Barnsley Metropolitan Borough Council

Masterplan Framework

Energy Strategy – Hoyland South and Royston

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Contents

References

Tables

Figures

Appendices

Appendix D – Longlist analysis

Appendix E – Hoyland South IRM

Appendix F – Royston IRM

Appendix G – Pathway assumptions

Executive Summary

This energy strategy study developed energy pathways for two new developments in Barnsley, as part of Masterplan Frameworks that aim to help Barnsley in their transition to becoming a net zero carbon emissions borough, by 2045.

The Hoyland South development is expected to consist of 1,064 houses, a community hub and a convenience store. The site has an estimated annual heating demand of 5,400MWh and annual electricity demand of 3,000MWh, once the development is completed.

The Royston development will comprise of 994 new homes (including 166 homes currently being built by Barratt Homes), a community hub, a convenience store and a new primary school. Royston is expected to have an annual heating demand of 4,400MWh and annual electricity demand of 2,400MWh, once the development is completed. These values exclude the Barratt Homes dwellings.

The recommended pathways for both sites were developed through an assessment of current building energy standards, energy demand estimates and an energy options appraisal alongside engagement with BMBC officers.

This methodology has resulted in the following recommended pathways:

Hoyland South Pathway:

- Distributed ASHPs in all dwellings
- Roof mounted PV panels with battery storage on dwellings with south-facing roofs, and grid backup
- Grid supply to all other dwellings
- Roof mounted PV panels on the shop, and grid backup

Royston Pathway:

- Distributed ASHPs in all dwellings
- Roof mounted PV panels with battery storage on dwellings with south-facing roofs, and grid backup
- Grid supply to all other dwellings
- Roof mounted PV panels on the shop, and grid backup
- Roof mounted PV panels on the school, and grid backup
- GSHP in the school with electric boiler backup

The recommended pathways are expected to emit 7,400 tonnes CO_2e from Hoyland South and 6,100 tonnes CO_2e from Royston, between the start of construction (estimated 2021) until 2045. In 2045, it is estimated the developments will emit 250 tonnes CO_2e combined. For Barnsley to reach its net zero goal, these remaining emissions should be offset.

The carbon emissions from these pathways are significantly lower compared to a counterfactual scenario, that would meet the heating and electricity demand through gas boilers and grid electricity. The counterfactual scenario would result in 32,500 tonnes CO_2e being emitted from Hoyland South and 26,500 tonnes CO_2e being emitted from Royston, over the same period (2021-2045).

However, these pathways are limited as they do not consider emissions from transport, street lighting or development maintenance. These sources of emissions should be explored further as part of Barnsley's next steps.

1 Introduction

In September 2019, Barnsley Metropolitan Borough Council (BMBC) declared a climate emergency and have since made a commitment to fight climate change by setting the goal of becoming a net zero carbon borough by 2045.

The aim of this study is to assess a range of low carbon technology options that could be implemented across two new developments, Hoyland South and Royston, to help move Barnsley towards their net zero carbon goal. The study has been commissioned by BMBC as a component of the Masterplan Frameworks, being conducted by Arup and Gillespies, as part of the Barnsley Local Plan adopted in January 2019.

This report documents the methods and assumptions used in order to identify low carbon pathways for both sites. The methodology and assumptions are followed by an exploration of current and future energy building standards for dwellings, to allow building standards recommendations to be made.

Energy benchmarks were then established, allowing the sites' energy demands to be estimated and emissions from a counterfactual scenario to be calculated. Following these calculations, an energy supply options appraisal was conducted to highlight the most suitable energy supply technologies for dwellings, shops and schools within the development.

The most suitable technologies were then combined to create a low carbon pathway for Hoyland South and Royston, that will aid Barnsley in moving towards a net zero carbon future. Other factors, such as infrastructure constraints and further carbon reduction measures have also been investigated as part of the study.

1.1 Hoyland South

Hoyland South is a new residential development located south of central Hoyland and will include 2- to 4-bed homes, a community hub, a convenience store and potentially a new primary school. Since a decision to build the primary school has not been made at this stage, it has been assumed that 1,064 houses are built on this site, across the residential parcels and the potential primary school site. The land for this development is owned by two separate parties, including BMBC. This development is planned to be delivered in six phases as per the Masterplan Framework. It is assumed this takes place between 2021 and 2033. A breakdown of the site and phases is shown in Figure 1.

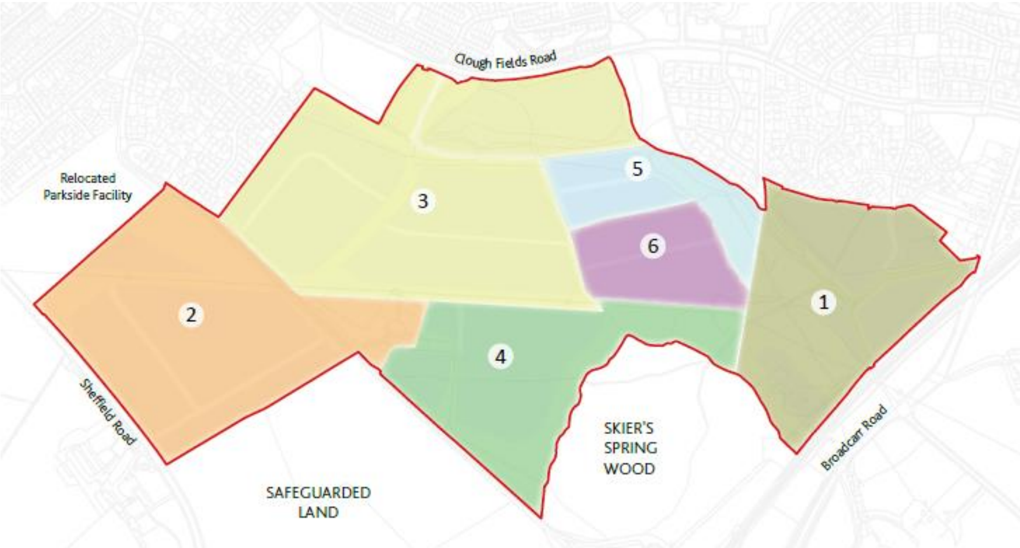


Figure 1: Phasing plan for Hoyland South.

1.2 Royston

Royston is a new mixed-use area in this study. The site is situated west of Royston central area and will comprise of 994 new 2-, 3- and 4-bed homes, 166 of which are currently being constructed by Barratt Homes. This development will also include a community hub, a convenience store and a new primary school. The land required for this development is owned by multiple parties. The development is planned to be delivered in six phases, excluding houses being built by Barratt Homes, as shown in Figure 2. It is assumed this takes place between 2021 and 2033.

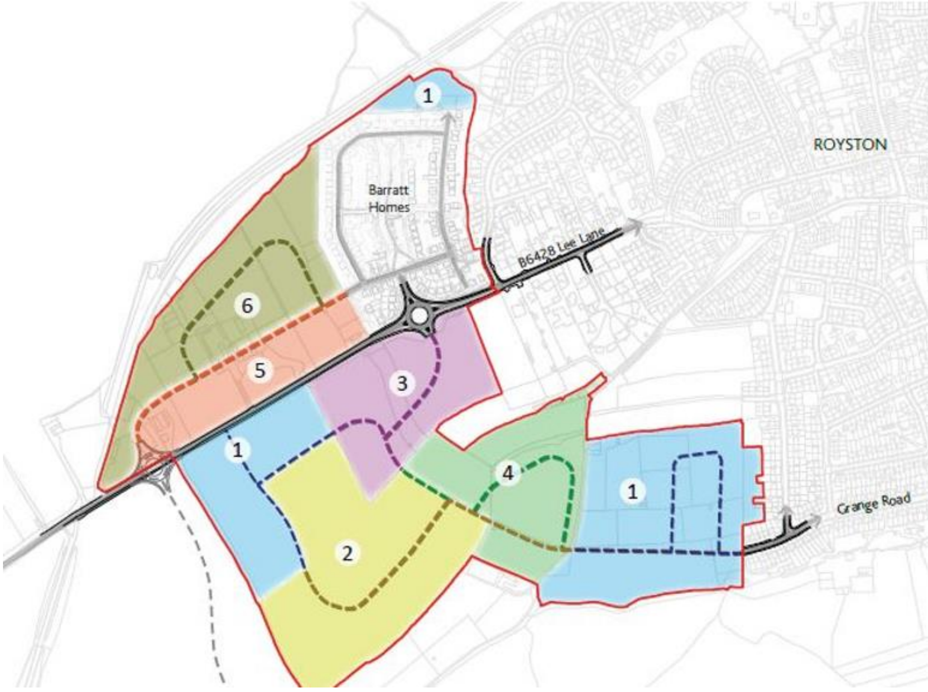


Figure 2: Phasing plan for Royston.

