Techno-Economic Analysis of Small Scale CCHP Systems Focused on Emissions Performance

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Outline

- Distributed generation (DG) and combined cooling, heating and power (CCHP)
- Air quality and implication of CCHPs in urban areas
- How to account for emissions impact on health and environment?
- Micro gas turbines (MGTs) perfromance compared to a reciprocating gas engine– *A case study*
- Concluding remarks

Distributed Generation (DG)

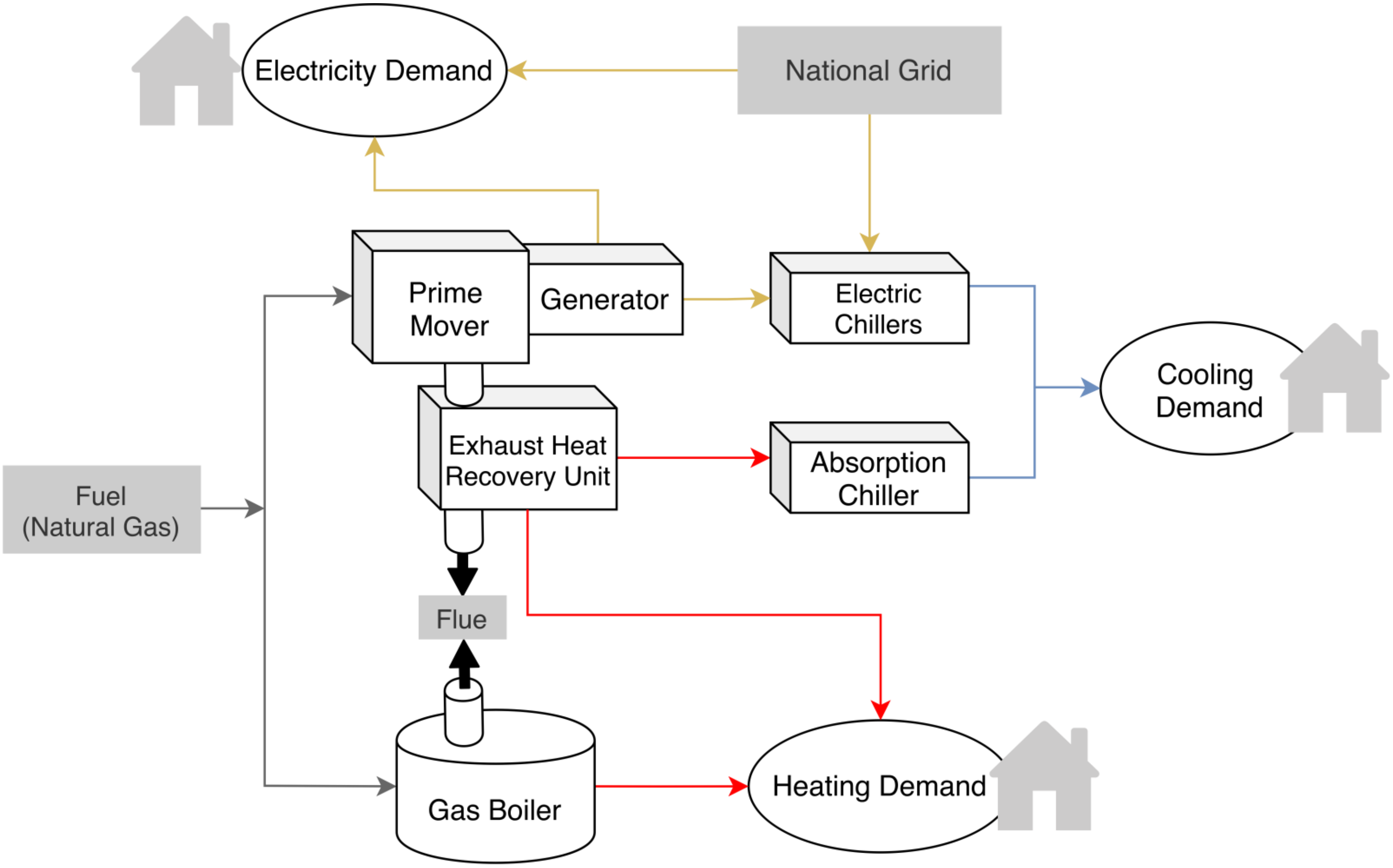
Generation directly connected to distribution network rather than transmission network

Some benefits:

- Significant reduction in transmission losses
- Reduced infrastructure costs
- Improved fuel efficency
  - ~80% compared to ~50% for centralised
  - Hence reduced emissions

Combined Cooling, Heating and Power (CCHP)

A process where electricity and heat are produced from one single energy source



CCHP Schematic

CCHP Incentives

The CHP Quality Assurance Programme (CHPQAP) is a government voluntary initiative that promotes a better application of CHP in the UK, eligible CHPs can benefit from:

- **Climate Change Levy (CCL):** A qualifying CCHP system is exempt from paying CCL on electricity and fuel used on-site. (HMRC, 2016).
- **Carbon Price Floor (CPF):** Good Quality CHP are exempt from paying Carbon Price Support (CPS). (DBEIS, 2019)
- **Business Rating Exemption:** Businesses containing a CHP scheme that is fully or partially qualified as Good Quality are exempt from paying the rate associated with such generation plant. (DBEIS, 2019).
- **Enhanced Capital Allowance (ECA):** Entitles an investor to fully claim the first-year tax relief on qualifying energy-efficient technologies. (HMRC, 2019)

