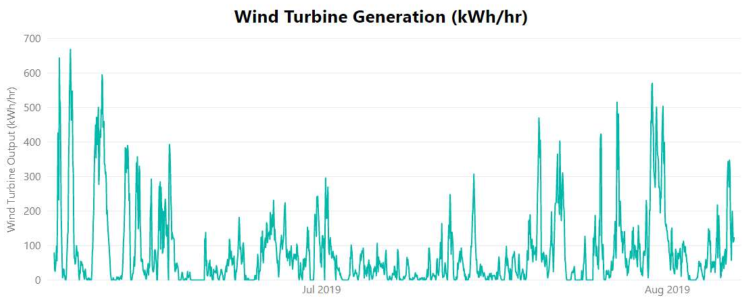


Cost Comparison (£)

Cost_Actual	Cost_Optimal	CostSaving
3,222.13	2,704.08	518.04

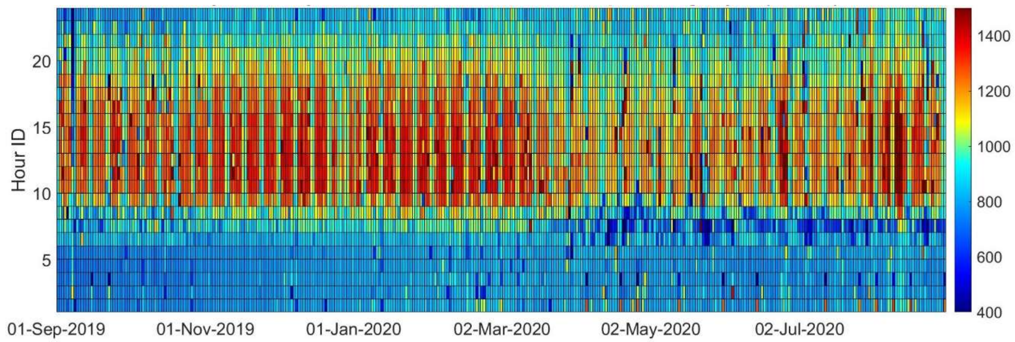
Energy Data Visualisations





Insight 1: Understanding the electricity and heat energy demand patterns and on-site generation is essential for decision making

Hourly Electricity Demand (kWh/hr)



Regular Diurnal Pattern

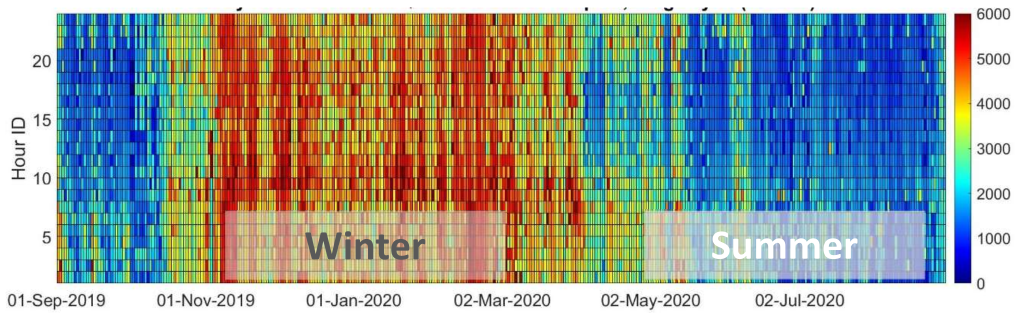
Min Demand ~ 600kWh/hr

Max Demand ~1600kWh/hr

Low Demand from 23:00-07:00

High Demand 09:00-20:00

Hourly Heat Demand (kWh/hr)

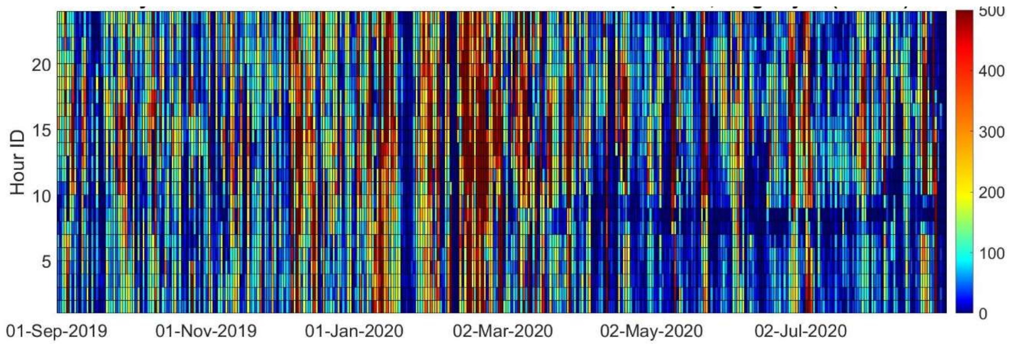


Seasonal variation

Min Demand ~ 400kWh/hr

Max Demand ~6000kWh/hr

Hourly Wind Generation (kWh/hr)