2 Methodology and assumptions

A summary of the methodology is shown in Figure 3 and described below. All assumptions made during the project are documented in Appendices A to G.

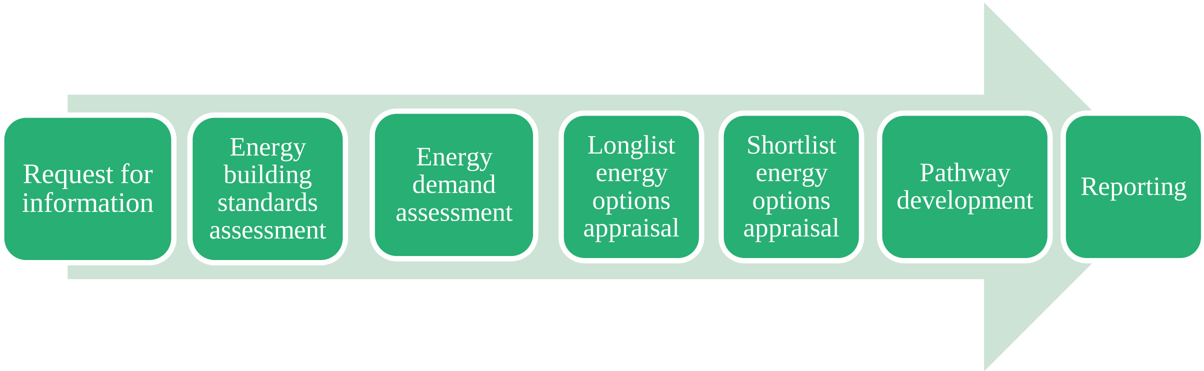


Figure 3: Summary of methodology.

Following exchange of information about the sites, Arup performed a literature review of energy building standards in order to establish appropriate building assumptions for the new developments. Energy benchmarks were selected to follow the chosen building quality and standards, allowing the energy demand for both sites to be determined.

Following these assessments, Arup created a longlist of energy supply options (heat and electricity) which were assessed against criteria that reflected the needs of the new developments and BMBC’s net zero carbon goals. The longlist of options and assessment criteria, along with the building standards and energy benchmarks, were discussed in a workshop held at this stage of the project. The slides from Arup’s workshop 1 presentation are presented in Appendix A.

All shortlisted options were explored further assessing the technology suitability, carbon emissions and economics. The results from the analysis were used to create an Integrated Risk Matrix (IRM) which was used to determine the preferred technology options. These were developed into a pathway for each development. A second workshop was held at this stage to present the preferred pathways and obtain BMBC’s input and agreement. The presentation slides from the second workshop are presented in Appendix B.

The key outcomes from this work are presented in this report.

3 Energy building standards

Industry standards have been used to inform and develop the recommended energy performance standards for both dwellings and schools within the new developments. This study has reviewed the following standards:

- Building Regulations Part L1A (2013): Conservation of fuel and power in new dwellings
- The Future Homes Standard consultation
- LETI Climate Emergency Design Guide
- Passivhaus

The recommended energy performance standards go beyond the current Building Regulations limiting requirements in order to help future-proof the developments and support the transition of the borough to be zero carbon by 2045.

3.1 Fabric performance

The review of the standards listed above can be summarised as follows:

- Air Permeability

- Roof U-values

- Wall U-values

- Floor U-values

- Window U-values

High fabric performance of a dwelling is key to reducing the space heating demand and the associated carbon emissions. Whilst systems can be modified in the future, it is much more difficult and costly to make alterations to improve the performance of the fabric. High performing fabric will help to reduce heat losses, and the costs of heating the dwellings. This includes minimising air infiltration and lower U-values for the different elements of construction.

Setting fabric performance standards should be a minimum when specifying building standards for dwellings in the new developments. The recommended fabric performance standards for dwellings are documented in Table 1.

Table 1: Recommended fabric performance standards for dwellings.

Fabric performance area	**Performance value**			
	Recommended minimum standard	Recommended minimum standard source	Recommended aspirational standard	Recommended aspirational standard source
Air permeability	≤ 5 m^3/ ($h.m^2$) @50Pa	Building Regulations Part L1A (2013)	≤ 1 m^3/ ($h.m^2$) @50Pa	LETI Design Guide
Roof U-value	≤ 0.15 W/m^2. K	Passivhaus standards	≤ 0.11 W/m^2. K	Part L 2020
Wall U-value	≤ 0.15 W/m^2. K	Part L 2020 LETI Design Guide Passivhaus standards	≤ 0.13 W/m^2. K	LETI Design Guide (lower boundary)
Floor U-value	≤ 0.15 W/m^2. K	LETI Design Guide Passivhaus standards	≤ 0.11 W/m^2. K	Part L 2020
Window U-value	≤ 1.2 W/m^2. K	Part L 2020	≤ 0.8 W/m^2. K	Part L 2020 LETI Design Guide Passivhaus standards

It is recommended that, at least, the minimum fabric performance standard is met. To meet Barnsley’s net zero carbon emission goal, it is advised that new dwellings aim to meet the aspirational standards outlined in Table 1. Whilst the aspirational targets may seem ambitious, as technology and construction techniques improve and costs decrease, these targets may become more obtainable. Therefore, as the development progresses over time, it is more likely developers will be able to build dwellings in line with the aspirational targets.

3.2 Energy performance

In addition to the fabric performance standards, energy performance metrics can be used to set the energy standards in these developments. This can be in the form of an EPC rating and/or an energy use targets.

3.2.1 EPC rating

An Energy Performance Certificate (EPC) is a rating given to buildings to indicate a buildings energy efficiency with an A rating being the most energy efficient and G being the least energy efficient. EPC ratings for dwellings built in Barnsley since 2015 are shown in Table 2.

Table 2: EPC ratings achieved by new dwellings in Barnsley since 2015.

EPC rating	Number of houses achieving rating
A	50
B	3,899
C	4,694

A minimum EPC A rating can be set as an energy performance target for dwellings within the new developments. This will reduce the energy demand from each dwelling, significantly reducing the overall energy demand for the new developments, aiding Barnsley's transition to a net zero carbon emissions future.

3.2.2 Energy use

The total energy use is the annual measure of all the energy consumed by a dwelling. It includes both regulated energy (heating, hot water, cooling, ventilation and lighting) and unregulated energy (small power loads, white kitchen goods, IT/AV equipment).

The LETI Climate Emergency Design Guide (published in 2020) provides guidance for designing new buildings to meet UK climate change targets. For dwellings, it recommends that the total energy use is limited to 35 $kWh/m^2.yr$ with space heating being limited to 15 $kWh/m^2.yr$. For schools, it recommends that the total energy use is limited to 65 $kWh/m^2.yr$ with space heating being limited to 15 $kWh/m^2.yr$. However, it is important to note that this is very new guidance and these low benchmarks may be difficult to achieve.

4 Energy demand assessment

The energy demands for Hoyland South and Royston have been calculated in the following sections. The energy demands for both developments were calculated based on benchmarks, informed by the building standards outlined in Section 3.

4.1 Energy benchmarks

The energy benchmarks for dwellings, shops and schools were developed through a review of energy consumption in new domestic buildings from 2017, cost optimal assessment of energy performance requirements for the UK, CIBSE Guide F, Department for Education energy benchmarks, and energy data from Barnsley schools.

This study assumes that by 2025, dwellings will be built to a higher fabric performance standard. Dwellings built from 2025 onwards will have a lower space heating demand. The benchmarks used throughout this study are summarised in Table 3.