Micro-Gas Turbines (MGTs)

Advantages:

- Magnetic bearings
  - Avoids lubricating oil
- Fuel flexibility
- Modularity
  - Improved operational strategy
- Few moving parts
  - Low noise and vibrations
  - Less maintenance
    - Lower costs
    - Higher availablity

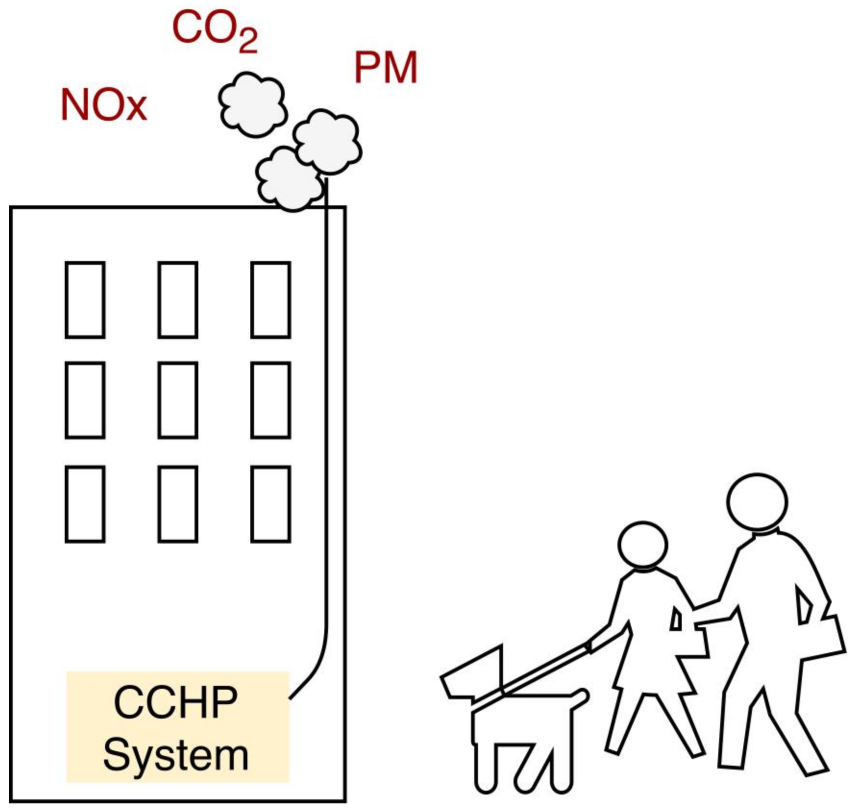
Disadvantages:

- High capital cost
- Low electrical efficiency
  - However recent technological advances have increased electrical efficiency of MGTs

CCHPs for Urban Application

Pollutant concentration in the air is higher close to the source of emissions

- Generation close to the end consumer inevitably inccurs risk of direct inhalation of noxius gases
- Environmental and health implications should be carfeully studied before selecting a prime mover for a CCHP



Health and Environmental Impact

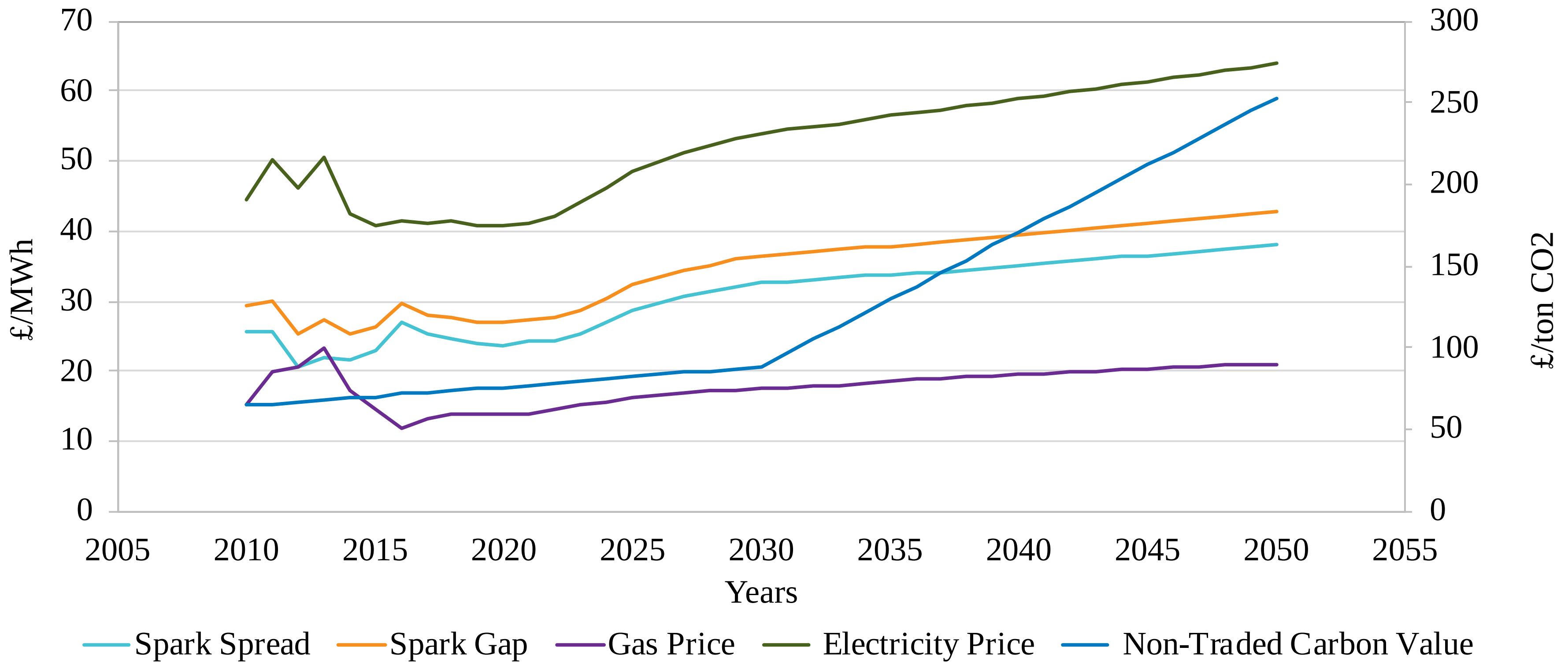
- **Particulate matter:** fine particulate matter can easily penetrate lung tissue and enter the bloodstream
- **Nitrogen Oxides:** proven to cause inflammation of the respiratory airways and a decrease in pulmonary function
  - The government has publicly announced intent in reducing NOx emissions with respect to 2005 baseline by 55% by 2020, upgrading to a 73% reduction by 2030 (DEFRA, 2019)
- **Greenhouse Gases:** cause greenhouse effect ultimately leading to global warming
  - On June 2019, the UK government became the first major economy to sign legislation for a net-zero greenhouse gas emission target
- **Used Engine Oil:** Used engine oil has devastating effects on the environment, a single litre can contaminate up to 1 million litres of water (DG ENV, 2021)

