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Biaco in the Sustainable Energy Landscape: A Comparative Analysis

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Abstract :
The UK housing market is driven by gas. In 2019, 23% of total UK CO2 emissions were from buildings, of which 17% were from homes and 4% from social housing. In addition, there is also a significant issue of fuel poverty in the UK with 3.2 million (13%) households in fuel poverty. This paper looks at the problem from the perspective of the Biaco plasma boiler. The Biaco system, is a vessel which turns water into a plasma under specific pressure conditions through the input of an electrical charge and achieves an all-year-round COP of 3.7, which can be increased to 5.1 through a proven development pathway. This heat is captured as steam and is seamlessly integrated into traditional radiator systems: hence the boiler can be introduced without requiring additional infrastructure. The study looks at the 15-year comparative performance of the Biaco system against the viable alternatives gas boilers, air and ground source heat pumps and electrical boilers. The comparison looks at the Opex and Capex requirements of all systems and discounts on those costs over the forecast period. The core conclusions are that the Biaco system compares against the known alternative in the following ways. The analysis shows economic and environmental benefits against all competing systems. The analysis indicates that the Biaco system reduces emissions by 96% compared to a gas boiler and is £900 cheaper a year than a heat pump over a fifteen-year period. Over the medium term, as more energy is produced through renewables and electricity prices are decoupled from gas then the plasma boiler will become increasingly competitive. The paper argues that the system will deliver benefits to housing providers, tenants’ and government.

JEL Codes: D61, Q53, L94

Keywords: Cost–Benefit Analysis, Air Pollution, Electric Utilities

Preface

The study was conducted by the University of Sussex Business School and the Strategia Group. The study was conducted on behalf of Biaco, a Sussex based company which has developed groundbreaking technology to use water as the primary fuel for a heating solution.

The objective of the paper is to compare the long TCO and their CO2 impact of five domestic heating solutions over a 15-year period in the social housing sector. The five solutions are

- Gas Central Heating
- Electric Central Heating
- Air Source Heat Pump
- Ground Source Heat Pump
- Biaco Plasma Boiler

The analysis is essentially a simple comparison. We have looked at the capex and opex of each system and assumed that they all are operating in the same environment, namely in an average sized flat with the same insulation levels and the same behaviour from the tenants.

The real operating environment would be more complex, and performance will be impacted by several variables. If we think of a normal bell distribution of homes and energy efficiency at one extreme there will be homes with high insulation and occupants who practice high energy efficiency behaviours at the other end of the distribution, there will be those who have poor energy efficient behaviour in poorly insulated homes.

Our analysis is focused on the centre of the distribution curve average behaviour in an average sized social housing unit. The resultant analysis should be read in the light of this assumption and limitations.

The Biaco system is a new low carbon system whose efficiency and attractiveness rest on its COP. The system has achieved at COP 6 in certain lab conditions but consistently and stably produces a COP of 3.7 with a clear development path of to 5.1, these two have been used for the main comparisons in the paper.

The analysis necessarily and particularly the cost analysis rest on both data provided by the company and secondary data. It makes various reasonable forecasting assumptions about both the price and level of consumption of heating powered by traditional fuels.

The key data provided by the company is.

- The plasma boiler has a target price to retail at a comparable installed price to a conventional gas boiler of around £4000.
- The plasma boiler will utilise single phase power and can be run from conventional domestic electricity supply.
- The system is primarily fueled using normal tap water; potentially a closed water system could be used. In this paper it is assumed the system is being fueled by tap water. There is potential for using water saving systems.
- The system operates reliably at a COP of 3.7, with a well-defined development pathway to achieve a consistent COP of 5.1. This paper presents calculations based on both COP values of 3.7 and 5.1 to show both the current performance of the Biaco system and its future potential.

The product claims are set out in Section 7 and have been provided by the company and reflect both their internal testing of the system and external verification.

The operating data has been achieved in laboratory test conditions in 2024. In 2025, a first product version of the solution will be tested in various operating conditions. This may lead to changes in some of the product design specifications to ensure that it is aligned to the requirements of a specific operating environment.

Whilst we believe the analysis is accurate based on the above data inputs, these figures may be revised once the system has been run in operating rather than laboratory environments and fresh performance data is available.

There are a few economic assumptions made in relation to fossil fuel prices and consumption. These are explicitly addressed in Section 9 and in the accompanying appendices.

1. The Challenge

The UK heating market is primarily driven by gas. Low gas prices since the 1980s and abundant domestic supply has made the UK economy dependent on gas for both electricity generation and heating.

This situation is no longer sustainable

- Net Zero Commitments require the Government and Country to reduce carbon emissions.
- Energy security issues are a concern given recent conflicts in Europe and the Middle East.
- Energy prices have been rising steadily with occasional periods of price volatility.
- High energy price increases fuel poverty and inequality which causes adverse socioeconomic impact and imposes significant economic costs on the wider economy.
- With electrification, it is critical that electrical power consumption is efficient as this will reduce pressure on, and the speed of investment required in both generation and in grid distribution.

Buildings contribute significantly to emissions

- In 2019, 23% of total CO_2 emissions (454.8 mega tons of carbon dioxide equivalent (MtCO2e)) of the UK were due to heating in buildings.
- Homes were the largest proportion, accounting for 17% of total heating emissions.
- Reducing emissions in homes is critical to achieving Net Zero targets.

Social Housing is a contributor to emissions, and where fuel poverty is concentrated.

- Social housing tenants are disproportionately impacted by rising fuel costs.
- Decarbonisation and enhancement of energy efficiency in social housing is a legislative requirement.
- Funding pressures necessitate efficient and effective use of Capex budgets.
- A comparatively old housing stock needs cost effective retrofit to meet policy goals.

Social Housing providers have been active in supporting and implementing sustainable heating solutions. However, current technologies have both benefits and limitations in relation to capital cost, operational cost and ease of operation.

This paper reviews these major socioeconomic challenges and reflects on what role the Biaco solution could play in addressing them.

2. UK Domestic Heating -The Gas Mountain

The UK domestic heating market is dominated by gas. In 2021, 74% of UK homes used gas central heating. As illustrated in the chart below only 9% of households used low carbon heating systems.

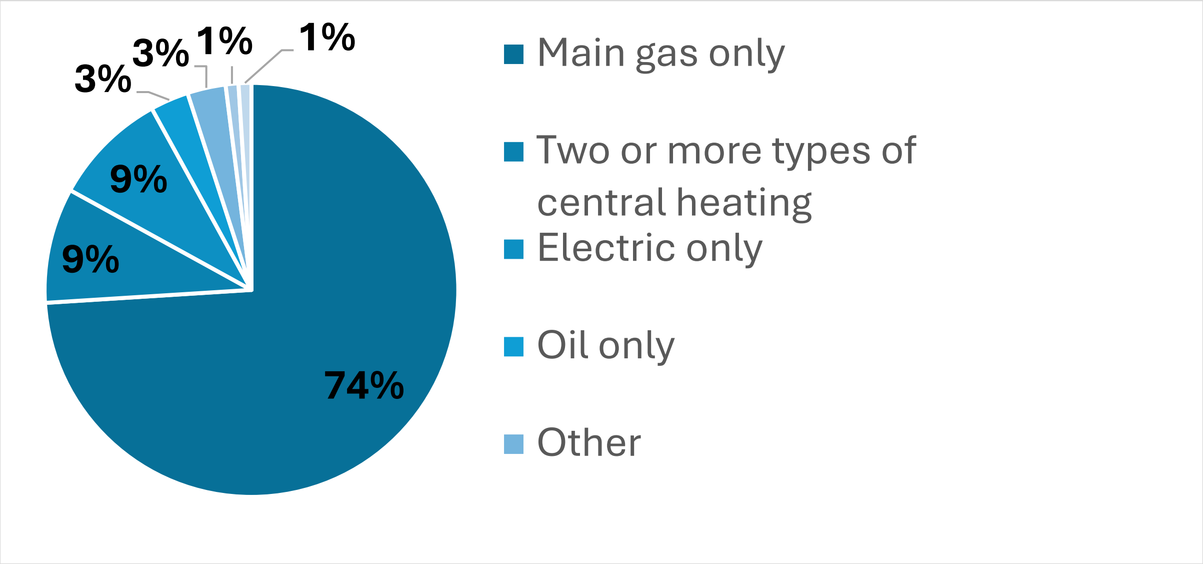


Figure 1:

In 2022, the UK consumed around 800 TWh of gas which declined from a peak of 1000 TWh in 2005. Domestic heating is the single biggest component of gas consumption in the UK. Whilst alternatives are developing for primary power generation there are currently few widely available economically viable options for domestic heating.

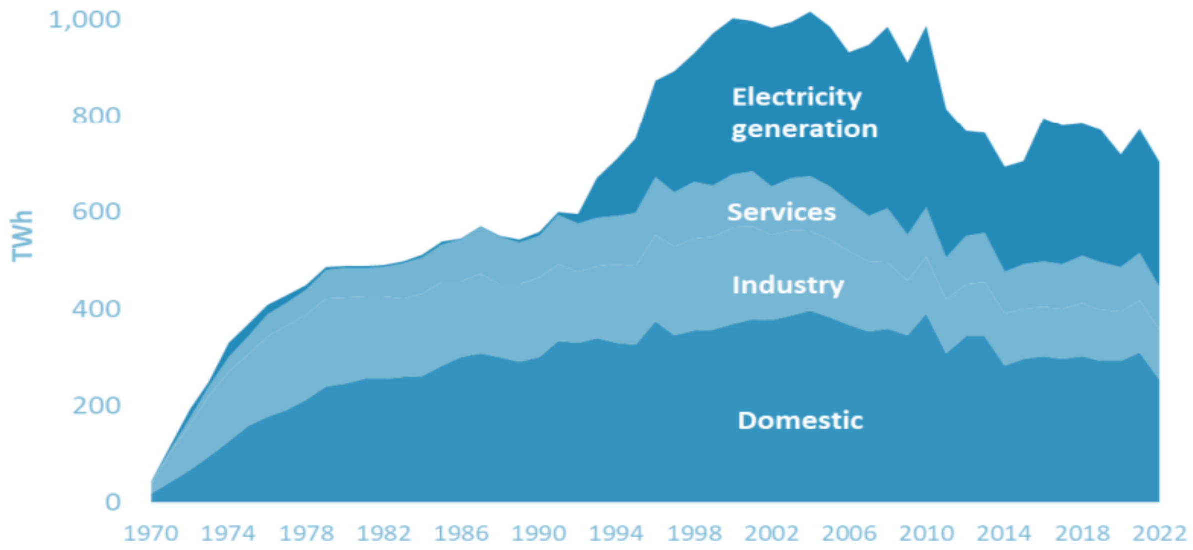


Figure 2:

- This reliance on creates several significant challenges
- Key Environmental indicators
  - 70% of UK gas consumption is used in primary heating across domestic and commercial applications.
  - Average UK annual gas consumption is estimated at 11,500 kWh for a typical household emitting 3,335kg CO2e per year.
  - Buildings account for around 23% of total greenhouse gas emissions with 17% in domestic heating of which 3.4% is produced in social housing.
  - The way in which social housing is provided means that decision structures are concentrated, and adoption could be rapid. Moving social housing to non-fossil fuel heating would have the same carbon impact as removing 7 million cars from the roads.
- Energy Security
  - With the depletion of domestic reserves, the UK has become more dependent on imported gas suppliers.

In response to these pressures

- UK government plans to phase out domestic heating through gas boilers over the medium term.

- Air Source Heat Pumps are perceived as the most viable alternative. However, they come with high capex and installation costs as additional domestic infrastructure investment is required to achieve the required heating output.
- Electrical heating whilst having a significantly lower carbon footprint is at current prices highly cost prohibitive.
- The transition towards renewable energy solutions for electricity generation is likely to have a positive impact on reducing long term prices

There is general agreement that a low cost environmentally sustainable domestic heating solution which has comparable costs to conventional gas boiler is required to meet current socio-political goals and challenges.

3. The Social Housing Sector in the UK

Social housing accounts for around 16% of housing stock in the UK, which is approximately 3.7 million homes in England.