Table 3: Heating and electricity benchmarks.

Building type	**Heating benchmark (kWh/m^2)**	**Electricity benchmark (kWh/m^2)**
Housing (pre-2025)	77	31
Improved housing (post-2025, inclusive)	44	31
Small food shop (all electric)	0	550
Primary school	71	64

4.2 Hoyland South energy demand

The energy demand for Hoyland South was estimated using the benchmarks above and hourly profiles for heat and electricity, for each building type. Hoyland South is to be built in six phases as shown in Figure 1. For this study, the larger phase 3 has been divided into 3a and 3b. The timing, duration and number of buildings assumed to be developed in each phase is listed in Appendix C.

The highest potential energy demand for the development has been calculated in line with the phasing plan.

As the Hoyland South site has been allocated for residential use in the Local Plan, and a decision to pursue a primary school on site has not been made, it has been assumed that the full housing allocation will be provided. This assumption can of course be re-visited at a later date.

This has resulted in an estimated annual heating demand (space heating and hot water) of 5,400MWh and peak of 3MW. The annual electricity demand is 3,000MWh, with a peak of 0.6MW, once the development has been completed. A breakdown of the heating and electrical annual demand are shown in Figure 4 and Figure 5, respectively.

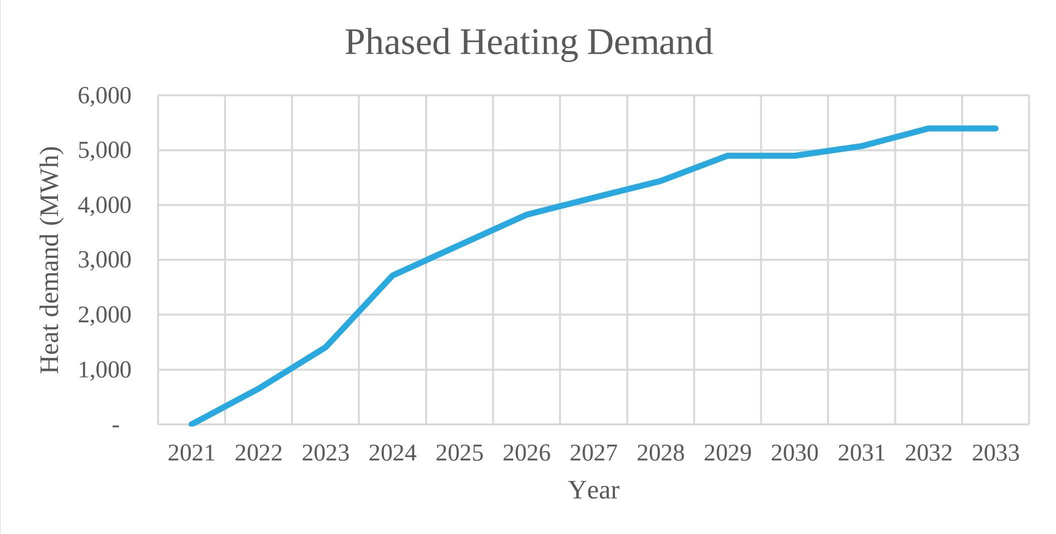


Figure 4: Phased heating demand for Hoyland South throughout the construction of the development.

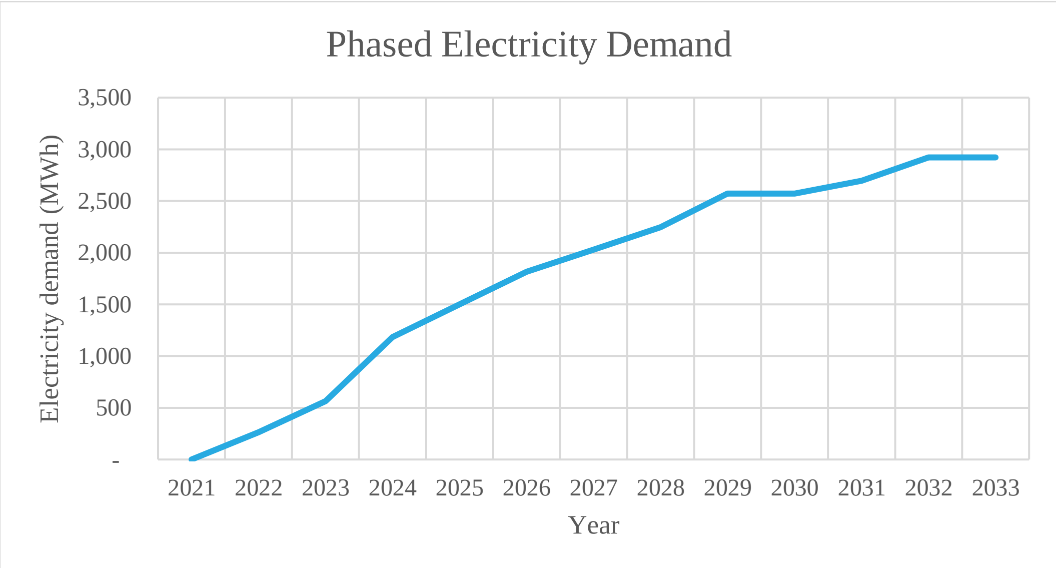


Figure 5: Phased electricity demand for Hoyland South throughout the construction of the development.

4.3 Royston energy demand

The energy demand for Royston was estimated using the benchmarks in Section 4.1 and hourly profiles for heat and electricity, for each building type. Royston is to be built in six phases as shown in Figure 2. For this study, phase 1 has been divided into 4 parts. Assumptions were made regarding the timing, duration and number of buildings developed in each phase. A breakdown for each phase of Royston's new development is shown in Appendix C.

The highest potential energy demand for the development has been calculated in line with the phasing plan. This has resulted in an estimated annual heating demand of 4,400MWh and peak of 2.4MW, and an annual electricity demand of 2,400MWh, with a peak of 0.5MW, once the development has been completed. These estimations exclude energy demands from the Barratt Homes development. A breakdown of the heating and electrical annual demand are shown in Figure 6 and Figure 7, respectively.

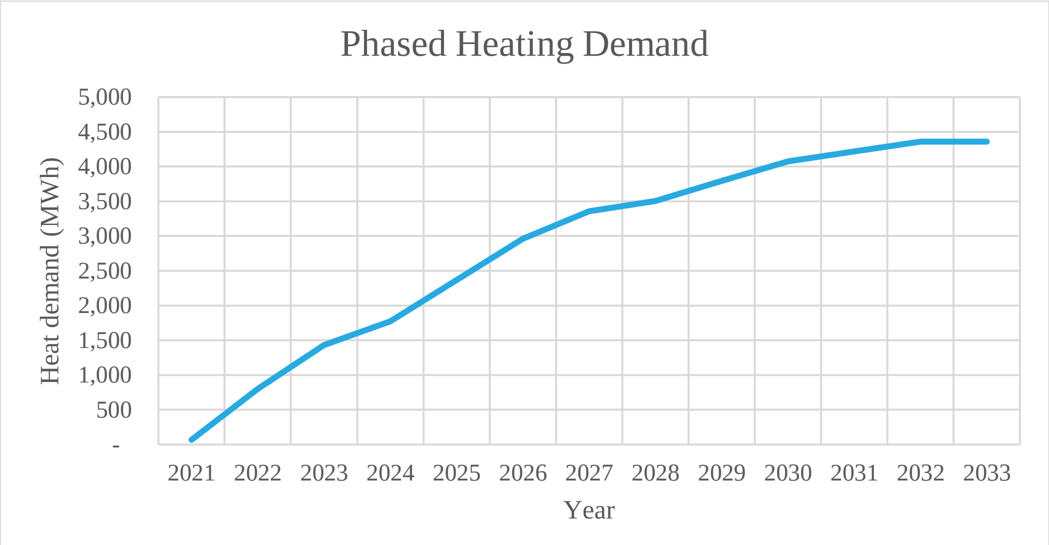


Figure 6: Phased heating demand for Royston throughout the construction of the development.