Assessment Methods

- Spark spread model to assess CCHP feasibility up to 2050
- Case study in urban application
  - We analysed replacing the current system with micro gas turbines
  - Electricity and natural gas cost comparison during operation
  - Discounted Payback Period and Net Present Value for three different emission monetization scenarios

Spark Spread Model

- Simultaneous assessment of electricty and gas prices
  - Electricity is projected to increase at a higher rate than natural gas
- Carbon value allows giving a monetary value to CO_2 emissions
  - Carbon value trend shows a steep increase from 2030



The Case Study
City, University of London

- Located in central London
- Current system: 772 KW_e CCHP reciprocating natural gas engine that powers 3 main buildings of the university campus
  - Denoted as GE System

Electrical Output KW_e	772
Heat Output KW_{th}	834
Prime Mover's Availability	92%
Electrical Efficiency at design load	41%
Absorption Chiller Power KW_{th}	540
Absorption Chiller Efficiency	70%
Electrical Chiller COP	4.0
Gas Boiler Efficiency	70%
NOx Emissions Factor g/kWh_e	0.8
Oil Consumption g/kWh_e	0.3

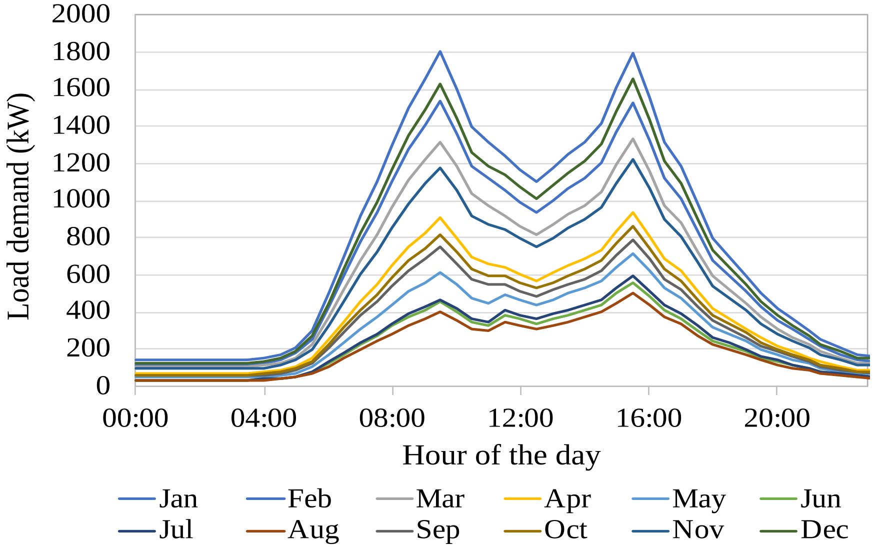
The Sytems Studied

We analysed replacing the current system’s prime mover with micro gas turbines:

- System 1 has a 400KW_e MGT
- System 2 has two mdoules of the MGT used in system 1, increasing its operational strategy and availability
- System 3 has 3 modules of a different MGT from systems 1 and 2, adding up to a similar heat output as the GE system