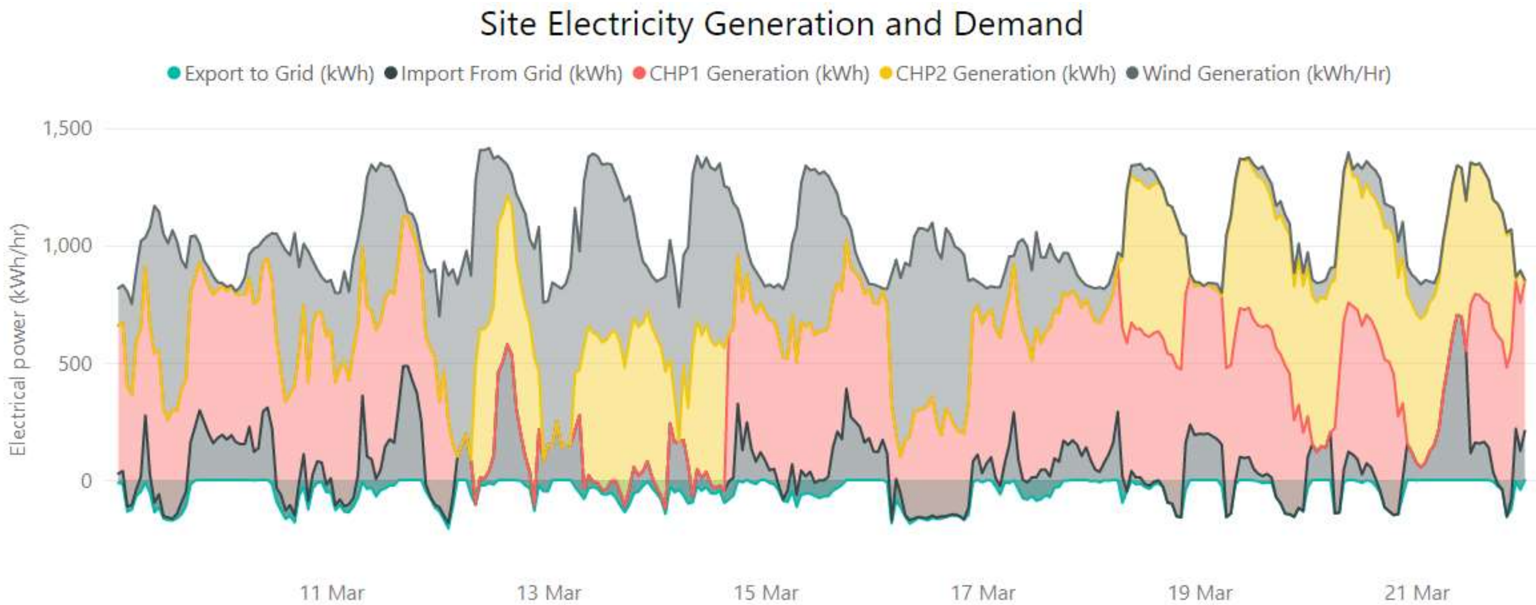
Low wind site

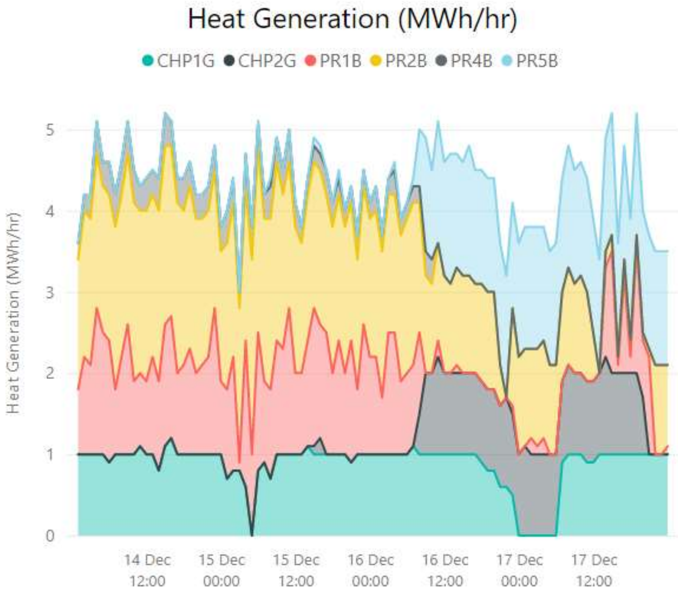
Power output <360kW 80% of the time

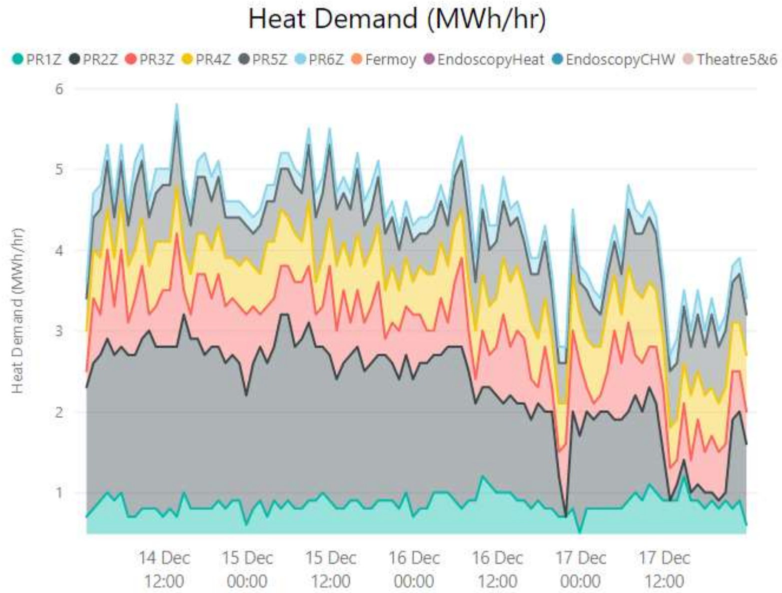
Capacity factor of 18% for this period

Irregular output

Hourly Data : 2019-Sept-1st to 2020-Aug-31st

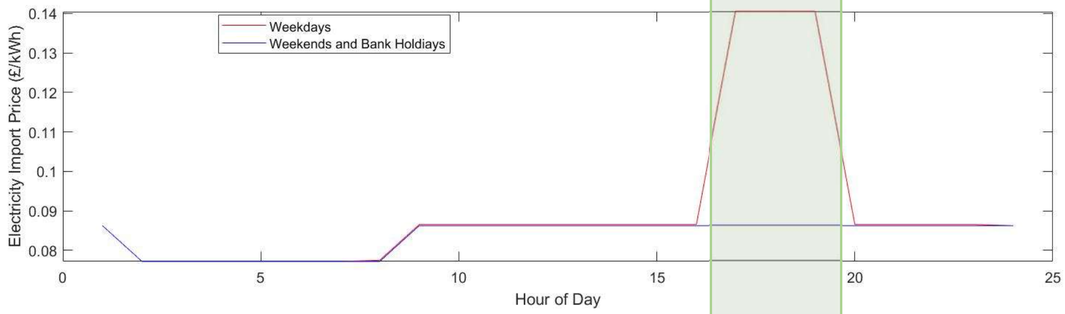

Site Electricity Generation and Demand
Export to Grid (kWh)
Import From Grid (kWh)
CHP1 Generation (kWh)
CHP2 Generation (kWh)
Wind Generation (kWh/Hr)
Electrical power (kWh/hr)
1,500
1,000
500
0
11 Mar
13 Mar
15 Mar
17 Mar
19 Mar
21 Mar


Heat Generation (MWh/hr)
CHP1G
CHP2G
PR1B
PR2B
PR4B
PR5B
Heat Generation (MWh/hr)
5
4
3
2
1
0
14 Dec 12:00
15 Dec 00:00
15 Dec 12:00
16 Dec 00:00
16 Dec 12:00
17 Dec 00:00
17 Dec 12:00


Heat Demand (MWh/hr)
PR1Z
PR2Z
PR3Z
PR4Z
PR5Z
PR6Z
Fermoy
EndoscopyHeat
EndoscopyCHW
Theatre5&6
Heat Demand (MWh/hr)
6
5
4
3
2
1
14 Dec 12:00
15 Dec 00:00
15 Dec 12:00
16 Dec 00:00
16 Dec 12:00
17 Dec 00:00
17 Dec 12:00

Understanding hourly variations in energy prices is important for site optimisation