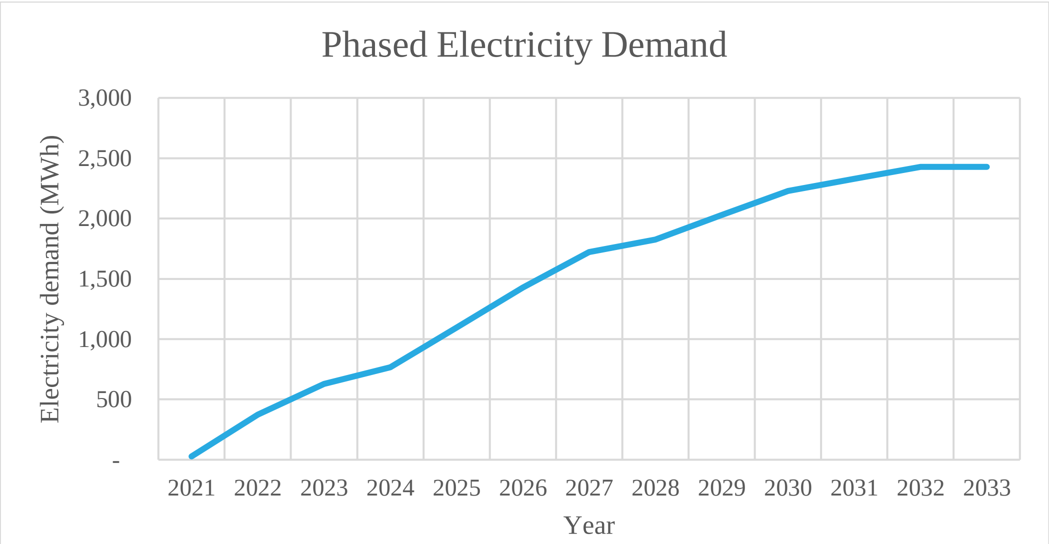


Figure 7: Phased electricity heating demand for Royston throughout the construction of the development.

The estimated annual energy demands for both sites will be used to determine the carbon emissions for a counterfactual scenario and emissions associated with the implementation of low carbon energy options.

5 Counterfactual scenario

As a base case, it was established that the heating and electricity demand of the homes in these new developments is to be met by a gas boiler and a connection to the grid respectively. These are both carbon intensive methods of meeting a dwelling's energy demand. The counterfactual scenario was produced to show the carbon emissions associated with supplying the new developments heat demand with distributed gas boilers, and electricity demand with a connection to the grid. The emissions from the counterfactual scenario, up to 2045, are shown in Figure 8 and Figure 9 for Hoyland South and Royston, respectively.

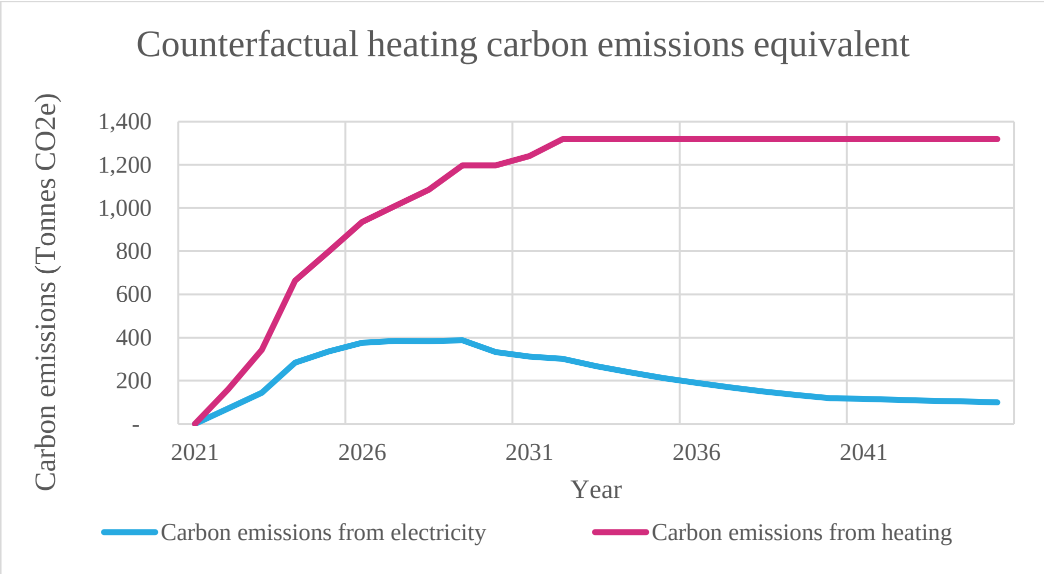


Figure 8: Hoyland South counterfactual carbon emissions.

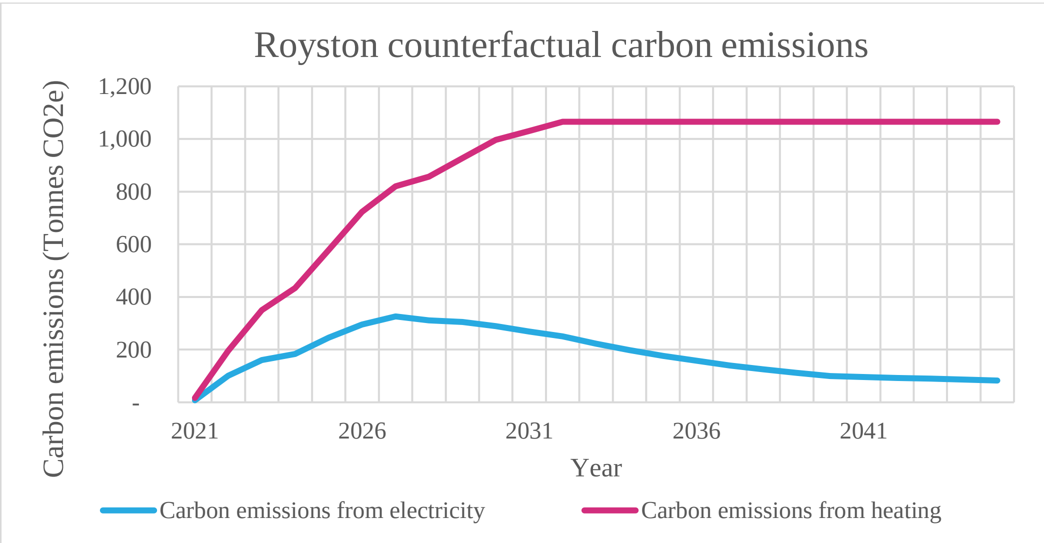


Figure 9: Royston counterfactual carbon emissions.

In the counterfactual scenarios, the heating demand is the largest source of carbon emissions, accounting for over 90% of the total emissions emitted in 2045, for both sites. This scenario assumes a constant carbon factor for the use of gas.

However, the gas network could be partially decarbonised in the future by blending up to 20% of hydrogen into the gas network. Alternatively, the gas network could be fully replaced by a hydrogen network, offering the potential to completely decarbonise heating if green hydrogen is used. The move towards a green hydrogen network is hard to predict and very unlikely to be implemented in time to be utilised in the new developments. Thus, other low carbon heating technologies should be explored to assist Barnsley in its transition to a net zero carbon future.

Despite the grid decarbonising, Hoyland South and Royston's electricity demand combined will still emit nearly 200 tonnes of equivalent carbon emissions in 2045. Although this is only a fraction of the site's overall emissions, it is still a significant amount of carbon. Therefore, low carbon electricity generation technologies should also be explored with any carbon offsetting measures being used as a last resort.

6 Utility infrastructure

The development of both Hoyland South and Royston will require the local electricity networks to be developed further. Northern Powergrid (NPg) is the local distribution network operator (DNO) for both sites. NPg 's online records were reviewed in June 2020 to assess spare capacity in the local areas. Hoyland South and Royston both have existing 11kV infrastructure within the sites. More information is required to understand their suitability to supply electricity to the new developments.

There are two substations less than 2km away from the Hoyland South site. These substations are Elsecar 11kV substation and Tankersley Park 11kV substation. Both substations have more than 2MVA spare capacity with no additional demand being accepted, currently, at either substation. It is estimated that there is a combined spare capacity of 15MVA.