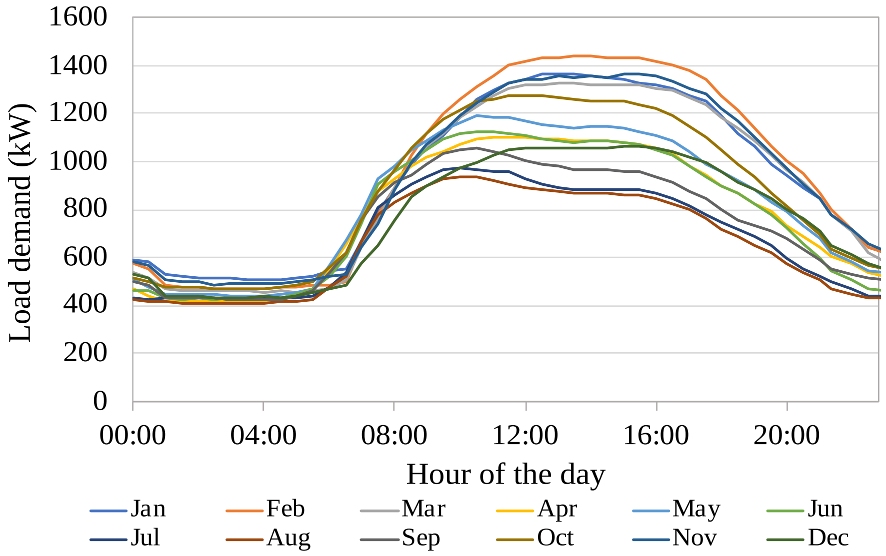
System	GE	1	2	3
Electrical Output KW_e	772	400	800	570
Heat Output KW_{th}	834	600	1200	860
Prime Mover’s Availability	92%	97%	98%	98%
Electrical Efficiency at design load	41%	40.2%	40.2%	33%
Absorption Chiller Power KW_{th}	540	400	800	540
Absorption Chiller Efficiency	70%	70%	70%	70%
Electrical Chiller COP	4.0	4.0	4.0	4.0
Gas Boiler Efficiency	70%	70%	70%	70%
NOx Emissions Factor g/kWh_e	0.8	0.3	0.3	0.223
Oil Consumption g/kWh_e	0.3	-	-	-