Electricity Import Price (p/kWh)

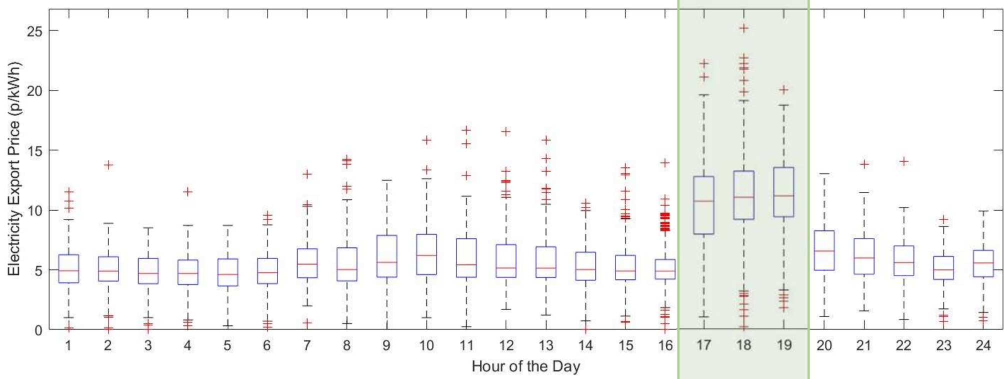


Regular Diurnal Pattern

Peak Prices 17:00-19:00 ~14p/kWh
Off peak prices ~8p/kWh

Electricity Export Price (p/kWh)

Hourly Export Price Data used in Model
2019-Sept-1st to 2020-Aug-31st



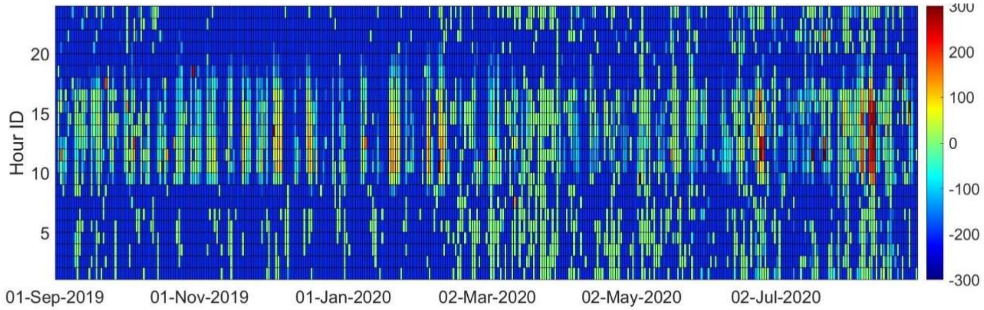
Large Variation

Associated with System Balancing Price
Peak Prices 17:00-19:00 Mean ~11p/kWh
Off peak prices ~5p/kWh

Gas Price constant at 2p/kWh

Insight 3: Cost optimal operation leads to higher utilisation of CHP generators and reduced electricity imports

Grid Electricity Import/Export (Modelled) [p/kWh]

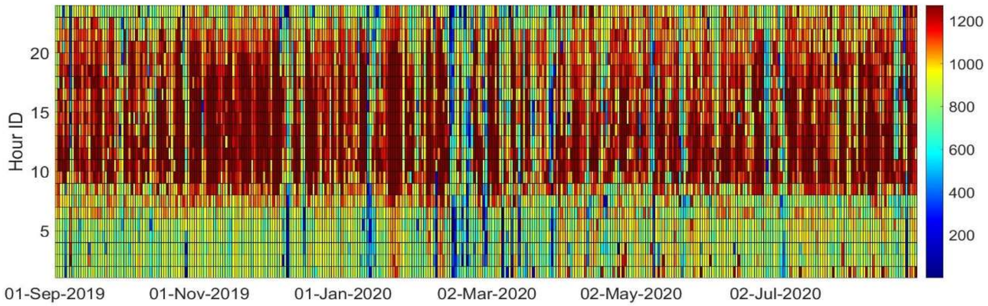


Grid Import / Export

Grid exporting majority of the time

Grid Importing during day time

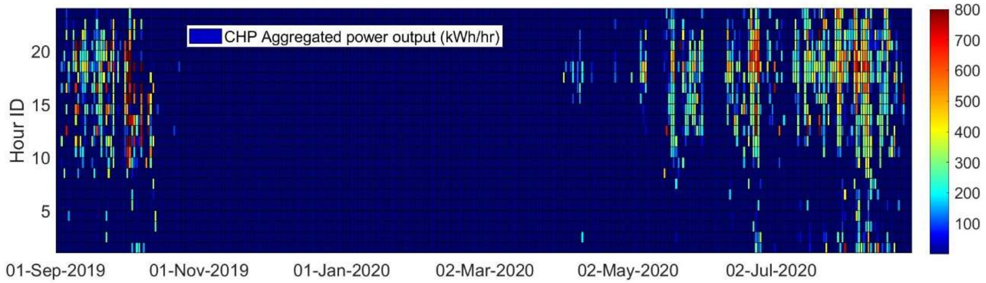
CHP operation (Modelled) [kWh/hr]