There are three substations, Monckton 11kV substation, Fish Dam Lane 11kV substation and Smithy Green 11kV substation all less than 3km away from the Royston development. All three substations have a spare capacity of over 2MVA and currently have no other accepted demand. It is estimated that there is a combined spare capacity of 20MVA.

It is expected that the Future Homes Standards, set to be introduced by 2025, may see the implementation of a gas boiler ban in new homes. It is unlikely that the developments will be connected to the gas network as gas heating and cooking methods are very carbon intensive and therefore do not align with BMBC's net zero carbon emission ambitions. This can potentially generate savings in the development of these new sites, if no gas infrastructure is required. It is recommended that all gas technologies are discounted.

7 Energy options appraisal

An initial longlist of energy options (heat and electricity) was produced in order to explore low carbon technologies for the sites. All technologies were assessed as part of a high-level analysis, taking the most preferable options forward to create a shortlist of options. The shortlisted options were modelled and analysed in more detail to highlight the most suitable options for each development. The preferred energy supply options were then used to develop a pathway for each site, to assist Barnsley's transition to a low carbon future.

7.1 Initial longlist options appraisal

Initially, a longlist of potential energy supply technologies was produced, with each technology being assessed against key criteria that aligned with BMBC's key drivers. The initial longlist of energy supply options includes:

<u>Distributed options</u>
Electrical options:

1. Roof mounted solar PV
2. Roof mounted solar PV with battery

Heating options:

3. Electric radiators
4. Electric boiler and wet heating system
5. Air source heat pump (ASHP)
6. Ground source heat pump (GSHP)
7. Biomass boiler
8. Hydrogen boiler
9. Hydrogen fuel cell CHP
10. Micro gas CHP boiler
11. Solar thermal hot water

<u>Centralised options</u>
Electrical options:

12. Ground mounted PV (Hoyland South only)
13. Ground mounted solar PV with battery (Hoyland South only)
14. Wind turbines
15. Wind turbines with battery
16. Hydro power
17. Geothermal power

Heating options:

18. District heating with electric boiler
19. District heating with biomass boiler
20. District heating with water source heat pump (WSHP)
21. District heating with ASHP
22. District heating with GSHP
23. District heating with mine water and heat pump
24. District heating with gas CHP
25. District heating with gas CHP and battery
26. District heating with biomass CHP
27. District heating with biomass CHP and battery
28. District heating with hydrogen boiler
29. District heating with hydrogen fuel cell CHP
30. District heating with hydrogen fuel cell CHP and battery
31. District heating with solar thermal

The assessment criteria used to explore each option included:

- **Technology suitability:** Suitability of the technology to meet site demand whilst complying with site specific constraints.
- **Spatial requirements:** The space occupied on site (within homes or centrally) by the technology.
- **Development risk:** The risks associated with technology from the planning stage to installation and commissioning.
- **Renewable energy contribution:** The amount of energy the technology can generate as part of the site's overall energy demand.
- **Carbon emissions reduction on site, offsetting potential and savings:** The potential for the technology to reduce emissions on site, offset other emissions and allow for carbon savings to be realised across the developments.
- **Incentives and grant funding potential:** The potential for each technology to receive grants and/or incentives.
- **Future expansion:** The potential to increase the technologies capacity.
- **Technology flexibility:** The ability for each technology option to adapt in the future or be replaced by a similar technology with little infrastructure changes.
- **Ownership:** The risk associated with the council, developer or homeowner owning the technology.
- **Cost commentary:** Potential costs associated with each technology.
- **Opportunities to expand:** The potential for a technology to be expanded to other sites or increase generation to meet higher demands.

Each technology option was ranked high, medium or low against each of the above criteria. A detailed record of the analysis can be found in Appendix D.

This process discounted a number of technologies including all electricity generation methods except roof mounted PV with battery, due to spatial requirements and limited resource availability. The potential for ground mounted PV outside of the site boundary was assessed for Hoyland South. However, the land surrounding Hoyland South is classified as Green Belt therefore, it is unlikely the implementation of ground mounted PV would be permitted.

Technology options for providing heat, including water source heat pumps, were also discounted as a heating method due to insufficient water availability. Minewater heat was not considered as an option for the Royston site due to the lack of mines in close proximity to this development. All gas CHP options were also discounted, as they are a carbon intensive technology, which does not align with Barnsley's net zero carbon goal. All hydrogen options were discounted due to the market being in the early stages of development, the lack of a hydrogen network available in the immediate future, and the high costs of transporting hydrogen to site by tankers.

All remaining energy generation options were taken forward to create the shortlist of options, described in Section 7.2.

7.2 Shortlist options appraisal

A shortlist of energy supply options for dwellings in both, Hoyland South and Royston developments, was created from the successful longlist options. The shortlists for both sites are listed in Sections 7.2.2 and **7.2.3** for Hoyland South and Royston, respectively.

An Integrated Risk Matrix (IRM) was used to assess each energy supply option further. The IRM assessed each option against three categories: sustainability, technical/operational and economic. Each category was split into the assessment criteria that aligned with BMBC's goals. Each category was given a weighting in order to prioritise the criteria and subsequent scores. The IRM criteria are outlined below with their corresponding weighting.

- **Sustainability (weighting: 40%):**
    - **CO_2e savings from the site completion to 2045 (weighting: 40%):** The CO_2e savings from phases 2, 3, 4 from the end of construction of these phases (2030) until 2045 (net zero carbon goal).
- **Technical/operational (weighting: 35%):**
    - **Technology suitability (weighting: 20%):** Suitability of the option to the site, including security of supply, risks to development and land ownership risks.
    - **Operational complexity (weighting: 15%):** Level of difficulty for homeowner or Council to operate and maintain the technology plant.
- **Economic (weighting: 25%):**
    - **Capex (weighting: 10%):** The capital investment required to implement the option.
    - **Opex (weighting: 10%):** The annual operational costs including operational, maintenance and fuel costs required to implement the option.
    - **Annual cost of heat (weighting: 5%)**: The cost of heat to the homeowner and Council (irrespective of owner), including Opex and repayment of Capex (centralised and distributed). For centralised solutions, this assumes the heat network costs are passed on to consumers from the Council via a break-even heat tariff.

The results from the IRM are also shown in Sections 7.2.2 and **7.2.3** for Hoyland South and Royston, respectively. A low carbon pathway for each development can then be made, based on the most suitable energy options determined by the IRM.

7.2.1 Development phasing risks

The Framework outlines plans to develop both sites in six stages. Developing the site in phases creates potential risks for the energy strategy and potential energy supply options. Firstly, there are risks regarding the ownership of both sites. Currently, the Hoyland South site is divided between two landowners whereas the Royston site is divided between 13 landowners. Developing sites with multiple landowners may require a land assembly exercise to be completed and may affect the ability to construct the site in line with the phases outlined in the Framework. Constructing the site in phases also leads to risks around the timing and completion of dwellings, making it difficult to accurately predict the sites' energy demands at each stage of the development.

The uncertainty created by both the phasing and landownership makes implementing a centralised heating solution and subsequent heat network a high-risk option. To mitigate the risk of not knowing when each dwelling would be complete and require heating, a heat network and centralised heating system could be fully built at the beginning of the project. However, this would require a large capital investment and whilst, the site is running at less than full demand, any centralised system and heat network would be less efficient and carry operational risks. The construction of dwellings after the heat network is installed could also damage the trenched pipework, posing a further risk.

At Royston, these phasing risks and the multiple live planning applications for the site lead to no centralised heating solution being assessed further for Royston. At Hoyland South, centralised solutions will be explored further for phases 2, 3 and 4 due the low number of landowners, expected phasing sequence, high density of houses and geographical location.

7.2.2 Hoyland South shortlist options

The shortlist of potential energy supply technologies for dwellings and the shop in Hoyland South includes:

<u>Distributed options</u>
Electrical options:

1. Roof mounted solar PV with battery

Heating options:

2. Electric radiators
3. Electric boiler and wet heating system
4. Air source heat pump
5. Ground source heat pump
6. Solar thermal hot water

<u>Centralised options</u>
Heating options:

7. District heating with electric boiler
8. District heating with biomass boiler
9. District heating with ASHP
10. District heating with GSHP
11. District heating with mine water and heat pump

To allow a comparison of both the centralised and distributed energy options, the IRM only assesses the options across phases 2, 3 and 4 for Hoyland South as a centralised solution is unsuitable across other phases.