Demand Profiles

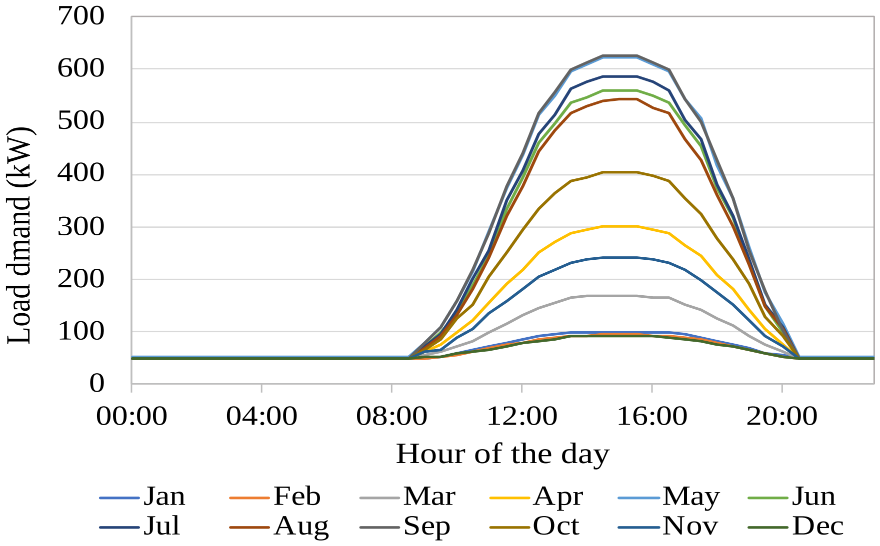


Electricity

Heating



Cooling

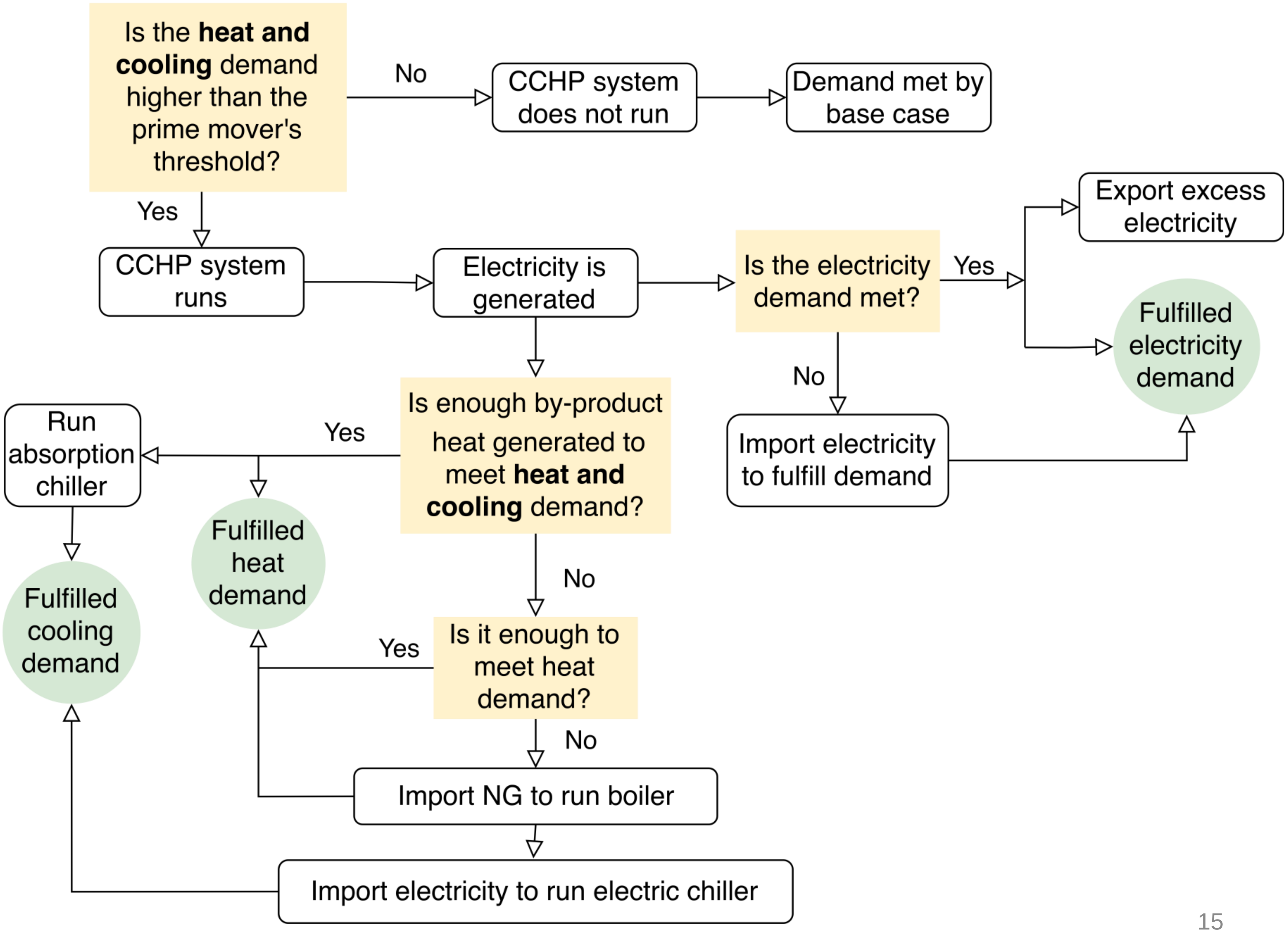


Importance of modularity!

The Model
Operational Strategy

- Driven by the heat and cooling demand
- Operating threshold defined by part-load efficiency of prime mover
  - Modularity is taken into account, where the modules can run at different loads
- Base case refers to importing electricity from the National Grid to meet electricity and cooling demand and import natural gas to run gas boilers for meeting the heat demand