CHP unit operation

CHP units in full power output during majority of day time

Wasted Heat (Modelled) [kWh/hr]

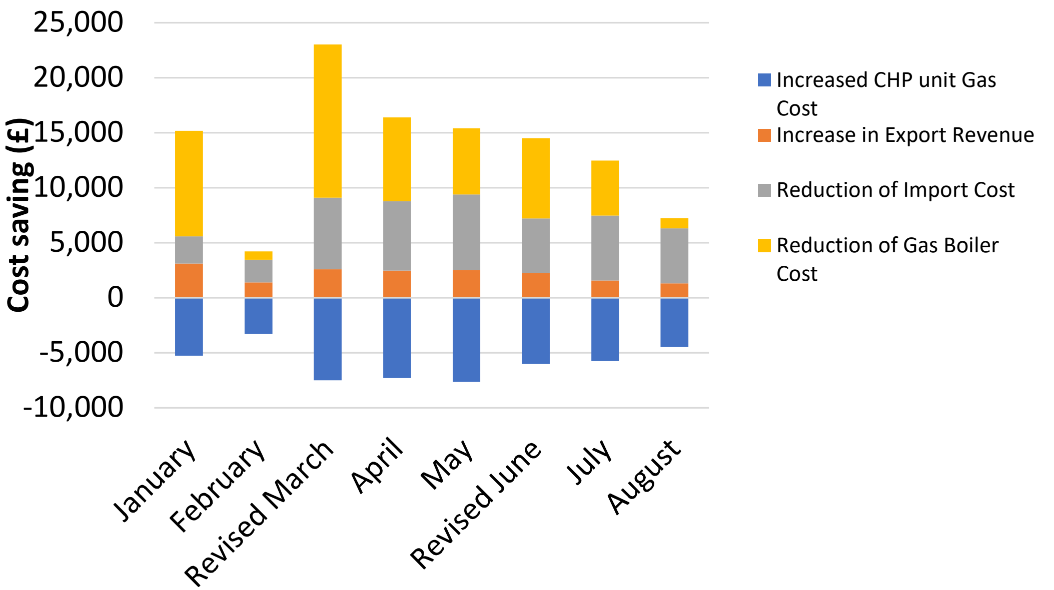


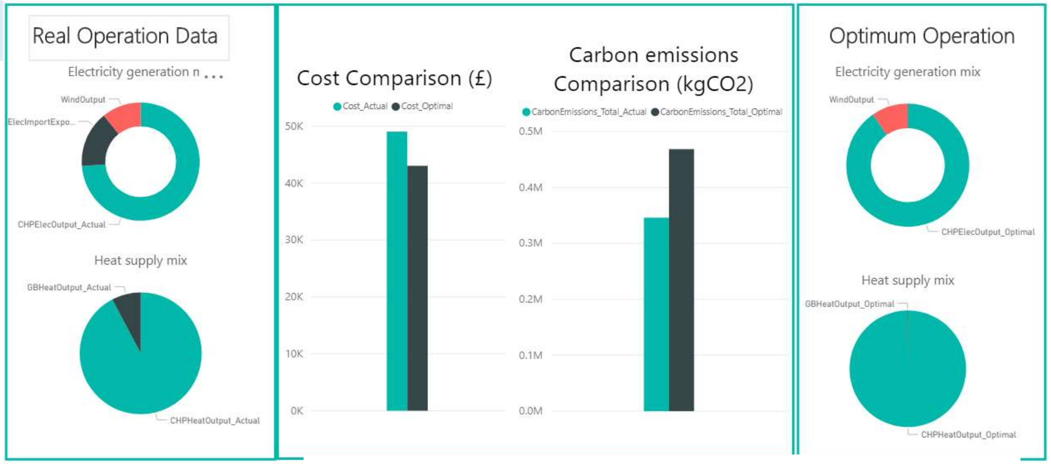
Excess heat

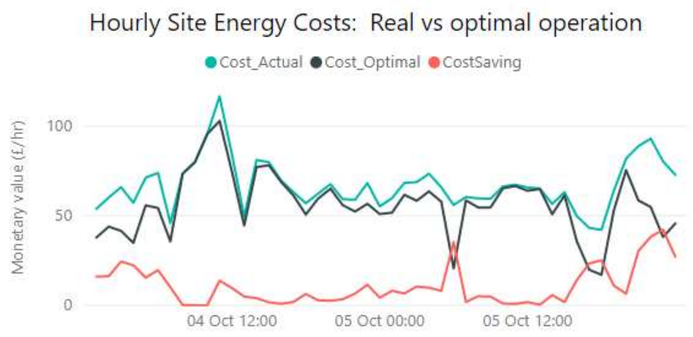
Heat dump during warmer periods as its economical to run the CHP

Insight 4: Cost savings ~12% available from operation optimisation but will lead to higher carbon emissions

Monthly cost savings at QEH







Cost Comparison (£)

Cost_Actual	Cost_Optimal	CostSaving
3,222.13	2,704.08	518.04

- Reduction of electricity import costs (grey bars in chart above) make up 50% of electricity cost savings
- Increases in export revenue (orange bars in chart above) make up 20% of cost savings

Key take away messages

- Public sector facing significant challenges to deliver Net-Zero ambitions
- Accessible, user-friendly ‘Decision support tools’ are required to support public sector energy managers
- Good quality energy data collection and analysis essential in decision support
- Dichotomy between cost saving and carbon savings for public sector sites due to relatively low natural gas prices

Outline – 20min presentation

1. Net Zero 2050 challenge – 1 slide
2. Public sector challenge – 1 slide
3. Workshop findings – 1 slide
4. Complexity for a public sector campus – 1 slide
5. Decision support tool – 1 slide