- These are provided by Council Housing (LARP's) and Housing Association Housing (PRPs). There are 213 registered LARPs managing 1.6 million units.
- The remaining 2 million houses are managed through the 1300 Housing Association providing housing for 5 million people (Home Views, 2024).
- The sector is concentrated with 80 organisations operating, over 70% of the stock. There is a mix of profit and non-profit organisations (Hall, 2022).
- There were 63,605 affordable homes delivered in England in 2022-23, an increase of 7% compared to the previous year (Department for Levelling Up, Housing & Communities, 2023). This is the highest number of completions since 2014-15 (Greater London Authority, 2022).
- The current government has set a target of 90,000 new homes a year. Shelter has argued that this would "pay for itself in just three years with a net benefit of £37.8bn through jobs, savings to the NHS and the benefits bill" (Ministry of Housing, Communities and Local Government , 2024)
- The October 2024 budget confirms this intention with additional grants to support both new build investment and rent support to increase capital availability for new build.

The social housing stock is mixed and relatively old and small (Department for Levelling Up, Housing & Communities, 2023)**.**

- Flats account for around 45%, the majority of which are purpose-built, low-rise units. 4% are high rise flats which create affordable heating challenges.
- Houses comprise of terraces (25% of stock) and small semidetached (20% of stock).
- The housing stock is comparatively old with 60% having been built between 1945 -1980.

- Dwelling size on average is smaller than other tenure types. 64% of the stock is under 89 square meters, mainly one- and two-bedroom dwellings.

Social housing heating systems are predominantly gas.

- Most of the social housing (87% LA/80% HA) uses a gas boiler system with radiators.
- Storage heating systems account for 10 % of housing association stock and there is some limited use of communal heating systems**.**
- This represents a significant challenge in relation to conversion.

Social housing compares favorably to the private sector in terms of heating efficiency of buildings (HM Government, 2021)**.**

- 60% of socially rented homes in the UK rated EPC band C and above in 2019.
- This still means just under 1.5 million homes are rated below EPC Band C.
- The Sunak government committed to upgrading as many homes as possible to achieve EPC band C by 2035 when cost-effective, practical, and affordable. It is expected that this target will become more aggressive as part of net zero targets.
- It has been argued that upgrading remaining social rent homes to EPC A, B, or C could save residents more than £700 million a year in heating costs (National Housing Federation, 2022).

Heating is a significant cost pressure for social housing renters.

- A housing association found that 60% of tenants struggled to pay gas/heating (60%).
- When tenants were asked how they would cope with the rising costs, 37% said they were not going to use their heating at all (Department for Energy Security and Net Zero, 2023).
- Increasing energy prices have placed a huge strain on social housing tenants' finances.
- Social renters in the most inefficient homes will have to spend 15.5% of their income on heating, equivalent to two months' worth of their annual income.
- Improving energy efficiency of social housing will have a significant impact on household finances and potentially increase disposable income.

The carbon effect of heating is significant.

- In 2019, The UK produced total emissions of 454.8 mega tons of carbon dioxide equivalent (MtCO2e).
- 17% of emissions were related to heating homes, of which 3.4% was from social housing equivalent to those 12 mega tons of emissions.

There are significant regulatory pressures for change, most notably social housing must achieve an energy performance of C by 2030 and net zero by 2050.

- The Warm Homes: Social Housing Fund (WH: SHF) has supported this. Another six specific building and policy regulations are targeted at energy efficiency in social housing in both retrofit and new buildings. These pressures are likely to intensify over the next five years.
- The WH: SHF has explicitly embraced as a set of social and environmental goals as part of the scheme. These include delivering warm energy efficient homes, reducing carbon, tackling fuel poverty, supporting green jobs, developing the retrofit sector, and improving the comfort, health, and well-being of social housing tenants.
- These goals are all consistent with the Biaco heating system.

Social housing providers have been innovative in implementing energy efficient building and seeking innovative solutions.

- The focus has been on insulation and efficiency.
- Some innovations introducing heat pumps particularly in new builds, these are proving effective at reducing carbon efficiency but in the retro fit market the additional infrastructure requirements mean that Capex costs are prohibitive.

The social housing market is looking for solutions which can effectively retrofit 3.5 million homes in a way which is consistent with the ambitions of the social housing carbon fund.

4. Social Housing Fuel Cost and Household Income

Heating is a major and disproportionate expenditure for low-income households.

- Lower income households, spend a larger share of their income on utilities, particularly in an environment of rising energy costs and economic insecurity.
- In March 2024 the lowest income decile spent an estimated 9.5% of their weekly household expenses on electricity, gas, and other fuels as compared to 4.6% by the highest decile.

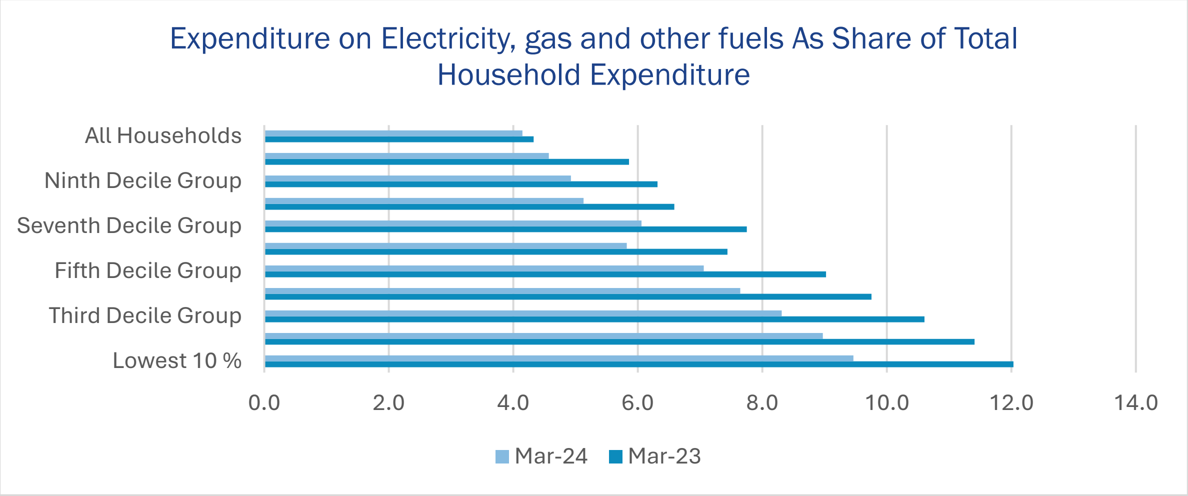


Figure 3: Source: Office for National Statistics Figures based on authors' calculations.

Energy costs have been both volatile and rising since 2020.

- Due to numerous supply chain disruptions in the energy market, particularly owing to conflict in Ukraine and the Middle East energy prices have risen drastically since 2022.
- Despite prices falling from the peak in 2022, prices are still double those of 2020
- This lowers the disposable income of low-income households'

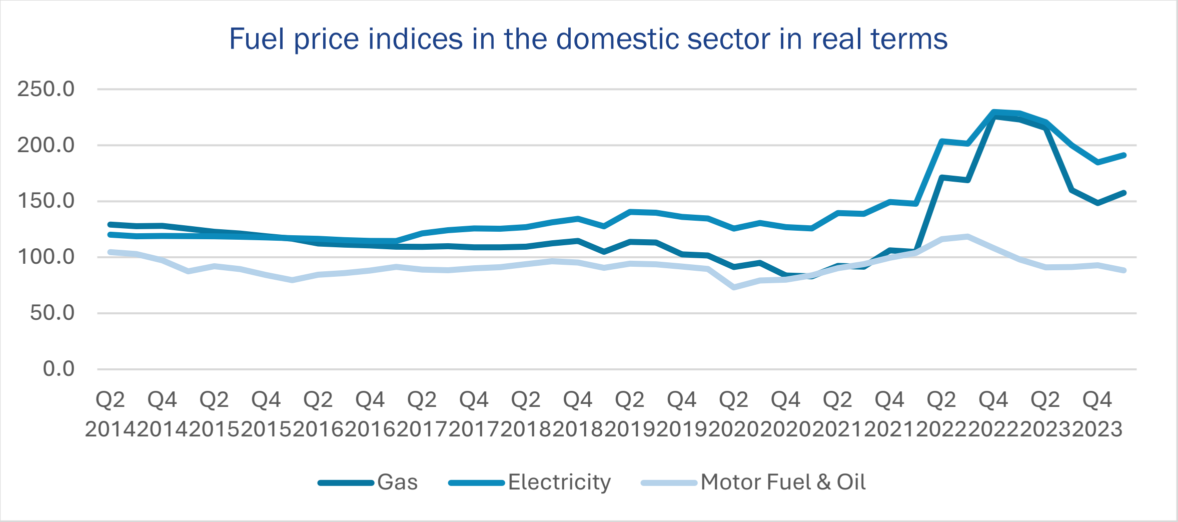
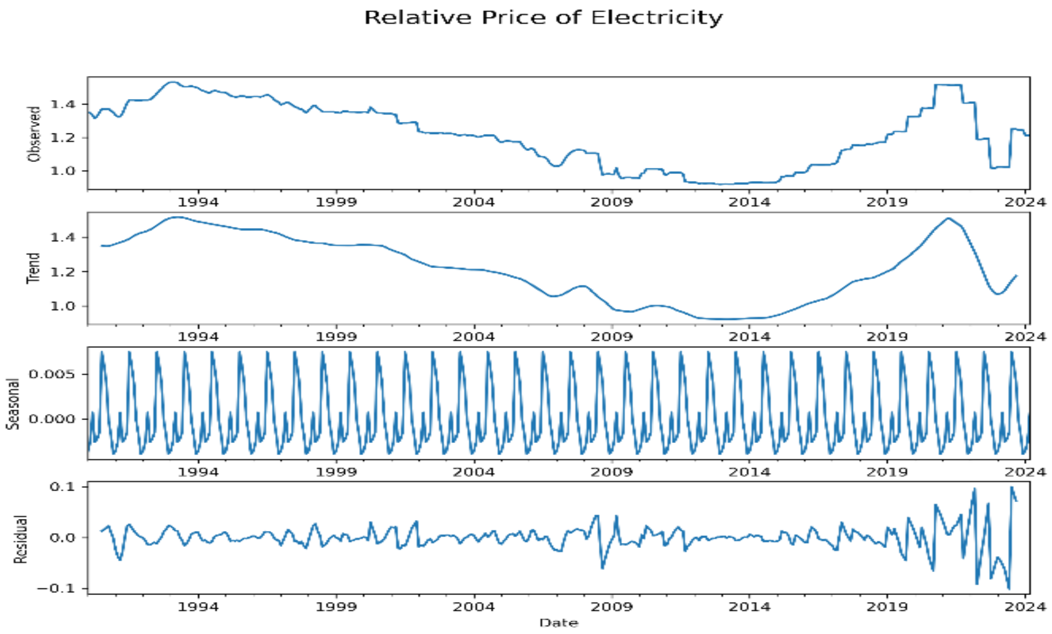
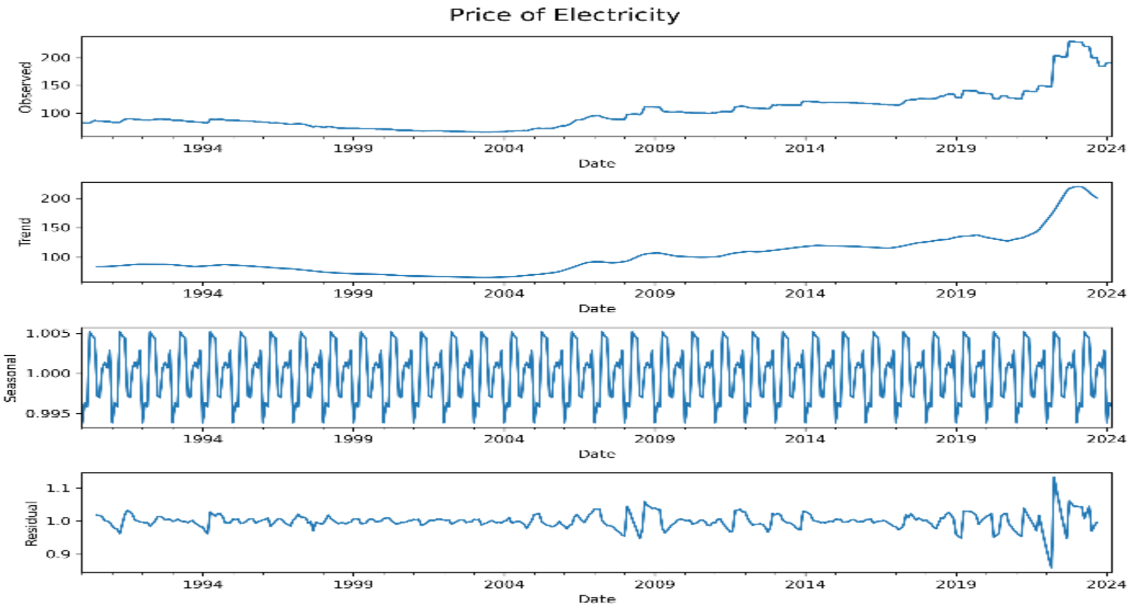


Figure 4: Source: (DESNZ, 2025)

- As the time series data in figure 4 indicates price volatility is currently the highest it has been since 1990. Electricity prices are less volatile than gas prices and they are within a range of + or-10% and 20%, respectively.
- As we argue below, volatility as well as the level of price is a key driver of fuel poverty. Therefore, moving to a fuel stock which has greater predictability will also have a positive impact. As the data shows electricity prices have had lower volatility than gas.
- Indeed, we will further demonstrate that as the proportion of electricity generated through renewables increases, the retail electricity prices fall. Consequently, a system which increases the efficiency of electricity use combined with increasing renewable energy generation has the potential to reduce long term fuel cost.