Operational Strategy

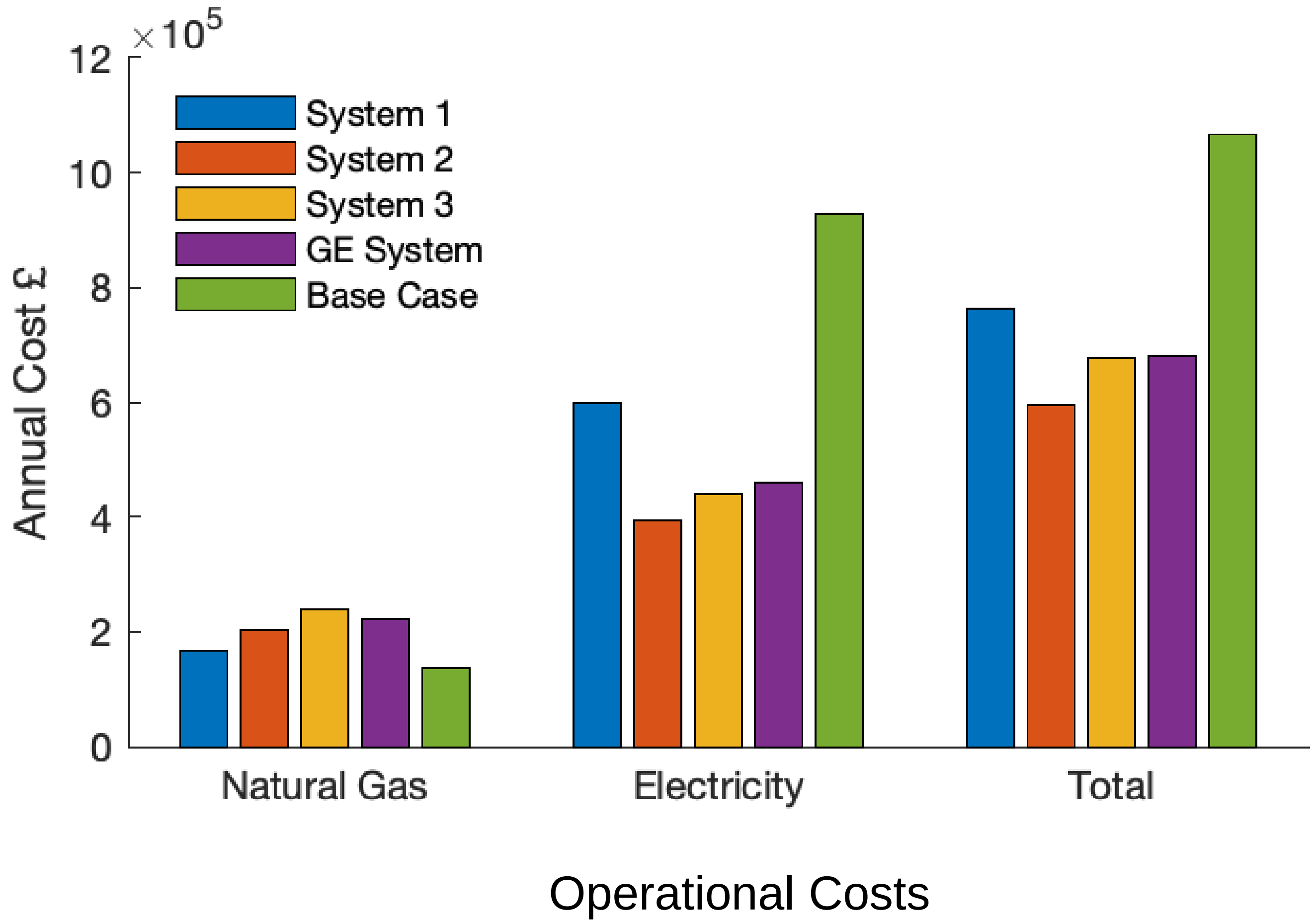


The Model
Economic model

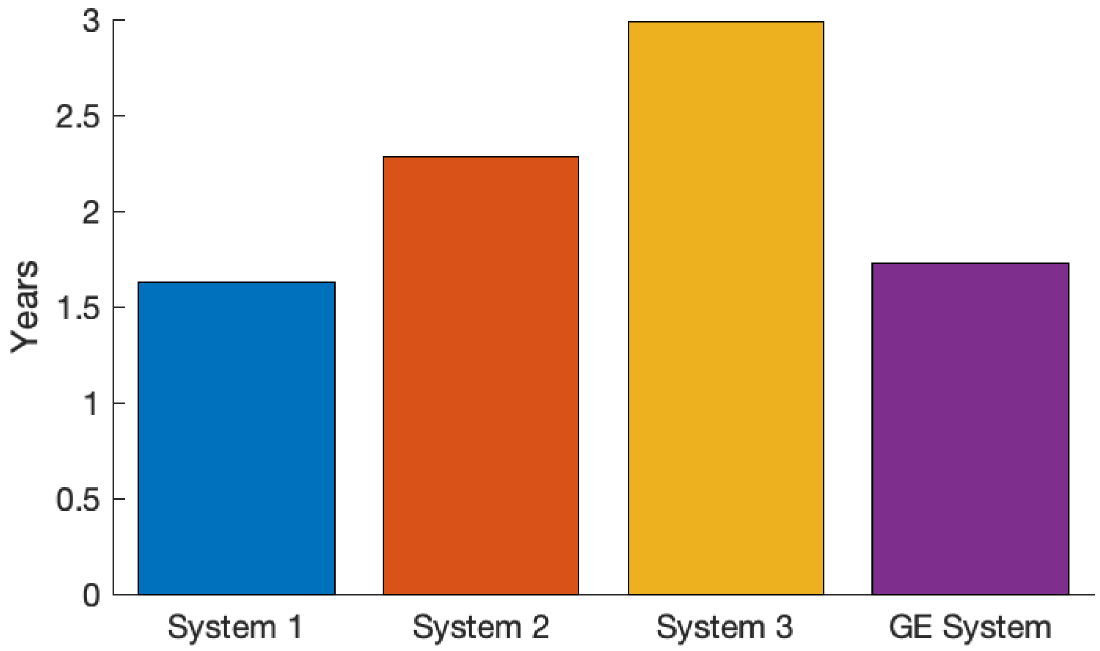
- CAPEX
- Maintenance costs
- Discount rate of 6% to acount for depreciation of money and materials
- Electricity price at 14.16 p/KWh
- Natural gas price at 2.11 p/KWh
- Excess electricty was exported at 5.38 p/KWh
- Carbon value for non-traded setor at £77/ton of CO_2
- NOx emissions valuation at £100,000/ton for inner London case

Results

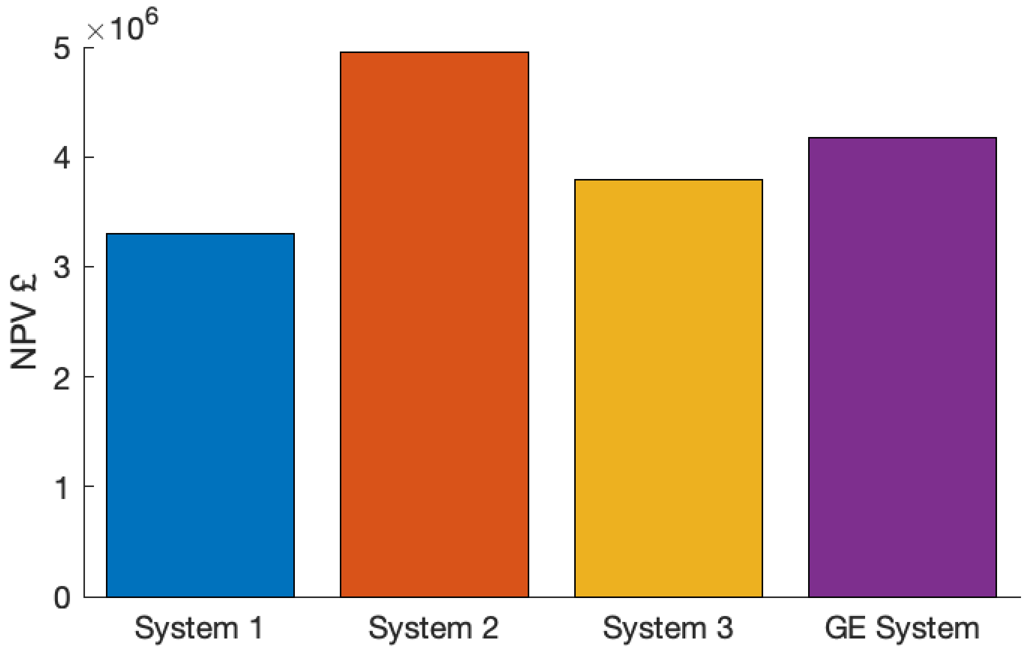
- Operational Costs
  - Costs of electricity and natural gas for running the different systems compared against the base case
- Scenario 1: no monetization
- Scenario 2: carbon valuation
- Scenario 3: carbon valuation and NOx emissions valuation