Heating energy supply options

There is potential for a heat network and centralised heating technology to supply heat for dwellings across phases 2, 3 and 4. Thus, both distributed and centralised technologies have been taken forward for further assessment across these phases. However, due to the phasing plan, housing density and topography of the site, a heat network would be unsuitable for phases 1, 5 and 6. Therefore, only distributed options will be assessed for these phases.

Each shortlisted technology has been assessed further using an IRM. To allow a comparison across all options, the IRM scores have been calculated for only phases 2, 3 and 4 of the development but the distributed scores are relevant for phases 1, 5 and 6. The IRM criteria and results are presented in Table 4. Further detail regarding the scoring of each technology against the assessment criteria can be found in Appendix E.

The majority of district heating options scored lower than distributed options due to the high capital costs and operational complexity. Therefore, all district heat networks and centralised heating technologies have been discounted from the study and will not be explored further in the pathway development.

Overall, the IRM has highlighted distributed heat pumps, specifically ASHP, as the most suitable technology to meet the heating demand of all dwellings across Hoyland South. Distributed ASHPs offer high carbon savings with low operational complexity, achieving a higher score than any centralised technology. Although GSHPs are more efficient than ASHPs, allowing GSHPs to realise higher carbon savings, GSHPs have higher capital costs and a higher annual cost of heat. Therefore, ASHPs will be taken forward to meet dwellings heating demand as part of Barnsley's pathway to a low carbon future.

The IRM rated electric radiators as next best heating option behind heat pumps. Electric radiators have lower capital costs compared to heat pumps however, they have higher operational costs and lower carbon savings. Electric radiators are popular with developers and will be explored further as part of an alternative pathway to allow comparison between the two electrified heating options.

Table 4: IRM for distributed and centralised heating technologies for Hoyland South.

Criteria Category	Sustainability	Technical/Operational		Economic			Total Score				
Category Weighting	40%	35%		25%							
Criteria	CO2e savings from site completion to 2045	Technology suitability	Operational complexity	Capex	Opex	Annual cost of heat	Sustainability	Technical/Operational	Economic	Total Score	Ranking
Weighting	40%	20%	15%	10%	10%	5%	40%	35%	25%		
Distributed and Centralised Systems - Phases 2, 3 and 4											
Electric radiators	3	5	5	5	1	2	1.20	1.75	0.70	3.65	3
Electric boiler with wet heating system	3	5	5	4	1	1	1.20	1.75	0.55	3.50	4
ASHP	5	5	4	3	4	2	2.00	1.60	0.80	4.40	1
GSHP	5	4	4	1	5	1	2.00	1.40	0.65	4.05	2
Solar thermal + gas boiler	1	4	4	3	5	5	0.40	1.40	1.05	2.85	7
DH + Electric/electrode boilers	2	4	3	3	1	1	0.80	1.25	0.45	2.50	10
DH + Biomass boilers	3	3	1	2	3	3	1.20	0.75	0.65	2.60	9
DH +ASHP	4	3	2	2	3	2	1.60	0.90	0.60	3.10	5
DH + GSHP	4	2	2	2	3	3	1.60	0.70	0.65	2.95	6
DH + Minewater and heat pump	4	1	2	2	3	1	1.60	0.50	0.55	2.65	8

Electricity energy supply options

Roof mounted PV paired with a battery was the only electricity generation technology taken forward to the shortlist. This option will be taken forward to the pathway development for the dwellings and shop at Hoyland South.

7.2.3 Royston shortlist options

The shortlist of potential energy supply technologies for dwellings, a school and a shop in Royston includes:

Distributed options
Electrical options:

1. Roof mounted solar PV with battery

Heating options:

2. Electric radiators
3. Electric boiler and wet heating system
4. Air source heat pump
5. Ground source heat pump
6. Solar thermal hot water

Heating energy supply options

The shortlisted technology options above have been identified as potential options to supply heat to both the dwellings and school within Royston. All centralised heating options have been discounted for Royston due to land ownership complications, current developments and planning applications, phasing layout and topography of the site. Therefore, only distributed heating options have been brought forward to the shortlist for further analysis.

The shortlisted heating options for both dwellings and the school have been assessed further using an IRM. The IRM results for the dwellings and school are shown in Table 5 and Table 6 respectively.

Table 5: IRM for distributed heating technologies for dwellings in Royston.

Criteria Category	Sustainability	Technical/Operational		Economic			Total Score				
Category Weighting	40%	35%		25%							
Criteria	CO2e savings from site completion to 2045	Technology suitability	Operational complexity	Capex	Opex	Annual cost of heat	Sustainability	Technical/Operational	Economic	**Total Score**	**Ranking**
Weighting	40%	20%	15%	10%	10%	5%	40%	35%	25%		
Distributed Systems											
Electric radiators	3	5	5	5	1	2	1.20	1.75	0.70	3.65	3
Electric boiler with wet heating system	3	5	5	4	1	1	1.20	1.75	0.55	3.50	4
ASHP	5	5	4	3	3	2	2.00	1.60	0.70	4.30	1
GSHP	5	4	4	1	5	1	2.00	1.40	0.65	4.05	2
Solar thermal + gas boiler	1	4	4	2	4	5	0.40	1.40	0.85	2.65	5

Table 6: IRM for distributed heating technologies for a school in Royston.

Criteria Category	Sustainability	Technical/Operational		Economic			Total Score				
Category Weighting	40%	35%		25%							
Criteria	CO2e savings from site completion to 2045	Technology suitability	Operational complexity	Capex	Opex	Annual cost of heat	Sustainability	Technical/Operational	Economic	**Total Score**	**Ranking**
Weighting	40%	20%	15%	10%	10%	5%	40%	35%	25%		
Centralised Systems											
Electric boilers	3	5	5	5	1	1	1.20	1.75	0.65	3.60	3
ASHP	5	5	4	3	4	3	2.00	1.60	0.85	4.45	1
GSHP	5	4	4	1	5	3	2.00	1.40	0.75	4.15	2

Similar to the results for Hoyland South’s IRM, distributed heat pumps have been highlighted as the most suitable technology to meet the heating demand of dwellings and schools within the Royston development. ASHPs will be included in Barnsley’s pathway to a low carbon future to meet the dwellings heat demand. For comparison, electric radiators will also be explored further as part of an alternative pathway.

A GSHP (with electrical boiler as backup) is to be included in the pathway to meet the school’s heat demand. This would lower its carbon emissions (further than an ASHP) to align with the Council’s objective of a net zero carbon school where possible.

Electricity energy supply options

Roof mounted PV paired with a battery was the only electricity generation technology taken forward to the shortlist. This option will be taken forward to the pathway development for the dwellings, shop and school at Royston.

8 Pathways

A preferred pathway for Hoyland South and Royston has been developed, to support Barnsley as they aim to become a net zero carbon borough by 2045. All pathways start from 2021, when the developments are assumed to start construction, until 2045.

The preferred pathways are based on the outcome of the IRM analysis with an alternative pathway also being described for comparison. It is assumed that all technology options will be installed as part of the construction process. For Barnsley to achieve their net zero carbon goal, any remaining carbon emissions should be offset through other means. Further carbon reduction and offsetting measures are explored in Section 9.

The pathways for Hoyland South and Royston are presented in the following sections.

8.1 Hoyland South pathway

The preferred pathway for Hoyland South includes the implementation of:

- Distributed ASHPs to supply heat in all dwellings
- Roof mounted PV panels with battery storage on dwellings with south-facing roofs (assumed as 33% of all dwellings), with grid backup
- Grid supply to all other dwellings
- Roof mounted PV panels on the shop, with grid supply backup

There is sufficient spare electrical capacity at nearby substations to support the preferred pathway. This pathway does not require gas network infrastructure on the site for supply of heat.

A number of assumptions have been made throughout the development of this pathway regarding the implementation, size and operation of these technologies. A list of these assumptions can be found in Appendix G.