Relative Price of Electricity



Price of Electricity

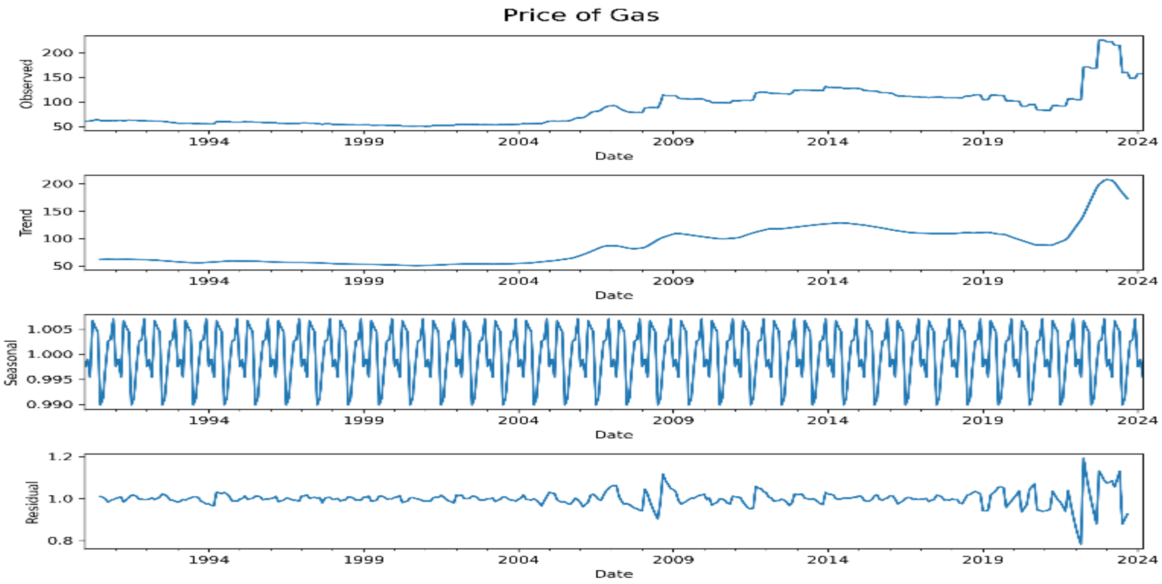


Figure 5: Time Series Decomposition of Energy Prices in the UK: Panel 1 decomposes the relative price of electricity compared to gas into its trend, seasonal, and residual components. Panel 2 and 3 break down the prices of electricity and gas respectively.

Energy price shocks significantly affect household finances,

- Demand for energy is inelastic in the short run, forcing families to accommodate shocks by reallocating spending and using limited savings for current expenditure.
- Low-income families are spending double the proportion of their income on utilities compared to medium income families, Therefore, price shocks have a particularly severe impact on living standards and disposable income. This is illustrated by the fact that in the euro area the reduction in savings due to higher energy bill is about five or six times greater for households in the lowest quintile of the income distribution relative to those in the top quintile (Battistini, et al., 2022).
- Unpredictable price spikes can lead to higher and more variable household expenses, affecting budgeting and financial stability. This price uncertainty causes energy indebtedness. This is illustrated by the fact that, energy debt, (unpaid utility bills owed by UK households to energy suppliers) is currently at a record high of £3.1 billion (Ofgem, 2024).

- Analysis by the Office for National Statistics (ONS) in 2022, reported 79% of respondents attributed the high cost of living primarily to increased gas and electricity prices. Among those who reported a rise in living costs, 32% reduced their gas and electricity consumption. More than half (53%) indicated they were curtailing their expenditures on non-essential items, and a quarter (26%) resorted to using their savings (Figueira, et al., 2022).
- Reducing energy bills and increasing price stability would have a positive impact on consumption and saving patterns and would have positive multiplier effects in the local economy

In 2023, there were an estimated 13% of households (3.17 million) in fuel poverty in England under the Low-Income Low Energy Efficiency (LILEE) metric

- Social renters who are 16% (over 4 million households) of households in England, are one of the most vulnerable to the energy crisis, since nearly half of UK households (47%) are in the lowest income quintile (Department for Levelling Up, Housing & Communities, 2023).
- The population residing in social housing has much smaller savings than private renters. Nearly three quarters of social renters do not have any savings and only 2% had savings over £16,000 (figure 6) . This implies that most social renters are unable to utilise savings and are thus more likely to reallocate expenditure from other essentials or reduce heating consumption.
- The resultant fuel poverty can lead to significant socio-economic consequences, for instance, during the winter of 2021/22 there were 2,731 excess winter deaths in England caused by living in cold damp homes (End Fuel Poverty Coalition, 2023).

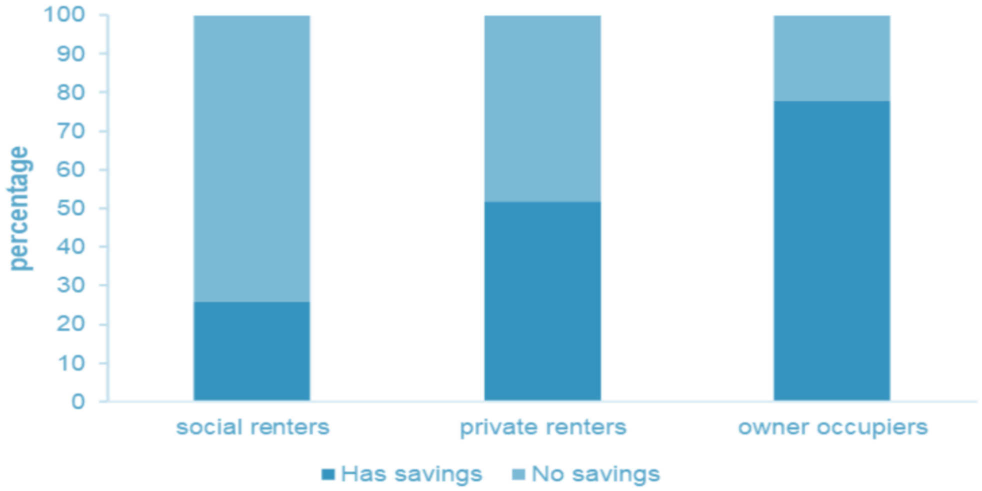


Figure 6: Presence of savings by tenure (2021-22): Source: (Department for Levelling Up, Housing & Communities, 2023)

Prepayment meters further exacerbate the problem

- This situation is made more unequal through the prevalence of prepayment meters requiring customers to limit usage to the amount already purchased with no credit facility available. This system can be particularly detrimental to low-income households.
- As of 2021 35% of social renters (1.4 million households) used a prepayment meter for electricity, and 36% (1.2 million households) used a prepayment meter for gas (DLUHC, 2022).
- This payment method can exacerbate financial strain and worsen standard of living by restricting access to essential energy, for instance, with over two million experiencing disconnection at least once a month (Citizens Advice, 2023).
- This highlights the disproportionate burden prepayment meters place on financially vulnerable groups, leading to frequent disconnections and exacerbation of energy poverty.

Summary

- The combination of high and volatile energy prices, the unequal social burden, and the challenge of 2050 Net Zero targets require all stakeholders to identify and support radical alternatives which can meet both sustainability ambitions and deliver social justice in the energy markets.
- Indeed, the ambitions of the Warm Homes: Social Housing Fund are unlikely to be met in the absence of coordinated and comprehensive innovation.

5. The Biaco Technology

Biaco Limited is a Greentech company based in Sussex. Over the last 5 years it has developed and patented, see e.g. patent GB2604853), a boiler system which utilises the gases and minerals held within aqueous solutions (such as tap water) to generate significantly more thermal energy than the electrical energy used to run and maintain the system.

This novel zero carbon energy system (boiler) utilizes a high voltage to generate a plasma that initiates an exothermic chemical reaction in the dissolved gases and salts in mains tap water.

- The reactions in the vessel are a direct result of the very particular arrangement of the electrodes and materials creating the plasma and the control system around it.
- These elements are the subject of several existing patent applications/patents in the Biaco patent portfolio, with many further filings still to come for enhancements and developments to this technology.

The system is currently undergoing further development and reliability trials at the company's site with additional work under a collaboration agreement with the University of Sussex. Publications in the next 6 months will include: -

- A peer reviewed papers on the technical observations and performance.
- A scientific publication showing chemistry and system understanding.
- Supporting papers in plasma high speed spectroscopy and visual recording studies.

Prototypes are being installed for initial demonstrations in agriculture and institutional buildings.

Primary claims of the technology

The claims either published or patented are considerable and important. The performance claims have been independently verified, some of the other potential claims are currently being verified.

"the system produces high grade thermal heat at a Coefficient of Performance (CoP) of 3.7-5.1 times the electrical energy used to create it"

- Performance of engines and similar devices such as boilers are measured by examining the CoP which is simply the energy used by the system (including all auxiliary equipment) against the energy outputted from the system.
- With the Biaco Zero Carbon Boiler energy output is steam at a temperature of greater than 104°C dependent on the pressure the system is being operated at.

Secondary Claims

- **Feedstock is an aqueous solution abundantly available such as tap water.**
    - The system runs on water, Biaco. Operational efficiency is similar with tap water (or simulated tap water) or adulterated water (with brine).
    - Without refreshing the feedstock, the reaction stops.
- **Utility of the output is very high compared to systems such as heat pumps.**
    - Heat pumps suffer from the quality of energy produced which often leads to additional equipment being used to increase heating or hot water in buildings and apartments. Biaco's energy exits the system at above 100°C under pressure which gives significant commercial advantage.
- **The system can be used to heat homes and businesses.**
    - Due to the high temperature of the steam and the pressure created the system output can be easily retrofitted into an existing heating system without additional fitments, piping etc. In 2023 Biaco successfully demonstrated that the steam output from one system heated a 90-litre water boiler to steam within 30 minutes to above operating temperature. One Zero carbon boiler produces 30kW of thermal energy which is sufficient for most UK Dwellings.
- **The operating and installed cost of the system will be the same as gas systems.**

- The CoP drives operating cost. So, to produce 4 thermal units 1 unit of electricity is needed. This is lower than the cost of gas-based systems.
- Capital cost is driven by materials and complexity. This is anticipated to fall significantly as the system moves from lab to commercial operation. No expensive or rare materials are used. The size of the system is like a gas boiler and will fit into the same space.
- Water utilised can be reused and/or recycled through the system and is insignificant in total cost.

Table 1: The potential relative performance benefits of the Biaco system

Comparison	Heat Pumps	Gas Boliers	BIACO
Coefficient Performance (Cop)	1.5-4	Less than 1	Greater than 3.7-5.1
Heat Temperature of Output	33C-55C	80C	80C

6. The Biaco System and Policy Alignment

There is a pressing need to implement zero carbon solutions for domestic and commercial heating, replacing fossil fuel powered heating appliances.

- Current developments are focused on either switching to a zero-carbon fuel, such as hydrogen, or replacement of fossil fuel-powered boilers with an electrical heating device or heat pump.
- All three approaches will have an impact on carbon emissions, electricity requirements and distribution networks to varying degrees.

A critical parameter in the use of zero carbon solutions is the conversion efficiency of the technology.