Scenario 1: No monetization

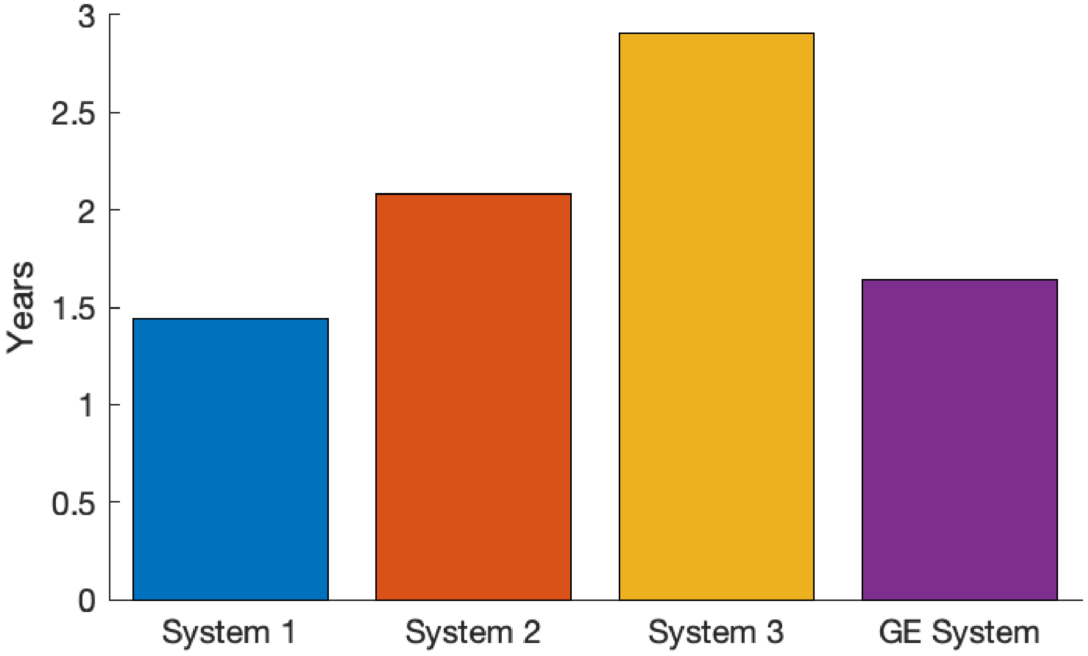


Discounted Payback Period

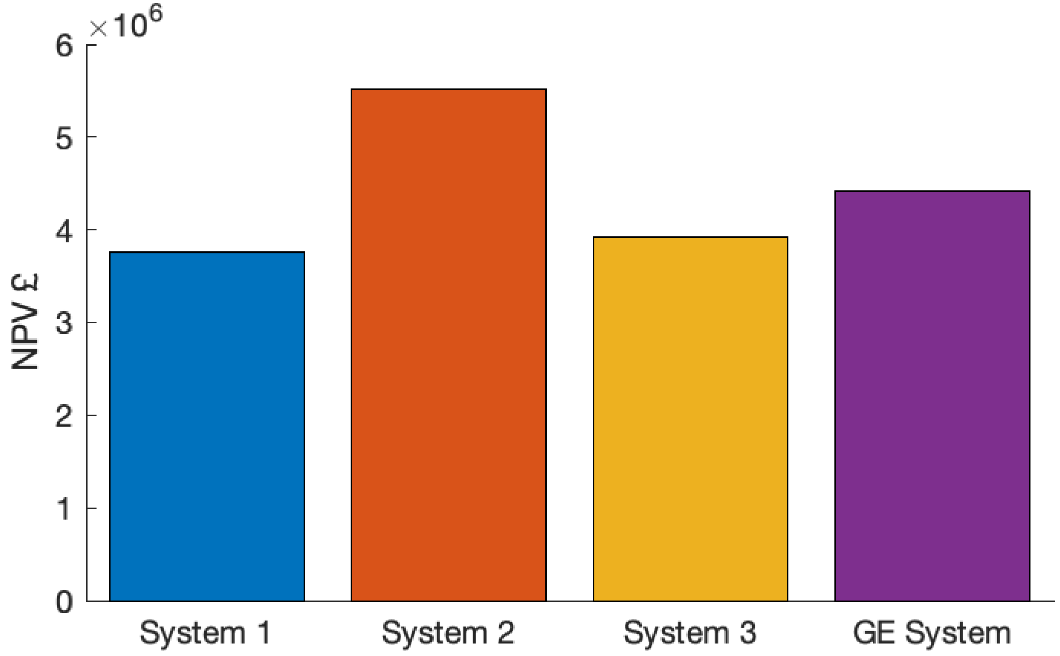


Net Present Value

Scenario 2: Carbon valuation

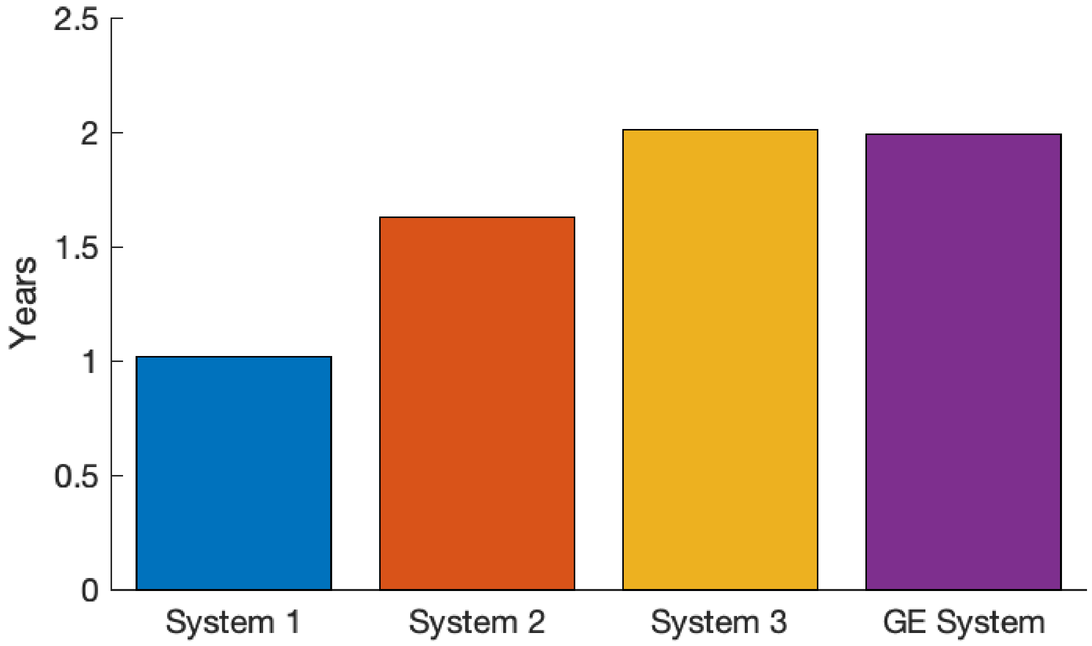


Discounted Payback Period

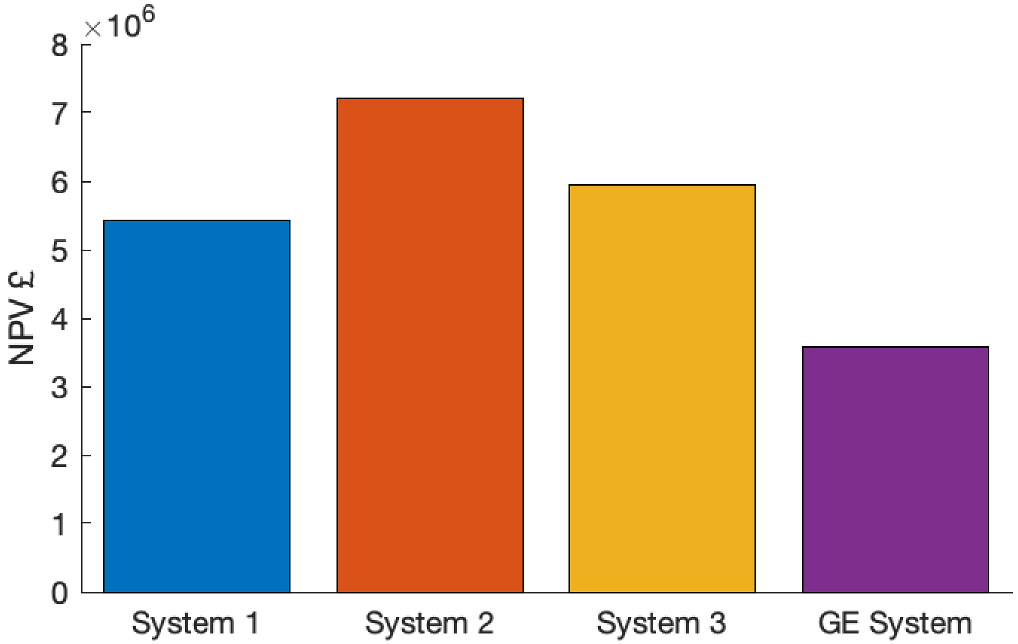


Net Present Value

Scenario 3: Carbon and NOx Valuation



Discounted Payback Period



Net Present Value

Conclusions

- The modularity of the MGTs allows optimized sizing of the system and improved operational strategy
  - Which tranlsates into lower electricty and natural gas costs during operation
- The three MGT systems studied performed better than the current GE system when emissions were considered
- System 2 performed better that the current GE system even without emissions monetization due to optimized sizing and hence lower operational costs
- The introduction of emission monetization could greatly affect the preferred choice of prime mover with reciprocating engines being the current leading option in the market

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Thank You!

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