6. Research projects – 1 slide
7. Case study sites – 1 slide
8. Methodology – 1 slide
9. Decision support tool overview – 1 slide
10. Historical data analysis – 1 slides
11. Operation savings – 1 slide
12. Flexibility –
13. Key messages –
14. Planning

Cost and Emissions of Flexibility from CHP generators in Campus

Heat system state	Electricity System State	Upward flexibility		Downward flexibility	
		Availability	Cost | CO2	Availability	Cost | CO2
Summer conditions	Low demand (night time)	Yes		No	-
	High demand (day time)	Yes	-7p +480gCO2	Yes	
Winter conditions	Low demand (night time)	Yes	-4p +680gCO2	Yes	+4p -580gCO2
	High demand (day time)	No	-10p +180gCO2	Yes	+7p -354gCO2

+10p -454gCO2

Flexibility cost: *Green indicates a negative cost where the provision of flexibility reduces overall energy costs for the site owner, Red indicates a positive cost where the provision of flexibility will increase the overall energy costs for the site owner*

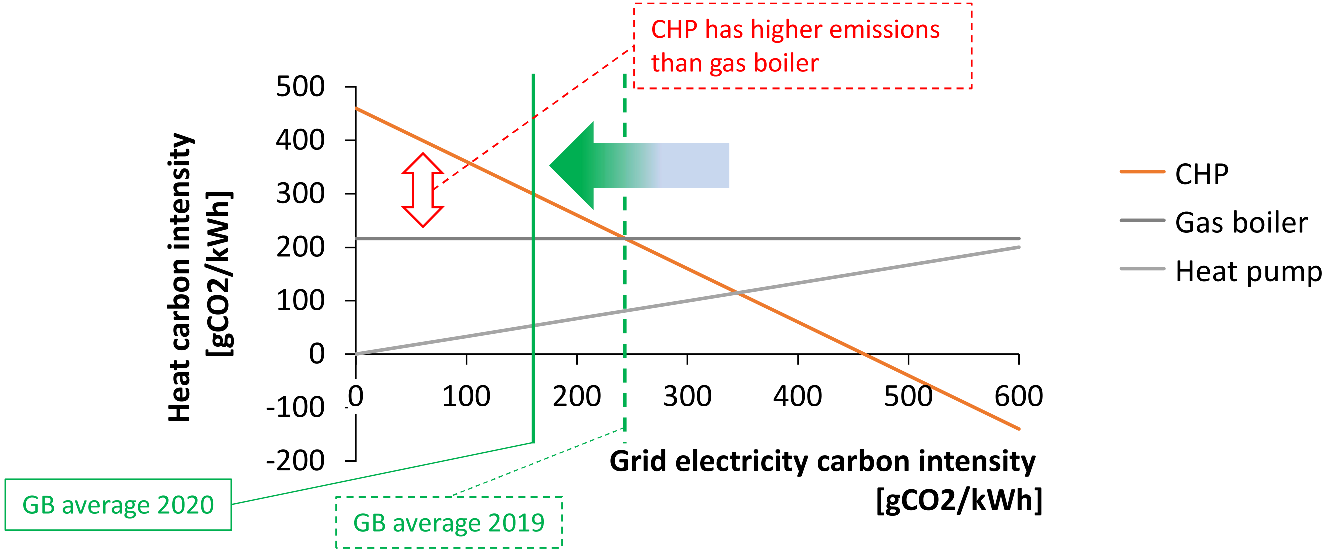
On-site carbon emissions associated with flexibility provision: *Green indicates reduced carbon emissions where the provision of flexibility reduces overall carbon emissions for the site owner, Red indicates positive carbon emissions where the provision of flexibility will increase the overall carbon emissions for the site owner*