- That is its ability to create useful heat from electricity. This is important not only at a macro level in minimizing the impact and cost on both the electrical generation and distribution system, but also at a household and application level in increasing the utility of the heat produced.
- Air and ground source heat pumps are now commercially available and reduce electricity demand per unit of heat up to a factor of 1.5 to 4 in real world operation [1].
- Although a heat pump reduces the electricity demand per unit of heat, the devices are expensive relative to the incumbent fossil fuel solutions and deliver hot water at a lower temperature (40-45°C) [3] relative to a fossil fuel fired boiler (80°C). This is not an issue with a new installation as the heat distribution system can be sized to operate efficiently over the temperature range delivered by the heat pump. In a legacy installation, which is majority of the market [4], the lower temperature will either degrade performance or require costly upgrades to the heating network of the building.

A device that matches or exceeds the heat to power ratio of a heat pump and delivers hot water at the same temperature as a fuel fired boiler at competitive cost would offer an attractive solution and expedite removing carbon emissions from domestic and commercial heating [5].

Adoption of sustainable technology is high priority for the UK government, with a particular focus on achieving net-zero carbon emissions by 2050.

- Measures such as the Future Homes Standard, set to be enforced from 2025, aim to reduce carbon emissions by 75-80% by prioritising low-carbon heating and efficient insulation of homes.
- Additionally, numerous government initiatives are directed towards constructing new homes with efficient heating solutions and retrofitting existing social housing stock with more efficient systems to replace traditional boilers.

A pivotal initiative in this context is the Social Housing Decarbonisation Fund which was renamed to Warm Homes: Social Housing Fund (WH:SHF) in 2024.

- The fund seeks to upgrade social housing stock currently rated below Energy Performance Certificate (EPC) band C.
- This fund facilitates the installation of energy performance measures in social homes, thereby enhancing their energy efficiency and reducing carbon emissions (DESNZ, 2023).
- Over the past three years, the state has invested over £1 billion. There are plans to allocate an additional £1.25 billion in support of retrofitting and improving of up to 140,000 social homes (National Housing Federation, 2024).

In addition to updating heating systems, new build homes can also integrate the Biaco system.

- There has been a stated policy intention to however this target now appears that will be soften but with a continuing ambition to decarbonise and improve efficiency of domestic heating (EDF Energy, n.d.).
- With around 160,000 new houses build annually there will be a significant shift towards greener building practices.

The Biaco solution can offer an alternative to the both the safety and cost concerns of high-rise building

- As of 2017, approximately 4% of social renting is in high-rise flats (Ministry of Housing, Communities & Local Government, 2019).

- 8% of social rented households reported feeling unsafe at home due to the potential risk of fire (Department for Levelling Up, Housing & Communities, 2023).

In conclusion, the Biaco system aligns with the goals of existing government policy aimed at achieving net-zero carbon emissions and enhancing energy efficiency in social housing.

7. Heating Systems Sustainability and Comparative Costs

Introduction

The government has a clearly stated intention to improve domestic energy efficiency. However, the challenge is to design and install systems which are both practical and ideally comparable to the current domestic system.

Currently there are four broad systems in use in domestic heating.

- Gas, which is dominant, and has historically delivered relatively low heating costs but has very high carbon emissions. In recent years, it has shown extreme price volatility. In addition, there is clear policy ambition to phase out gas heating systems.
- Electrical boilers delivered low carbon emissions but at operating costs that are prohibitive at 6-times gas prices. This appears to be non-viable given the current impact of energy prices on cost of living. Electrical boilers would exacerbate fuel poverty from its current level of 15% of the population. In addition, a mass switch to electrical heating would increase pressure on grids requiring investment in grid strengthening and maintenance.
- Air source heat pumps (ASHP) are recognised to deliver lower cost heating than electricity and significantly lower carbon emissions than gas. However, their capital costs (although subsidised) are high and there is a requirement to invest in the expansion or replacement of radiators. ASHPs have significant potential in the new build market especially when integrated to solar panel systems however building complexity and space make it more challenging to adapt into the conventional social housing stock.
- Ground Source Heat Pumps (GSHP) are efficient, electricity-powered heating system and a lower-carbon alternative to boilers. They are more efficient than ASHPs, leading to reduced heating bills and lower emissions. However, GSHPs typically have capital costs that are nearly 50% higher than ASHPs. While they offer similar benefits in the new build market, GSHPs are significantly more complex to install due to the need for underground loops. This makes them a more expensive option for retrofitting market in social housing.

This chapter explores these product features and arguments in more detail.

Methodology

This section details the projected net cost savings from using the Biaco heating system compared to ASHPs, GSHPs, electric boilers and gas combi boilers from 2024 to 2040. To achieve this comparative analysis, we have developed a staged methodology which is applied to the four heating systems and then analysed under four policy and pricing scenarios.

Our modelling approach speaks to a broader literature on expenditure forecasting. Expenditure has two components – price and demand. To forecast expenditure over a 15-year period, we individually forecast price and demand. While forecasting energy price and demand we make certain assumptions on price movement, household size, and potential policy scenarios that could influence both.

The stages of the methodology are outlined as follows:

1. The annual net savings from the Biaco system are estimated by integrating forecasts for gas prices and the renewable energy share in the UK's energy mix. These projections are based on data from the Department for Energy Security and Net Zero (DESNZ's) report, "Net Zero's Energy and Emissions Projections: 2021 to 2040."
2. To forecast electricity prices, we draw on an International Monetary Fund (IMF) working paper that uses panel data from 24 European countries observed annually over the period 2014 to 2021 (Cevik & Ninomiya, 2022). The paper concludes that a 1 percentage point increase in the renewable energy share typically reduces electricity prices by 0.6%. This relationship has been applied to the UK's renewable energy projections to estimate electricity price trends from 2024 to 2040.
3. We have then calculated the net present value (NPV) of purchasing the Biaco system relative to alternative heating systems, including both capital and operating expenses.
    a. NPV offers a comprehensive evaluation of costs and benefits over the system's lifespan while considering the time value of money.

    b. The analysis assumes that each heating unit is purchased and installed at the end of 2024, with a 15-year operational period from 2025 to 2040.

4. Based on the target go to market price of the Biaco system the analysis is based on the estimated capital cost of installing each heating system under the assumption that the Biaco system costs the same as a gas combi boiler.
5. We have then estimated the annual heating consumption and operational cost of various sizes of social housing. We have assumed that the average heating demand per household remains constant based on the house size. By considering the respective COPs for the three heating systems, we estimate the electricity consumption required to operate each one. This is then converted into monetary value using our price forecasts, reflecting the annual operating costs of each system. For the Biaco system we consider both a conservative COP of 3.7, and a target COP of 5.1
6. We then estimate emissions per kilowatt-hour (kWh) of electricity using forecasts of total emissions from UK power stations and total electricity production. This serves as a proxy for the emissions generated by the Biaco system during heating operations. For gas boilers, emissions are assumed to be 220 gCO_2eq/kWh across the forecast period, reflecting the average energy efficiency requirements for new gas boilers (Houses of Parliament, 2016).
7. Net annual cost savings and emissions reductions have been estimated for homes with 1, 2, and 3 bedrooms, with total floor areas (TFA) of 45, 69, and 100 square meters, respectively. To estimate the total electricity consumption for different heating systems, we use an annual energy demanded of 133 kWh per square meter for heating (Ovo Energy, 2024). The savings and emissions figures have been weighted based on the proportion of 1, 2, and 3-bedroom homes, which each make up approximately 30-37% of the total social housing stock, ensuring a more accurate representation of the projected benefits.

These calculation have then be applied to four scenarios which have been derived from a report by the DES

1. The first is the reference scenario, which includes policies that had been implemented by July 2022, as well as those in the final stages of planning.
2. The second scenario considers only policies that were fully implemented by July 2022.
3. Scenario three explore the impact of low fossil fuel prices
4. Scenario four explores the impact of high fossil fuel price

Finally, gas price forecasts are based on the DES's Fossil Fuel Price Assumptions 2023 final report.

- The first is a low gas price scenario where global average temperatures stabilise at a 1.5-degree increase by 2100 relative to 1990.
- The second is a realistic scenario wherein the government's current aspirational pledges are met global temperatures stabilise at 1.7 degrees Celsius by 2100 relative to 1990
- The third is a high gas price scenario wherein today's policy settings result in a 2.5-degree temperature increase by 2100 relative to 1990.

The paper now uses the methodology to analyse the comparative performance of the Biaco system against the four alternatives

The key assumed input costs are shown in the table below and is discussed in detail in appendix B. As the table illustrated from a capex perspective, we have assumed that the Biaco system can be installed at the same price as a conventional gas boiler and a considerably lower capital cost than heat pumps.

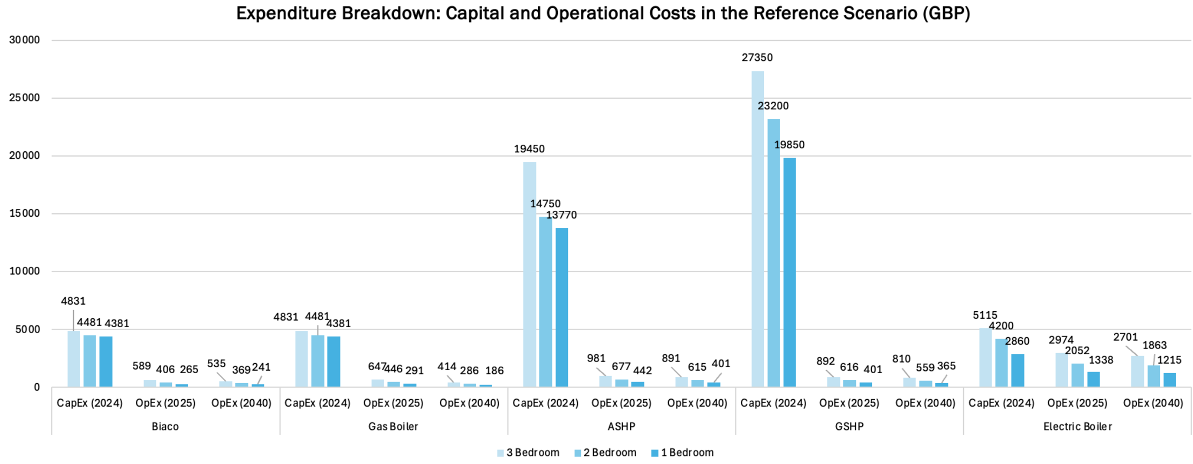


Figure 7: Source: (Delta Energy & Environment, 2018)

Gas Heating Systems compared to Biaco

When forecasting the net savings, only the reference scenario is considered for electricity prices, whereas gas prices are varied based on fossil fuel price forecasts.

When comparing the Biaco system to a gas boiler, the cost advantages are more modest due to the lower gas prices relative to electricity.

However, the benefits are sensitive to the variability of future gas price trends.

- Under a low gas price scenario, the NPV is -£2,574 and -£4,240 with a COP of 5.1 and 3.7 respectively, making the gas combi boiler the most affordable option.
- However, in the event of a high gas price future, the Biaco system's benefit become substantial, with an NPV of £3,967 and £2,318 depending on the COP (see Figure 8 & 9).
- Under the scenario of meeting the government's current aspirational targets, the cost of the Biaco system remains negative with an NPV of -£577 and -£2,250. Therefore, under a realistic scenario, the cost of using the Biaco system is more than using a gas boiler, with the extent depending on the COP.
- The base scenario shows that the Biaco system is comparable to gas in terms of opex costs, and it significantly reduces price volatility risk. Moreover, if electricity prices fall as generation

moves to renewables, then there is potential for higher operational cost savings over the medium term.