8.1.1 Carbon emissions

The total equivalent carbon emissions emitted during the construction period (2022-2033) from the preferred pathway is 5,000 tonnes CO_2e, and 2,400 tonnes CO_2e from the site completion (2034) to 2045. A breakdown of these emissions, from construction to 2045 is presented in Figure 10.

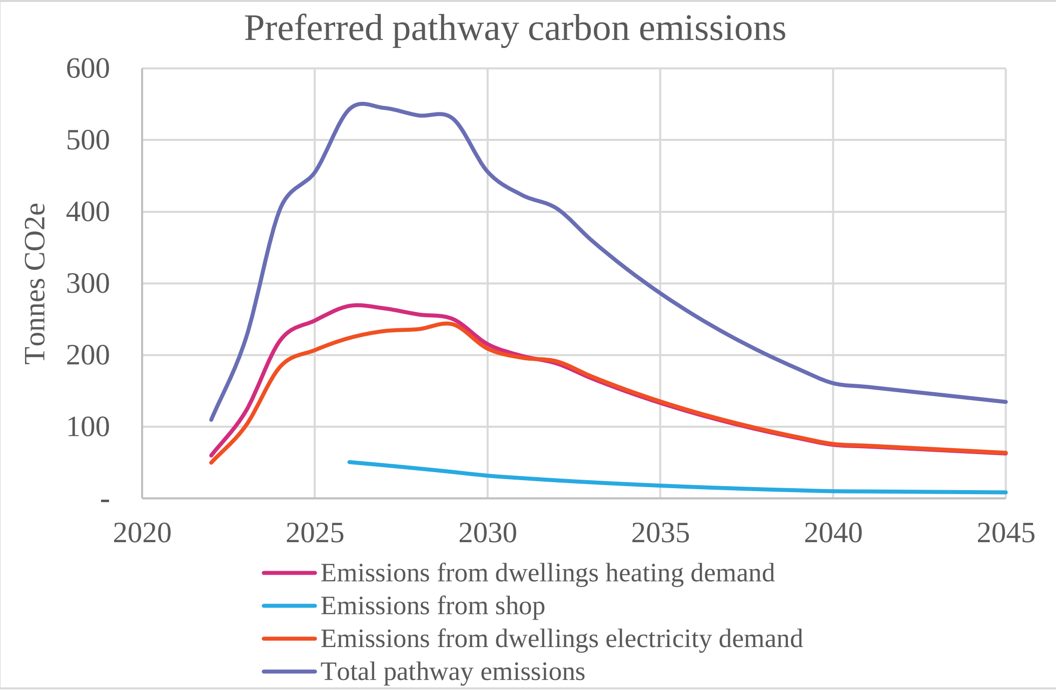


Figure 10: Equivalent carbon emissions emitted from Hoyland South's preferred pathway.

The counterfactual scenario at Hoyland South produced 14,900 tonnes CO_2e during the construction period, and 17,500 tonnes CO_2e from site completion to 2045.

Under this pathway, it is estimated the Hoyland South development will emit 135 tonnes CO_2e emissions in 2045. For Barnsley to achieve its goal of becoming a net zero carbon emissions borough by 2045, these emissions will have to be offset. Other carbon reduction methods have been explored in Section 9.

8.1.2 Costs to developers

The cost of installing the low-carbon heating and renewable electricity measures in dwellings is estimated in Table 7. This consists of distributed ASHPs in all dwellings, and installing PV panels and batteries in a third of the dwellings.

Table 7: Cost to developers for pathway options at Hoyland South.

Dwellings pathway options	No. dwellings with technology	Capex (£m)
Distributed ASHP	1,064	9.1
Roof mounted PV with battery storage and grid backup	355	4.5
Total dwelling intervention costs	**-**	**13.6**

An alternative pathway for the decarbonisation of heat is electric radiators in all dwellings. This would offer an electrified heating solution with a lower capital investment of £1.6m.

8.1.3 Costs for homeowners

A breakdown of the annual costs to homeowners for the preferred pathway is presented in Table 8. This includes annual Opex for each option (fuel and maintenance costs), and an annual cost of heat or electricity which reflects Opex plus a repayment of the Capex over the lifetime of the technology.

The values in Table 8 are based on dwellings built after the improved building standards have been implemented, as it is expected the majority of dwellings will be built to better standards.

Table 8: Annual costs to homeowner for heat and electricity interventions at Hoyland South.

Dwellings pathway options	Annual Opex (£/dwelling)	Annual cost of heat/electricity (£/dwelling)
Distributed ASHP	300	900
Roof mounted PV with battery storage and grid backup	50	850
Total dwelling intervention costs	**350**	**1,750**

An alternative pathway for the decarbonisation of heat consists of the implementation of electric radiators in all dwellings. The operational costs for electric radiators would be £600 per year per dwelling, compared to £300 for an ASHP. The cost of heat would be £700 per year (which reflects the smaller Capex invested), and is slightly lower than the ASHP solution of £900 per year. However, an alternative pathway using electric radiators would result in 10,500 tonnes CO_2e being emitted between 2022-2045 (from heating only), almost 3 times the emissions from ASHPs which would emit 3,500 tonnes CO_2e for the same period.

Regarding electricity, it is estimated that the dwellings with a PV panel and battery would have annual Opex of £50, compared to £450 for a typical home with all electricity met by the grid. The annual cost of electricity of £850 reflects the additional Capex required for the PV panel and battery, which will need to be replaced after 25 years and 15 years respectively.

To assist BMBC in reaching zero carbon emissions by 2045, it is suggested that the preferred pathway, consisting of ASHPs and roof mounted PV with a connection to the grid, is followed across the Hoyland South development. Whilst other decarbonisation methods may offer cheaper installation and operation, the combination of ASHPs and roof mounted PV allows significantly lower emissions. To reach net zero emissions, the emissions from supplying heat and electricity across the site should be offset.

8.2 Royston pathway

The preferred pathway for Royston includes the implementation of:

- Distributed ASHPs to supply heat in all dwellings
- GSHP in the school with electric boiler backup
- Roof mounted PV panels with battery storage on dwellings with south-facing roofs (assumed as 33% of all dwellings), with grid backup
- Grid supply to all other dwellings
- Roof mounted PV panels on the shop, with grid backup
- Roof mounted PV panels on the school, with grid backup

There is sufficient spare electrical capacity at nearby substations to support the preferred pathway. This pathway does not require gas network infrastructure on the site for supply of heat.

This pathway does not include interventions for houses under construction in the Barratt Homes development. Further assumptions have been made throughout the development of this pathway and can be found in Appendix G.

8.2.1 Carbon emissions

The total equivalent carbon emissions emitted during the construction period (2021-2033) from the preferred pathway is 4,100 tonnes CO_2e, and 2,000 tonnes CO_2e from the site completion (2034) to 2045. A breakdown of these emissions, from construction to 2045 is presented in Figure 11.

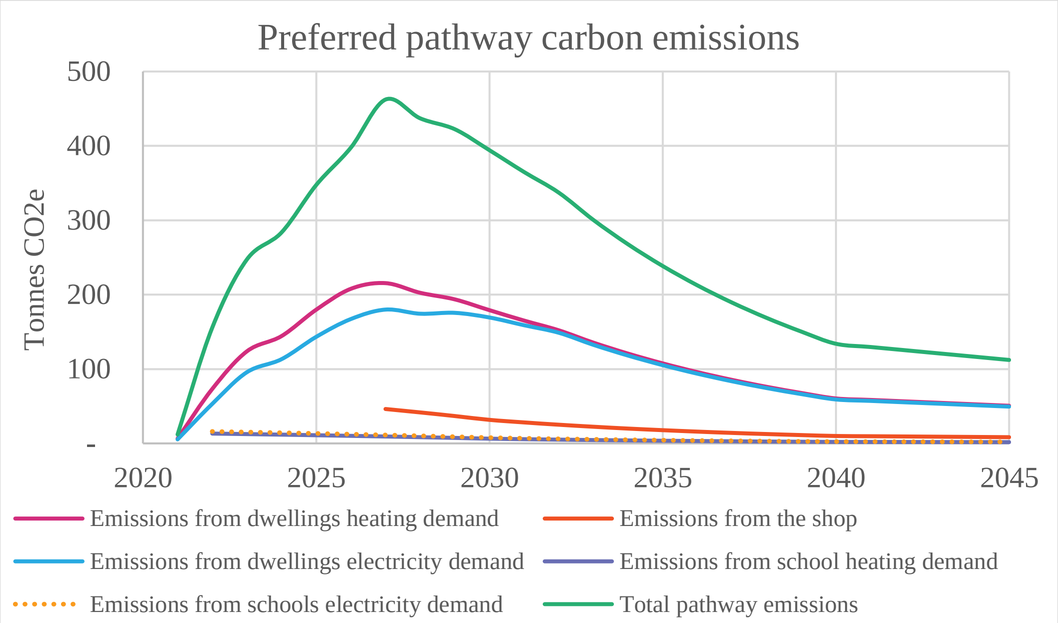


Figure 11: Equivalent carbon emissions emitted from Royston's preferred pathway.