Summary findings:
Modes of LES operation (QEH site – Export of electricity and the use of CHP constrained)

Heat Demand ↑	Night time	Day time	
Heat system requires gas boiler operation	**A** CHP Upward Flexibility available Upward Flexibility save costs Increased site carbon emissions from Upward Flexibility (~380gCO2/kWh)	**C** CHP downward Flexibility available Downward Flexibility at a high cost Reduced Site Carbon from Downward Flexibility (<400gCO2/kWh)	Warm periods
Excess heat available	**B** CHP Upward Flexibility available Upward Flexibility save costs Carbon intensity of Upward Flexibility (~680gCO2/kWh)	**D** CHP downward flexibility available Downward Flexibility at a low cost Reduced Site Carbon Emissions from Downward Flexibility (<600gCO2/kWh)	Cold periods
	Electricity Exporting	Electricity Importing	

Electricity Demand →

CHPs are likely to be exchanged for lower carbon alternatives in the next 5-10 years



- Heat generated from a **CHP** plant fuelled by natural gas has **lower carbon intensity than** that from a **gas boiler**, if the **electricity it displaces** (from the public electricity grid) has high carbon intensity
- With **reducing carbon intensity of the displaced electricity**, the **carbon intensity of** heat generated by **CHP increases**. At power grid carbon intensities below 240 gCO2/kWh, heat generated from CHP produces more emissions than heat from gas boilers.
- **Increasing decarbonisation of power** grids therefore **reduces the carbon benefits of** CHPs (cp. above figure[1]).

1) Adapted from DECC, 2015, *Assessment of the Costs, Performance, and Characteristics of UK Heat Networks*; cp. Also https://www.cibsejournal.com/cpd/modules/2021-01-gdhv/

Ongoing Research

Research Questions:

a) What is the roadmap and investments required to achieve emission reduction commitments in campus energy systems?

b) How would the campus energy system's techno-economic-emissions behaviour change with the new system configuration?

Development of the decision tool

CESI stage2 project

1

Mathematical modelling to quantify POTENTIAL cost/carbon/energy saving opportunities

+

2

'Digital twins' of campus multi-energy systems for non-intrusive testing of new control strategies