- These relationship are shown in the diagram below

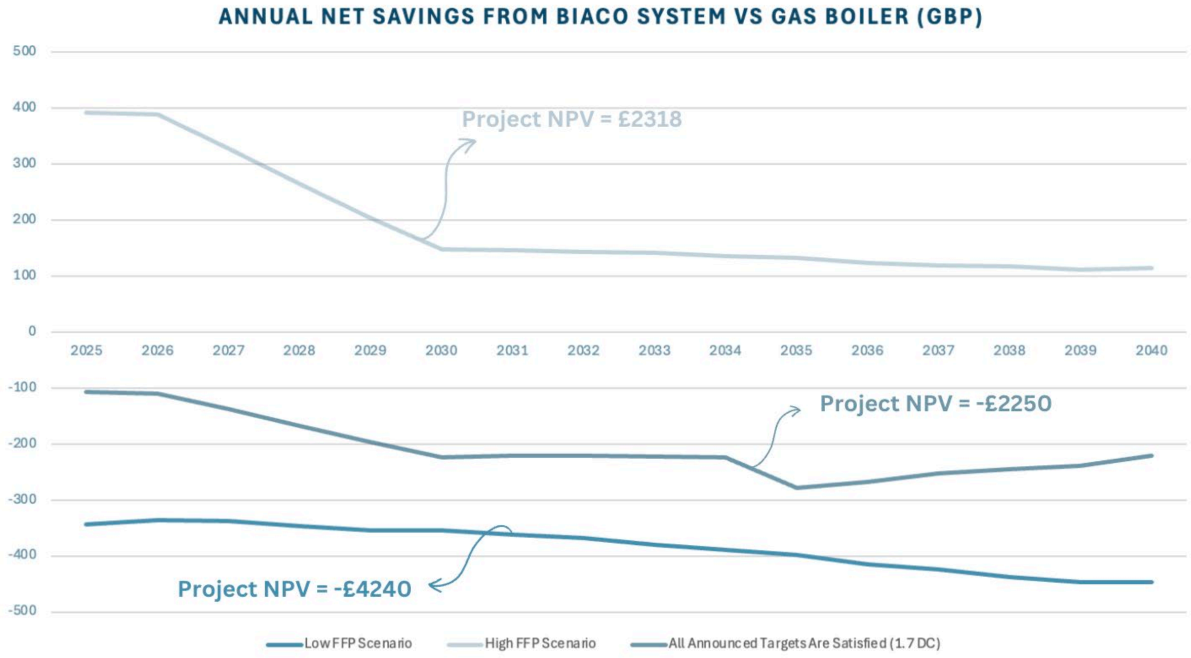


Figure 8: With Biaco System COP = 3.7

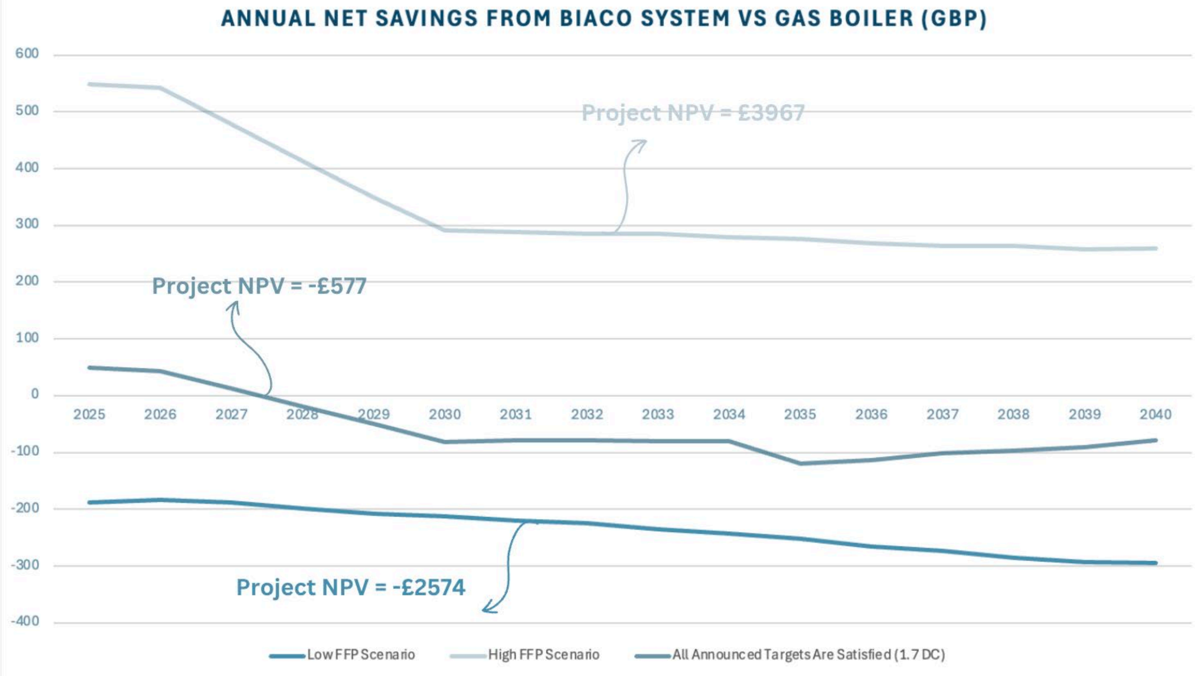


Figure 9: With Biaco System COP = 5.1

When looking at the system relative to gas boilers, the environmental benefits of the Biaco system are significantly higher.

- Over 15 years, a 2-bedroom household using the Biaco system instead of a gas boiler would avoid emitting more than 38,000 kilograms of CO_2 and on average save over 2,400 kgs in emissions each year in both the high and low COP scenario.

The table below illustrates the significant impact converting social housing to the Biaco system could have on UK carbon emissions

- If just 5% of the existing 4.2 million social housing units adopted the Biaco system instead of a gas boiler, CO_2 emissions would decrease by over 500,000 tonnes per year. This amounts to 0.17% of UKs current total emissions, this is the equivalent of over 363,000 cars taken off the road. At a 100% rate of adoption, the system would reduce approximately 3.4% of all emission which is equivalent to over 7.2 million cars taken off the road. The number would increase at a higher COP

Table 2: The table shows the potential impact of the Biaco system on CO2 emissions from social housing with 1-3 beds (96% of all social housing stock) (COP = 3.7)

Percentage Take Up	Number of Social Housing Units	Annual CO_2 Reduction (000t)	Equivalent Cars Removed p. a	% Of UK Total Emissions in 2024
5%	202,082	509	363,337	0.17
10%	404,164	1,017	726,673	0.34
25%	1,010,411	2,543	1,816,683	0.85
50%	2,020,822	5,087	3,633,367	1.70
75%	3,031,233	7,630	5,450,050	2.54
100%	4,041,644	10,173	7,266,733	3.39

The Biaco heating system is -aligned with existing sustainability measures and fits effectively within the framework of the UK government's Environmental Improvement Plan (EIP). The EIP outlines the government's strategy to enhance environmental protection and promote sustainable practices across various sectors, including energy. Overall, the system's reliance on electricity, particularly as the UK grid continues to decarbonise through increased renewable energy integration, aligns with the EIP's emphasis on clean energy transition.

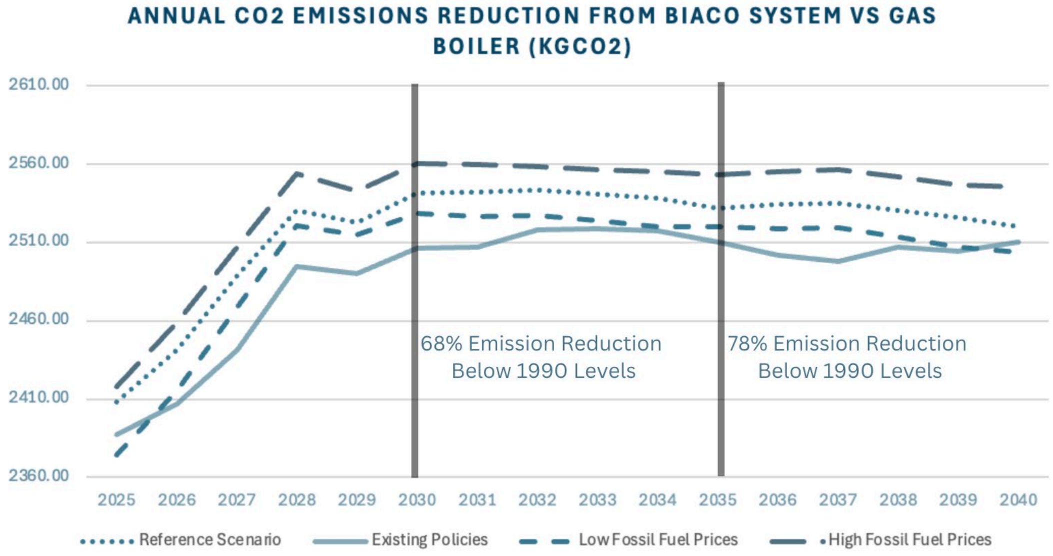


Figure 10: With Biaco System COP = 3.7

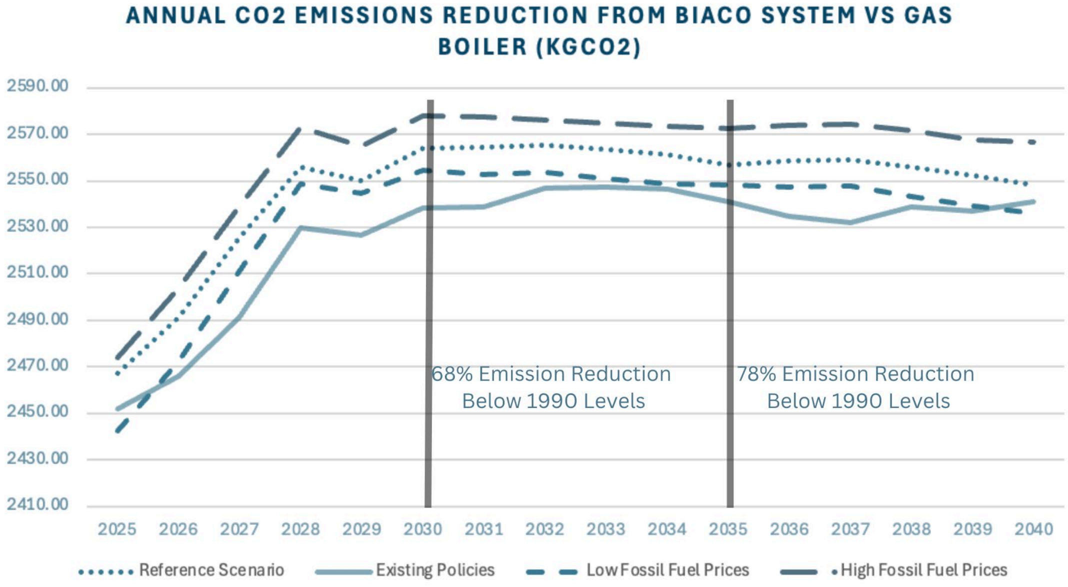


Figure 11: With Biaco System COP = 5.1

Electrical Boiler Systems Compared to Biaco

The Biaco system is considerably more efficient both in terms of cost and emissions.

- Due to the lower COP of 0.99, electric boilers are approximately 3.7 to 5 times less energy-efficient than the Biaco System, contingent on the COP.
- The capital expenditure for purchasing and installing an electric boiler system is estimated at £4,200 for a 2-bed house.
- The analysis indicates that average annual savings from using Biaco exceeds £1,400 and £1,550 annually for a COP of 3.7 and 5.1 respectively (figures 12 & 13). The NPV of net savings after accounting for capital costs, is £16,206 and £17,879 respectively under the reference scenario, with the lowest savings in the high FFP scenario.
- The Biaco system's higher efficiency results in 80.6% or 73.2% lower CO_2 emissions subject to the COP for the same amount of heat generated.

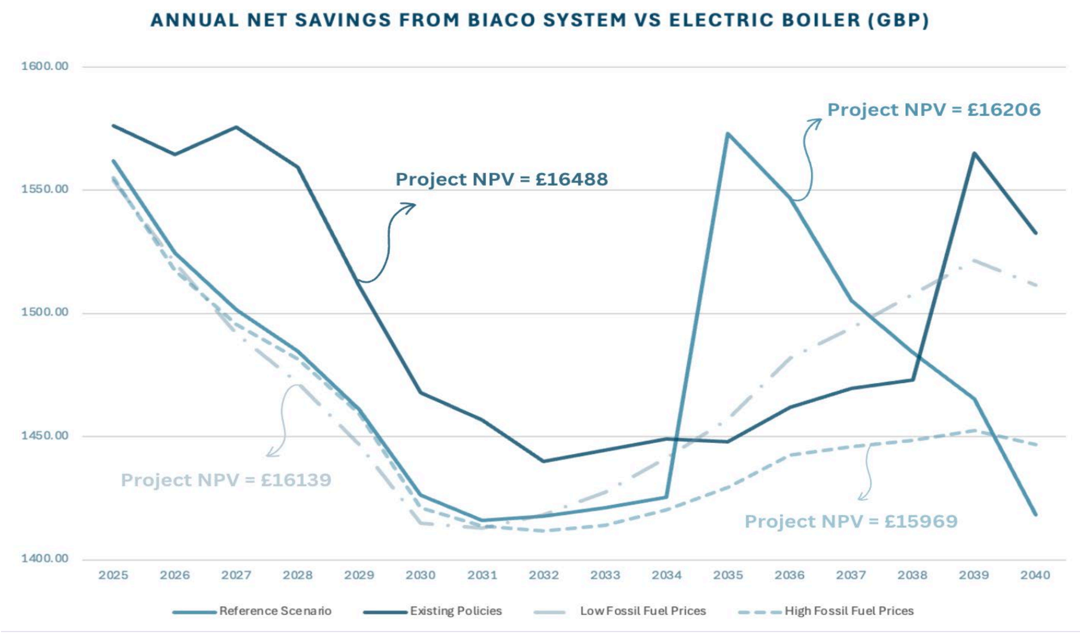


Figure 12: With Biaco System COP = 3.7

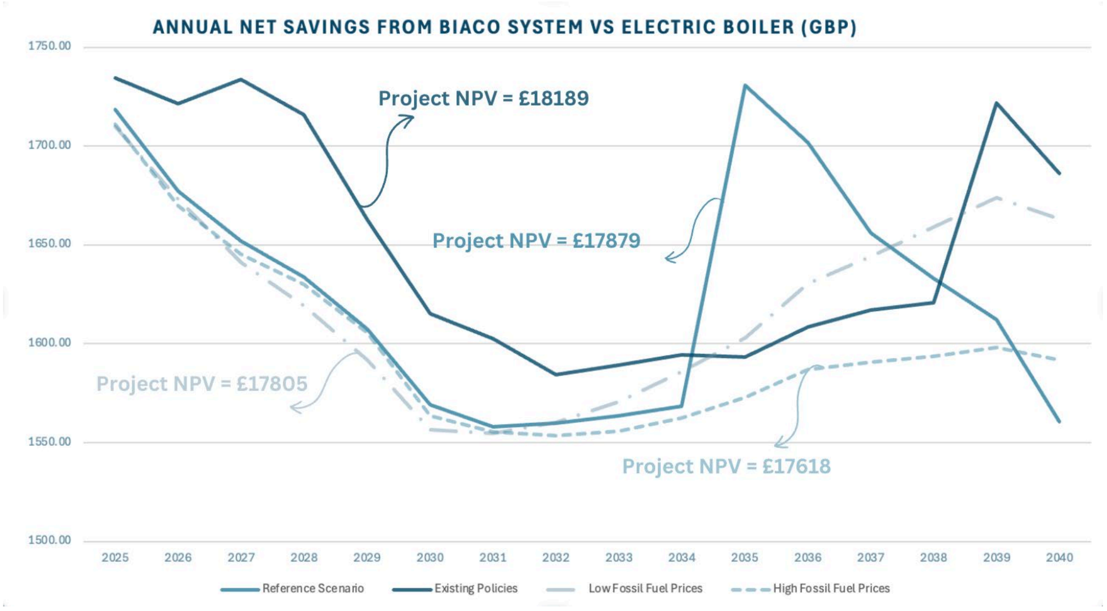


Figure 13: With Biaco System COP = 5.1

Air Source Heat Pumps Compared to Biaco

On average, we estimate that the Biaco system is significantly more cost-effective to install and operate compared to an ASHP, with annual expenses for the Biaco system nearly half that of the ASHP. The capital expenditure for purchasing and installing an AHP is approximately £14,750, compared to around £4,400 for a gas boiler in a two-bedroom house.

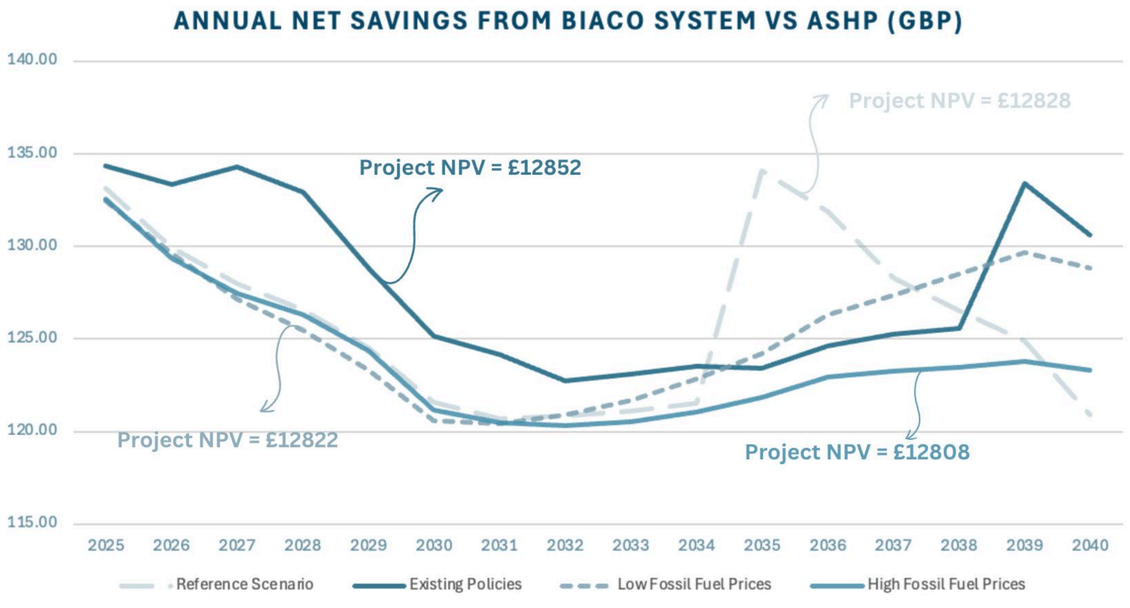


Figure 14: With Biaco System COP = 3.7

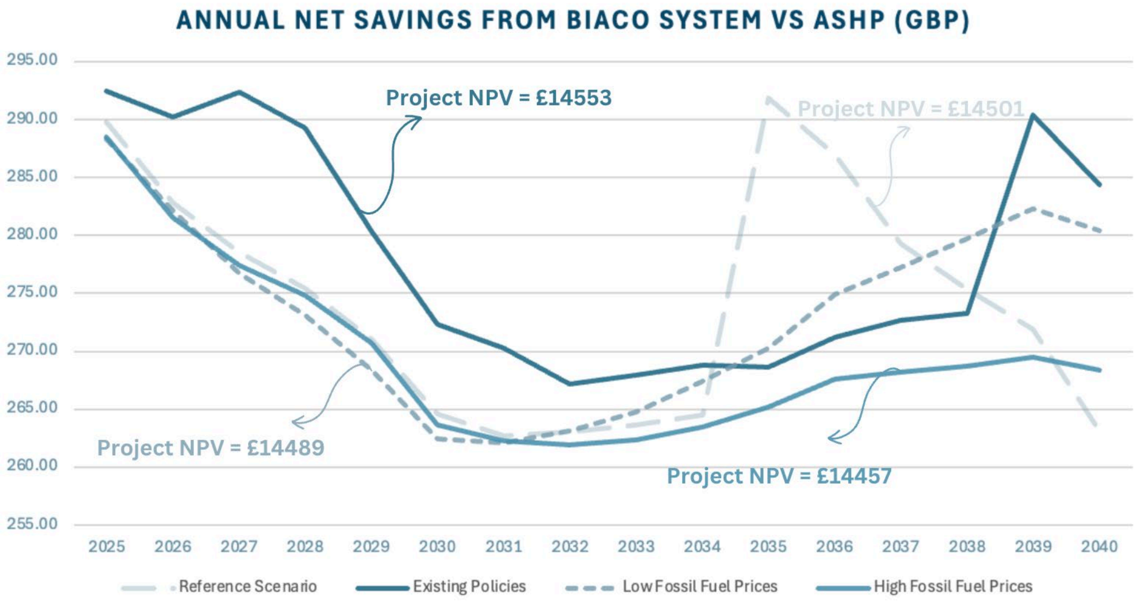


Figure 15: With Biaco System COP = 5.1

Overall, we find that the NPV of total savings from purchasing the Biaco system in 2024 and using it until 2040 is approximately £14,400 and 12,800 for COP 3.7 and COP 5.1, respectively across the scenarios (see Figures 14 & 15).

- In the reference scenario, the NPV is £14,501 and £12,828, depending on COP. In the scenario considering only existing policies, the benefits increase slightly to £14,553 & £12,852.
- From a financial perspective the reduced capital costs benefit the social landlords, enabling a more rapid conversion of property for the same capital costs.
- For tenants, the higher COP of the Biaco system create opex benefits.

The higher COP also means that Biaco performs better from an emission perspective

- Since both ASHP and the Biaco system are powered by electricity, meaning that the emissions generated per unit of electricity consumed are the same for both systems. These emissions are determined by the energy mix used in electricity generation, such as coal, natural gas, or renewable sources.

- With COP 5.1**,** Biaco operates 41% more efficiently than a standard ASHP, consuming 59% less electricity to produce the same heat. While at the current COP of 3.7, emissions are reduced by 18.9%**.**
- As a result, to meet the annual heating demand of a typical household, contingent on Biaco systems COP, it will generate 19-41% less emissions than an AHP, assuming the same electricity mix is used.

Ground Source Heat Pumps Compared to Biaco

- The results for GSHPs are comparable to that of ASHPs, but the annual net savings from the Biaco system are slightly lower due to GSHPs higher COP of 3.3, which reduces operating costs. In all scenarios, the NPV exceeds £19,600 or £21,600 depending on Biaco's COP, with only marginal variation across scenarios. While GSHPs offer higher efficiency than ASHPs, the Biaco system still generates significant savings largely due to the higher capital costs associated with the installation of GSHPs. Moreover, the Biaco system delivers the same amount of heat while reducing CO_2 emissions by approximately 11-35% (based on final COP).