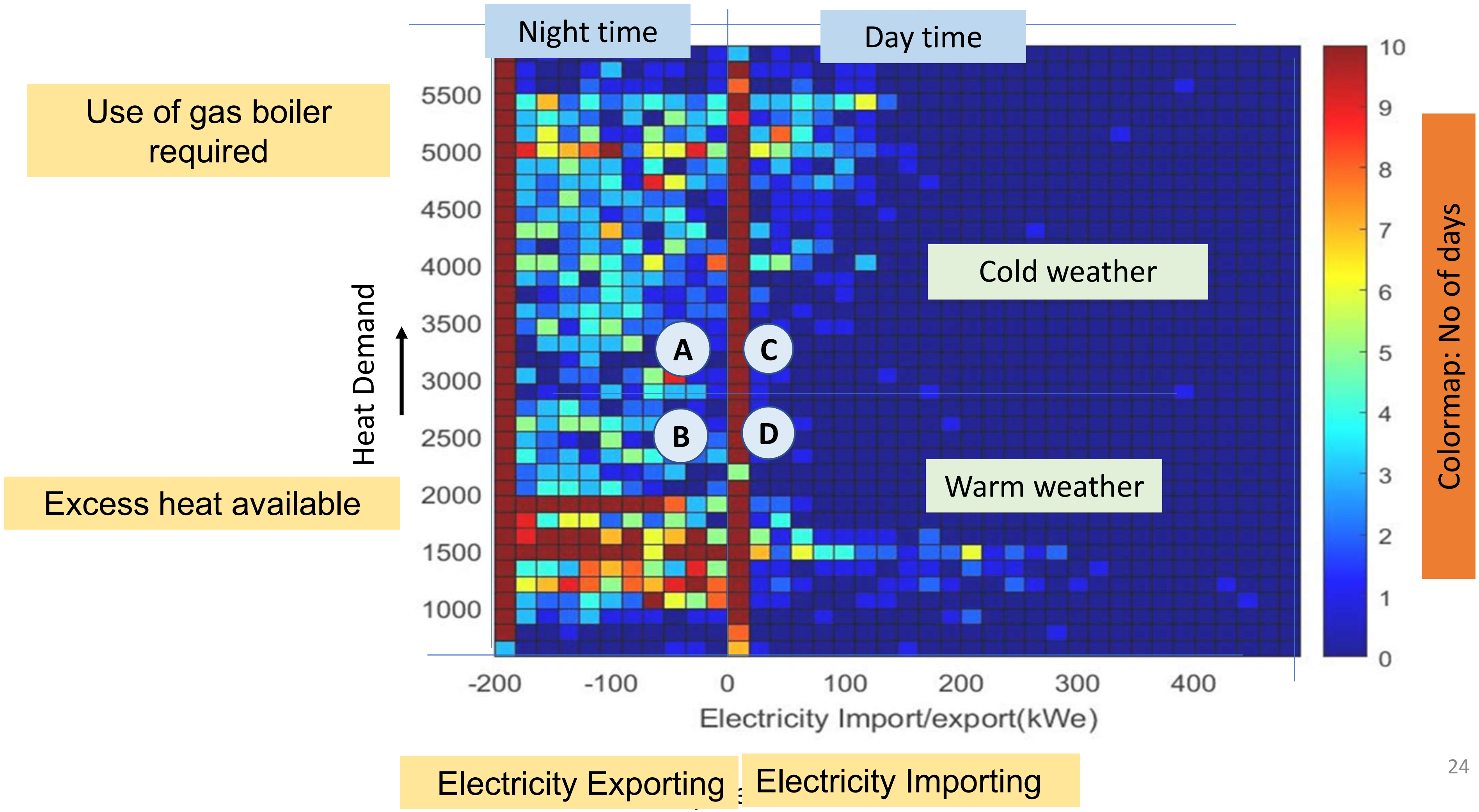
→

3

Improve control rules of BEMSs' based on modelling/optimisation and forecasting tools for real site operation optimisation + 'Hardware in the loop test bed'

Methods/tools to improve real-time operation of public sector multi-energy systems

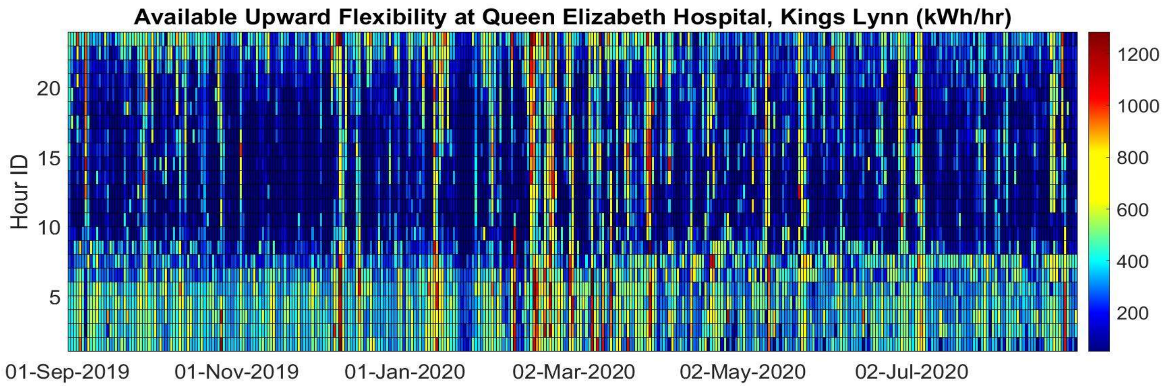
Summary findings:
Modes of LES operation (QEH site – Export of electricity and the use of CHP constrained)



Characterisation of Grid Edge Flexibility

Available CHP Upward Flexibility [kWh/hr]

Available during night time
<u>**Not**</u> available during day time



Available CHP Downward Flexibility [kWh/hr]

Available through out year
More availability during day time