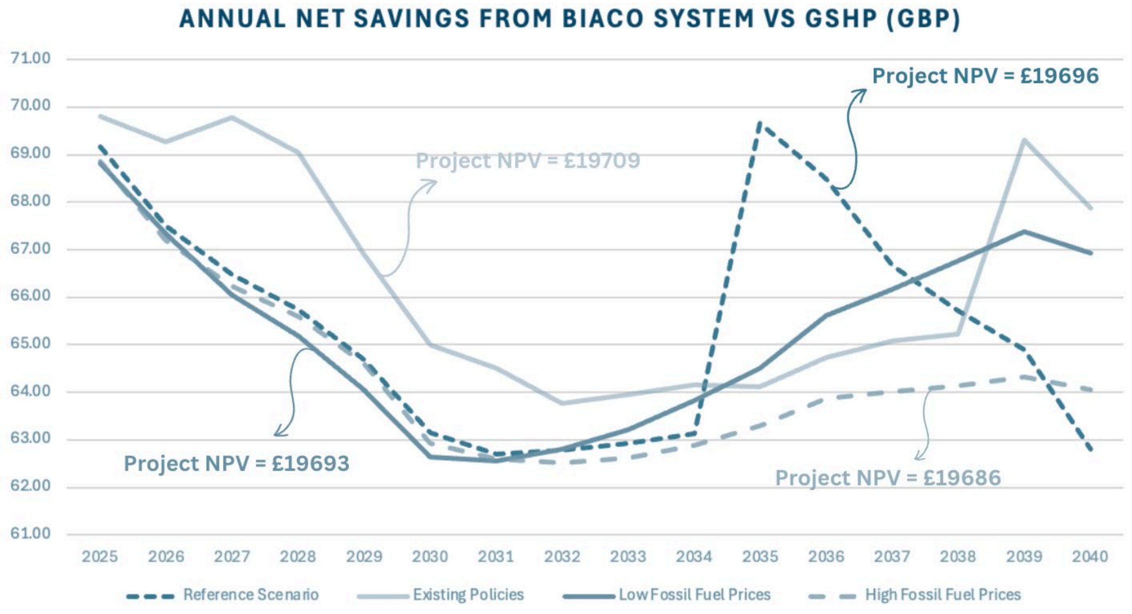


Figure 16: With Biaco System COP = 3.7

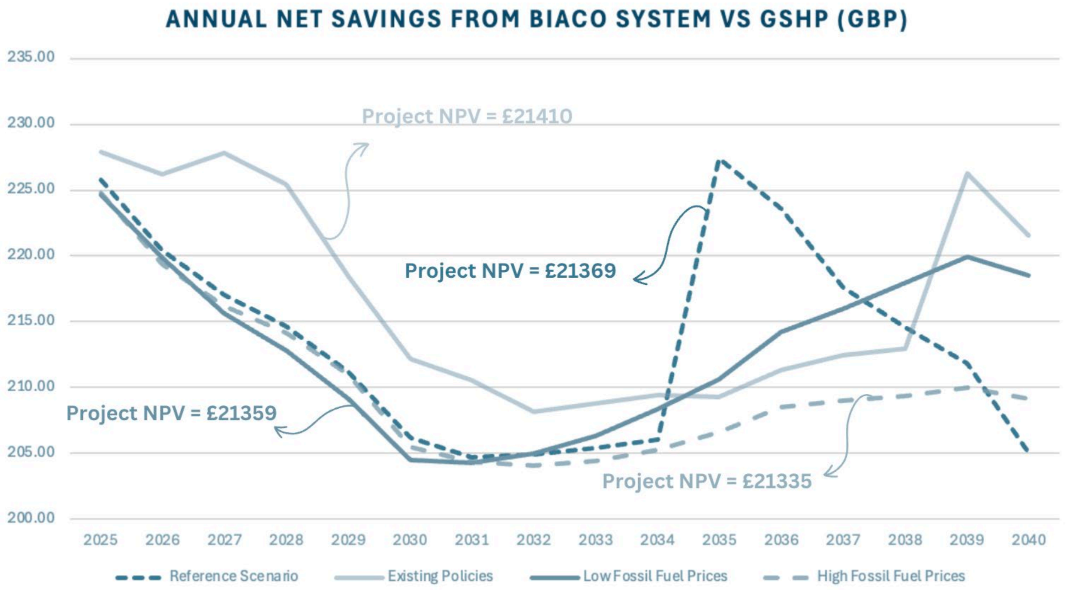


Figure 17: With Biaco System COP = 5.1

Summary of Analysis

The analysis indicates that there is a significant cost and environmental benefits if the Biaco system were adopted in the social housing market. The key benefits are:

- Emissions - there are significant gains on emissions the Biaco systems reduces emissions by 35% to 97% when COP is 5.1 compared to alternate technologies, driven by its superior COP. If the system was linked to local solar generation emission figures would fall further.
- The Biaco system is more cost effective than the alternate lower carbon systems
    - The Biaco system results in total savings of approximately £14,500 (COP 5.1) and £12,800 (COP 3.7) over its lifetime compared to ASHPs.
    - The Biaco system results in total savings of approximately £17,800 (COP 5.1) and 16,000 (COP 3.7) over its lifetime compared to Electric Boilers.
    - The Biaco system results in total savings of approximately £21,300 (COP 5.1) and £19,600 (COP 3.7) over its lifetime compared to GSHPs.
    - In relation to gas the Biaco system reduces emissions by approximately 96%, making it a significantly cleaner alternative to gas boilers.

- While the system is nearly cost-neutral compared to gas heating, current policies mandate the phase-out of gas boilers in domestic heating, reinforcing the need for low-carbon alternatives.

The details of these conclusions are summarized in the table below:

Table 4: Biaco System of COP 5.1

Net Present Value of Annual Cost Savings in Pounds (2024–2040) From Using Biaco System (COP 5.1) vs. Conventional Heating Systems				
Scenario	**ASHP**	**GSHP**	**Electric Boiler**	**Gas Boiler**
Reference Scenario	14501	21369	17879	
Existing Policies Scenario	14553	21410	18189	
Low FFP Scenario	14489	21359	17805	-2574
High FFP Scenario	14457	21335	17618	3967
All Announced Targets Are Satisfied (1.7 DC)				-577
CO2 Emissions Reduction with Biaco (%)	41.2	35.3	80.6	97

Table 5: Biaco System of COP 3.7

Net Present Value of Annual Cost Savings in Pounds (2024–2040) From Using Biaco System vs. Conventional Heating Systems				
Scenario	**ASHP**	**GSHP**	**Electric Boiler**	**Gas Boiler**
Reference Scenario	12828	19696	16206	
Existing Policies Scenario	12852	19709	16488	
Low FFP Scenario	12822	19693	16139	-4240
High FFP Scenario	12808	19686	15969	2318
All Announced Targets Are Satisfied (1.7 DC)				-2250
CO2 Emissions Reduction with Biaco (%)	18.9	10.8	73.2	96

10. Key Conclusions

The analysis shows that there is both a strong financial and sustainability case for the Biaco system particularly in the retrofit market. Successfully retrofitting existing stock will be critical to meeting net zero targets. Whilst energy efficiency and insulations initiative are important, a fundamental shift in boiler technology is required. The Biaco system has significant advantages when compared to alternatives and has potential to deliver social and policy objectives for all stakeholders.

Biaco system against alternative systems

- **Gas Boilers**: Comparable capex and opex price but significantly reduced CO_2 emissions by 96%. Additionally, less vulnerable to short term gas price shocks. Potential for medium term price decline as electricity generation moves to a greater share of renewables.
- **Electric Boilers:** Capital and operational costs are significantly lower. Depending on the scenario, a Biaco system operates with a COP of either 3.7 or 5.1, meaning it correspondingly uses less electricity to produce the same amount of heat, with equivalent reduction in CO_2 emissions relative to heat output. This also reduces the impact on the generation and distribution system which is significant as electrification of the economy will drive the requirement for significant investment in these areas.
- **ASHP/GSHP:** Main relative benefit from a Biaco system here is significantly lower capex, and easier installation especially in the retrofit market as existing radiator infrastructures can be used with no loss of functionality. With the potential to achieve a COP approximately 70% higher than conventional heat pump systems, Biaco can significantly reduce electricity consumption for the same heat output. This translates to lower energy costs for tenants and a substantial reduction in CO_2 emissions associated with primary energy generation.

Stakeholder Benefits

- **Social Housing Providers:** Significant reduction in capex for conversion of individual houses will enable the ablity to do more conversions within the same budget. In addition, the CO2 impact enables the sector to reach 2050 Net Zero If the Biaco system is implemented in conjunction with energy efficiency schemes there is potential to move the whole of the housing stock to the higher standards of building efficiency.

- **Tenants**: A viable heating system which will in the short term be no more expensive than gas, has reduced risk of price volatility and in the long term one which has the potential to reduce bills as renewables increase in the energy mix.
- **Government:** A technology which can be instrumental in meeting the aspirational goals of the Warm Homes: Social Housing Fund (WH: SHF), the net zero targets and reduction of fuel poverty and its associated socio-economic costs. The technology also generates efficiency and effectiveness gains for public expenditure, as it will decrease the subsidy demands for retrofitting and sustainable housing projects. For example, under the WH: SHF, the government has planned to allocate £1.25 billion to upgrade up to 140,000 social homes (National Housing Federation, 2024). However, by adopting the more cost-effective Biaco system instead of an ASHP, these funds could be leveraged to either retrofit additional homes or empower households to invest in further energy efficiency improvements such as insulation. Additionally, while the Energy Price Guarantee has been discontinued following relative stabilisation of energy prices, it had previously cost the Exchequer £27 billion. The Biaco system, which is about two-thirds as efficient as a heat pump and more than 5 times as efficient as an electric boiler, presents a significant opportunity to reduce potential financial liability of the government if it had to intervene in the energy market to ensure affordability in the future.

11. Considerations and Next Steps

The data presented is based on assumed averages we recognise the relative benefit of each system will be dependent on the actual housing unit, the age, the insulation levels, the viable alternatives and the consumption behavior of the occupiers.

The next step will be to take this model and work with social housing providers to analyse the relative cost and benefits of the solution in real housing situations.

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Appendix

A. Scenario Descriptions

Our estimates for household savings and heating emissions are based on scenarios outlined in the Energy and Emissions Projections 2022–2040 report by the Department for Energy Security and Net Zero.

a. **Reference Scenario**: Assumes that emissions and the renewable energy mix evolve based solely on policies that are already implemented or near finalisation, with funding secured and design nearing completion.

b. **Existing Policies Scenario**: Reflects a moderate fossil fuel price and economic growth outlook, considering only current policies and measures, without accounting for future or planned initiatives.

c. **High Fossil Fuel Prices Scenario**: Uses the same assumptions as the Reference Scenario but with higher projected fossil fuel prices. The trajectory aligns with current policy settings, leading to a global temperature rise of 2.5°C by 2100 compared to 1990 levels (DESNZ, 2023).

d. **Low Fossil Fuel Prices Scenario**: Uses the same assumptions as the Reference Scenario but assumes lower fossil fuel prices. This scenario follows a pathway that would limit global temperature rise to 1.5°C by 2100 compared to 1990 levels, consistent with achieving net zero emissions by 2050 (DESNZ, 2023).

e. **Announced Pledges Scenario**: Assumes that all government-announced targets, including long-term net zero commitments and energy access goals, are fully achieved on time. This results in a global temperature rise of 1.7°C by 2100 compared to 1990 levels.

B. Methodology for NPV Calculation

a. Forecasting Price of Electricity

We estimate the share of renewable energy in the UKs energy mix from 2024 to 2040 and calculate the year-on-year percentage point change in this share (DESNZ, 2023). Using this change in the share of renewables, we adjust electricity prices starting from 2024 (22.4 pence/kwh) (Ofgem, 2024) based on the findings of Cevik and Ninomiya (2022). Their research indicates that for every 1 percentage point increase in the share of renewables, wholesale electricity prices decrease by 0.6%. We assume that this entire cost reduction is passed on to customers, meaning household electricity tariffs also decrease by 0.6%. Price changes have been calculated for each scenario, reflecting a different mix of energy sources used in electricity generation.

b. Forecasting Price of Gas

Gas price projections are based on DESNZ's Fossil Fuel Price Assumptions 2023 report, which provides pricing forecasts for various fossil fuels from 2021 to 2050 under three scenarios outlined in Annex 1. We use gas price estimates from 2023 to 2040 across these scenarios. The prices, originally provided in pence per therm, were converted to pence per kWh using the conversion factor of 1 therm = 29.3 kWh.

c. Annual Heating Demand Estimation

Heating demand has been estimated based on the number of bedrooms in a house and the corresponding average house size. We consider three house sizes: 1-bedroom, 2-bedroom, and 3-bedroom (Table 4). Using the average heating requirement of 133 kWh per m² per year for the UK, we calculate the total annual heating demand for each household size (Ovo Energy, 2024). This figure, sourced from OVO Energy, a British energy supplier, is intended as a representative estimate and does not account for seasonal, geographical, or other variations.

Table 6.

House Size	Total Floor Area (sq m)	Energy Demand (kWh)
1 Bed	45	5985
2 Bed	69	9177
3 Bed (terraced house)	100	13300

d. Capital Expenditure

The capital expenditure for the different heating systems has been estimated using cost breakdowns from the Cost of Installing Heating Measures in Domestic Properties report by Delta Energy & Environment, 2018. The breakdown includes the installation cost of the boiler and pump, heat distribution system, labour, and any other associated costs based on the size of the house being estimated. These figures have been taken for a newly fitted heating system; costs associated with a retrofit are expected to be lower. We base our calculations on the assumption that the system has been installed at the end of 2024, the initial year.

e. Operating Expenditure

Operating expenses reflect the monetary cost of using each system to meet heating demand based on either the cost of electricity or gas depending on the system. These figures have been calculated for the expected lifetime of a system, taken to be 15 years (2025-2040) simplified without accounting for repair work or maintenance.

The calculation of annual operating expense per household uses the following formula:

$$heating\ demand\ /\ COP\ of\ heating\ system\ =\ electricity\ used$$

$$=>\ electricity\ used\ *\ cost\ per\ kWh\ in\ GBP\ =\ operating\ expense$$

Table 7: COP Considerations System of

Heating System	Coefficient of Performance
Biaco Zero Carbon Boiler	3.7 / 5.1
Gas Boiler	0.8
ASHP	3
GSHP	3.3
Electric Boiler	0.99

f. Net Annual Savings, NPV Calculation

Net annual savings per household are estimated as the difference between the operating costs of each of the four heating systems compared to the Biaco System. The NPV is calculated by discounting the annual savings over time, as well as the difference in capital expenditure of the different systems in the initial year. We use the UK 30-Year Gilt Yield of 4.45% as the discount rate, as it provides an accurate representation of the time value of money (Bloomberg UK, 2024).

NPV and annual savings have been estimated for each heating system across the four scenarios and for each bedroom type. To present a concise estimate in the main text, we calculate the weighted average based on the distribution of 1, 2, and 3-bedroom houses within the UK social housing stock, which makes up approximately 96% of the total. For houses with 4 or more bedrooms (the remaining 4%), the relative shares of 1–3-bedroom houses have been proportionally scaled up to 100% to provide a more representative estimate.

g. CO2 Emission Reduction

Emissions from electricity used for heating are calculated using data on total electricity production (Annex J, DESNZ) and CO2 emissions from power stations (Annex B, DESNZ). Electricity production and emission figures are converted to kWh and gCO2eq, respectively, and then divided to estimate the carbon intensity of electricity production, expressed in gCO2eq/kWh. These per-unit values are then multiplied by the electricity demand to find CO2 emissions by household.

Similarly, CO2 emissions per unit of gas consumption are estimated at 220 gCO2eq/kWh for gas boilers, assuming efficiency levels equivalent to the most efficient models currently available. Emission reductions may be greater for households using older, less efficient boilers (Houses of Parliament, 2016).

Emission figures are reported by source, meaning emissions generated during electricity production are attributed to the power stations themselves, not the end users (homes, businesses, or industries) that consume electricity. This approach provides an accurate measure of the carbon intensity of electricity generation. Our methodology focuses solely on electricity generated within the UK and does not account for energy imports or exports, which could affect the emissions per unit of electricity consumed by households.

C. Forecast Gas Prices 2023 to 2040

Table 8: Gas prices by scenario

p/kWh	Existing Policies (2.5 DC)	All Announced Targets Are Satisfied (1.7 DC)	1.5 DC
2023	3.07	3.48	4.27
2024	2.56	4.33	7.37
2025	1.88	3.89	8.05
2026	1.84	3.75	7.92
2027	1.74	3.45	7.34
2028	1.6	3.14	6.76
2029	1.47	2.83	6.18
2030	1.37	2.49	5.6
2031	1.3	2.49	5.56
2032	1.26	2.49	5.53
2033	1.19	2.49	5.53
2034	1.16	2.49	5.49
2035	1.13	2.49	5.49
2036	1.06	2.49	5.46
2037	1.02	2.49	5.43
2038	0.96	2.49	5.43
2039	0.92	2.49	5.39
2040	0.89	2.49	5.39

Source: Department for Energy Security and Net Zero report “Fossil Fuel Price Assumptions 2023”.

D. Net Present Value of heating systems by house size (£)

Table 9. NPV with Biaco System COP of 3.7

Number of Bedrooms	Scenario	ASHP	GSHP	Electric Boiler
1 Bedroom	Reference Scenario	10281	15933	8947
	Existing Policies Scenario	10296	15940	9124
	Low FFP Scenario	10278	15931	8905
	High FFP Scenario	10269	15926	8798
2 Bedroom	Reference Scenario	11637	19430	15770
	Existing Policies Scenario	11660	19442	16041
	Low FFP Scenario	11632	19427	15706
	High FFP Scenario	11618	19419	15541
3 Bedroom	Reference Scenario	16602	23549	23546
	Existing Policies Scenario	16635	23566	23939
	Low FFP Scenario	16594	23545	23453
	High FFP Scenario	16574	23534	23215

Weighted Average	**Reference Scenario**	12828	19696	16206
	Existing Policies Scenario	12852	19709	16488

	Low FFP Scenario	12822	19693	16139
	High FFP Scenario	12808	19686	15969

Table 10. NPV with Biaco System COP of 5.1

Number of Bedrooms	Scenario	ASHP	GSHP	Electric Boiler
1 Bedroom	Reference Scenario	11331	16982	9997
	Existing Policies Scenario	11364	17008	10191
	Low FFP Scenario	11323	16976	9951
	High FFP Scenario	11303	16961	9833
2 Bedroom	Reference Scenario	13247	21039	17379
	Existing Policies Scenario	13297	21078	17678
	Low FFP Scenario	13235	21030	17309
	High FFP Scenario	13204	21006	17128
3 Bedroom	Reference Scenario	18935	25882	25879
	Existing Policies Scenario	19008	25939	26312
	Low FFP Scenario	18917	25868	25777
	High FFP Scenario	18873	25834	25515

	Reference Scenario	14501	21369	17879

Weighted Average	**Existing Policies Scenario**	14553	21410	18189
	Low FFP Scenario	14489	21359	17805
	High FFP Scenario	14457	21335	17618

Table 11. NPV with Biaco System COP of 3.7

Number of Bedrooms	Scenario	Gas Boiler
1 Bedroom	Low FFP Scenario	-2661
	High FFP Scenario	1454
	All Announced Targets Are Satisfied (1.7 DC)	-1412
2 Bedroom	Low FFP Scenario	-4080
	High FFP Scenario	2230
	All Announced Targets Are Satisfied (1.7 DC)	-2165
3 Bedroom	Low FFP Scenario	-5913
	High FFP Scenario	3232
	All Announced Targets Are Satisfied (1.7 DC)	-3137
Weighted Average	Low FFP Scenario	-4240
	High FFP Scenario	2318
	All Announced Targets Are Satisfied (1.7 DC)	-2250

Table 12. NPV with Biaco System COP of 5.1

Number of Bedrooms	Scenario	Gas Boiler
1 Bedroom	Low FFP Scenario	-1615
	High FFP Scenario	2489
	All Announced Targets Are Satisfied (1.7 DC)	-362
2 Bedroom	Low FFP Scenario	-2477
	High FFP Scenario	3817
	All Announced Targets Are Satisfied (1.7 DC)	-555
3 Bedroom	Low FFP Scenario	-3589
	High FFP Scenario	5532
	All Announced Targets Are Satisfied (1.7 DC)	-804
Weighted Average	Low FFP Scenario	-2574
	High FFP Scenario	3967
	All Announced Targets Are Satisfied (1.7 DC)	-577

E. Average Annual Emissions Reduction (KGs) in Biaco System vs Gas Boiler by House Size

Table 13. Emission Savings with Biaco System COP of 5.1

Scenarios	1 Bedroom	2 Bedroom	3 Bedroom
Reference Scenario	1598	2450	3551
Existing Measures Scenario	1585	2430	3522
FFP Low	1590	2438	3533
FFP High	1606	2463	3570

Table 14. Emission Savings with Biaco System COP of 5.1

Scenarios	1 Bedroom	2 Bedroom	3 Bedroom
Reference Scenario	1580	2422	3510
Existing Measures Scenario	1562	2395	3470
FFP Low	1569	2406	3486
FFP High	1591	2440	3537

F. Challenges in Heat Pump Installation (Carbon Trust, 2020)

There are numerous challenges to heat pump installation, particularly in retrofitting flats and urban housing stock.

a. **Space Requirements:** Heat pumps demand more space than traditional gas boilers. Internally, a hot water cylinder or a larger thermal store is needed, which can be prohibitive in smaller homes or buildings with limited plant room space. Externally, both ASHPs and GSHPs require space for their components, including outdoor units, ground trenches, or boreholes.

b. **Technical Constraints:** Ground loops for GSHPs necessitate extensive land for trenches (60–100 meters of pipe per kW), making them unsuitable for most London homes. Vertical boreholes, while space-efficient, are costly and generally viable only for larger applications where the shared cost improves feasibility.

c. **Noise and Aesthetics:** ASHPs produce noise that can breach strict limits in dense urban areas, posing compliance challenges. Additionally, the aesthetic impact of external fan units for ASHPs, especially in terraced housing and flats, often conflicts with planning permission.

    (i) Ground floor flats may have good potential and a strong financial case where noise issues can be overcome. In mid and top floor flats there is often a lack of suitable external space for heat pumps.

d. **Energy Efficiency of Housing Stock:** Large parts of London's housing stock is often inefficient, requiring higher flow temperatures to maintain comfort. This reduces heat pump efficiency, creating both operational challenges and increased energy costs.

e. **Expensive:** Smaller heat pumps, especially in blocks of flats or small terraced houses, are more likely to require specialist solutions, such as premium low-noise models, shared ground loops, or fully internal heat pumps.

    (i) This suggests that the capital costs of heat pumps in London could be higher than in other parts of the country, as the city's higher density of population and greater number of flats make standard, lower-cost air source heat pump (ASHP) options less viable.

G. Relationship Between Gas & Electricity Prices

Electricity prices in Europe are closely linked to gas prices, and this is due to the merit order. Electricity markets operate on a merit-order system where electricity generators submit offers (based on their production costs), and buyers submit bids for how much electricity they need. The system is designed to meet demand at the lowest possible cost. The price for all electricity is set by the last, most expensive generator required to meet demand — the so-called *marginal generator*. Natural gas plants often play this role due to their flexibility in ramping production up or down (Orso & Gabriel, 2023).

In Europe despite fossil fuels having a declining role in generation, they still dominate price setting in electricity markets. Across Europe in 2021, they set prices 58% of the time while generating 34% of electricity, down from 66% and 37% in 2019. In contrast, the UK experienced the opposite trend. In 2021, gas determined electricity prices 98% of the time, even though it accounted for just over 40% of electricity generation. Non-fossil sources set prices for the remaining 2%. This marks a significant shift from 2015–2019, when gas set prices 80–90% of the time, with lower-cost imports via interconnectors playing a larger role in setting prices. Gas played an increasingly significant role in price setting due to its supply flexibility, enabling electricity generation to match demand. This was further supported by a global decline in gas prices until 2021 and the impact of carbon pricing, which made coal less economically competitive (Zakeri & Staffell, 2023).

a. Decoupling of Electricity and Gas Prices

Decoupling electricity and gas prices are incentivised because renewable energy (wind and solar not biomass), which has near-zero variable costs, is increasingly dominating the energy mix. However, the current system ties electricity prices to expensive fossil fuel-based generators used as backup, leading to inflated costs and excessive profits for 'inframarginal' generators (i.e., renewable sources) (Zakeri & Staffell, 2023). Furthermore, most of the gas in Europe is imported, exposing electricity prices to geopolitical risks, disruption, and currency fluctuations. For instance, according to Ofgem the volatility in peak electricity prices in the UK is 54% correlated with the variations in the market price of natural gas. Decoupling would shield consumers from these issues and better reflect the true cost of renewable energy.

b. Policy Initiatives to Decouple Prices

i. In the UK, Contracts for Difference (CfDs) were introduced as part of the Electricity Market Reform in 2013 to stabilise electricity prices and encourage investment in renewable energy. CfDs guarantee a fixed "strike price" for electricity generated by large-scale renewables over the first 15 years of operation. If the market price for electricity is below the strike price, the generator is compensated for the difference. Conversely, if the market price is above the strike price, the generator pays the excess back to the government or authority.

    a. Initially allocated in 2014, the system transitioned to competitive auctions in 2015 to secure renewable projects at the lowest cost (Zakeri & Staffell, 2023).
    b. By insulating renewable generators from market price volatility and preventing fossil fuel-driven spikes from influencing electricity prices, CfDs decouple electricity prices from gas prices, stabilising costs for consumers and supporting the shift to a greener energy mix.

ii. The DESNZ launched a Review of the Electricity Market Arrangements (REMA) in July 2022, to, 'explore changes to the wholesale electricity market that would stop volatile gas prices setting the price of electricity produced by much cheaper renewables.' (DESNZ, 2024)

Some proposals under consideration in the 2nd REMA Consultation are:

i. 'Maintain a wholesale market unified by technology accompanied by a CfD-type support mechanism as the central driver behind renewable investment and passing through the value of renewables to consumers.'

ii. Introducing zonal pricing which would split the wholesale market into around five to ten pricing zones to reflect regional grid constraints and reduce inefficiencies in generation and transmission.

    a. This can deliver lower wholesale power costs by reducing 'inframarginal rents.

iii. Reforms to existing Capacity Market (CM) which is a a mechanism designed to ensure the security of electricity supply in the UK by incentivising the availability of sufficient electricity generation capacity during periods of high demand.

    a. Optimise the CM through a minimum procurement target (minima) within CM auctions aims to prioritise investment in low-carbon flexible technologies, such as battery storage and demand-side response systems.

H. Impact on other utilities of using Biaco system.

This paper has concentrated on the impact on fossil fuel usage of using the Biaco system (which is mainly electricity or gas). Biaco's core proposition also uses 12 grams of water per second as aqueous feedstock into the system. This requires 43 liters of water for one hour of running which would produce 20 kW (low case) of heating output. We are working on solutions to recycle the water which is clean when it leaves the system.