The counterfactual scenario at Royston produced 12,000 tonnes CO_2e during the construction period, and 14,300 tonnes CO_2e from site completion to 2045.

Under this pathway, it is estimated the Royston development will emit 115 tonnes CO_2e emissions in 2045. For Barnsley to achieve its goal of becoming a net zero carbon emissions borough by 2045, these emissions will have to be offset.

8.2.2 Costs to developers

The cost of installing the low-carbon heating and renewable electricity measures in dwellings is estimated in Table 9. This consists of distributed ASHPs in all dwellings, and installing PV panels and batteries in a third of the dwellings.

Table 9: Cost to developers for pathway options at Royston.

Dwellings pathway options	No. dwellings with technology	Capex (£m)
Distributed ASHP	828	7.1
Roof mounted PV with battery storage and grid backup	276	3.5
Total dwelling intervention costs	**-**	**10.6**

The alternative of electric radiators in all dwellings has an estimated capital cost of £1.3m.

8.2.3 Costs for homeowners

A breakdown of the annual costs to homeowners for the preferred pathway is presented in Table 10. This includes annual Opex and annual cost of heat or electricity to the customer. These values are the same as those for Hoyland South.

The values in Table 10 are based on dwellings built after the improved building standards have been implemented, as it is expected the majority of dwellings will be built to better standards.

Table 10: Annual costs to homeowner for heat and electricity interventions at Royston.

Dwellings pathway options	Annual Opex (£/dwelling)	Annual cost of heat/electricity (£/dwelling)
Distributed ASHP	300	900
Roof mounted PV with battery storage and grid backup	50	850
Total dwelling intervention costs	**350**	**1,750**

The alternative pathway for the decarbonisation of heat with electric radiators has associated operational costs of £600 per year per dwelling, twice as much as those estimated for an ASHP. The annual cost of heat of £700 per year (which accounts for Capex and Opex) is slightly lower than the ASHP solution which would cost the homeowner £900 per year. However, an alternative pathway using electric radiators would result in 8,500 tonnes CO_2e being emitted between 2021-2045 (heating only), almost 3 times the emissions from ASHPs which would emit 2,900 tonnes CO_2e for the same period.

Regarding electricity, it is estimated that the dwellings with a PV panel and battery would have annual Opex of £50, compared to £450 for a typical home with all electricity met by the grid. The annual cost of electricity of £850 reflects the additional Capex required for the PV panel and battery, which will need to be replaced after 25 years and 15 years respectively.

To assist BMBC in reaching zero carbon emissions by 2045, it is suggested that the preferred pathway, consisting of a combination of ASHPs, GSHP and roof mounted PV panels with a connection to the grid is followed across the Royston development. Whilst other decarbonisation methods may offer cheaper installation and operation, the combination of ASHPs, GSHPs and roof mounted PV panels allow significantly lower emissions. To reach net zero emissions, the emissions from supplying heat and electricity across the site should be offset.

8.3 Pathways limitations

The pathways described in Sections 8.1 and 8.2 have some limitations. This study only considers equivalent carbon emissions from dwellings, shops and schools within the developments. However, there will be emissions emitted from other sources such as street lighting, public transport and the day to day maintenance of the development (e.g. waste disposal collections). Emissions associated with these sources should be explored further. A brief description of supplementary carbon reduction measures is presented in Section 9.

The equivalent carbon emissions for each development are based on developers constructing the sites in line with the phasing plan proposed in the Masterplan Framework documents. The emissions associated with electricity from the grid are based on the grid decarbonising as predicted by BEIS.

The pathways were also developed with respect to the current uncertainty around the hydrogen market. Thus, it has been assumed there is no hydrogen network established locally at the start of the construction period. However, a hydrogen network may be established in the future. Decarbonising heat via blending hydrogen into the gas network has not been explored in this study as it is still a carbon intensive process and is also in the early stages of development.

9 Further carbon reduction measures

Additional carbon saving methods could be implemented to reduce emissions and assist BMBC in becoming at net zero carbon emissions borough by 2045. The additional measures include, but are not limited to:

- **Smart devices at home:** Smart devices such as thermostats and lighting controls can implemented as part of smart homes. Smart devices have the potential to reduce the energy (heat and electricity) demand of dwellings and the associated emissions.
- **EV home charging:** Promoting the uptake of electric vehicles by providing in-built electric vehicle charging capabilities in the dwellings, could reduce transport emissions within Barnsley. It is noted this is already BMBC policy. An increased uptake of electric vehicles would also reduce the developments' negative impact on local air quality.
- **Vehicle-to-Grid scheme:** The vehicle-to-grid scheme is a smart charging system that also allows energy stored in batteries of electric vehicles to be injected back into the grid when required.
- **Microgrids:** a localised energy grid for these developments would provide control capability, and can be powered by generators, batteries and renewable sources. It can operate autonomously or alongside the grid.
- **Demand side response (DSR):** DSR refers to the process of managing energy more efficiently through modifying the energy requirements of consumers. This can be achieved through incentives or behavioural change. The new developments could implement a DSR system to maximise the use of onsite energy generation. Consumers can switch to use the local energy source, the grid or local energy storage at different times.
- **LED streetlights and streetlighting controls**: The energy required for street lighting can be reduced by installing LED streetlights with flexible controls. Streetlighting controls allow lights to only be switched on when required and offer inter-seasonal flexibility.
- **At schools**: a building energy management system (BEMS) along with smart meters can be used to plan and deliver reductions in energy consumption and carbon emissions. Renewable electricity can be purchased in bulk to reduce the unit price of low-carbon power. Training for operation of new heating systems should be provided to staff and the school curriculum presents opportunities for education of greener technologies.
- **Power purchase agreement (PPA) for green electricity:** A PPA can be established between an electricity provider and BMBC or a third party to provide renewable electricity to the new school. This could provide a lower carbon alternative to the electricity supplied by the grid in the preferred pathways.

- **Using hydrogen**: The potential to decarbonise heat through the use of hydrogen is currently being explored in the UK through the Hy4Heat programme. This scheme aims to assess the potential to use hydrogen for heating and cooking. Locally, the H21 programme is studying projects in the north of England to test the feasibility of a hydrogen gas network. Whilst hydrogen may not be a suitable option for these developments currently, it could be an option for the future.

9.1 Offsetting carbon emissions

Carbon offsetting is a method of reducing carbon emissions in one location, to compensate for carbon emissions emitted elsewhere. Carbon emissions can be offset by investing in renewable energy projects offsite and tree planting schemes.

By following the proposed pathways, the Hoyland South and Royston developments will still emit approximately 135 tonnes CO_2e and 115 tonnes CO_2e annually in 2045, respectively. These values are linked to the predicted grid electricity carbon factors by BEIS, which flattens to a constant value from 2050.

Planting trees is one of the options to offset carbon emissions while providing local habitat to wildlife. Carbon dioxide absorbed by the tree is converted into stored carbon. The amount of carbon dioxide a tree can offset depends on the type of tree, space available to grow, and age. Estimates to offset 1 tonne CO_2 range between one broad leaf tree across 100 years, to four mature trees (at least 10 years old).

Using a conservative approach, it is estimated that 1,000 mature trees would be required to offset the carbon emitted over one year from heating and electricity by these developments.

Any offsetting activity has to demonstrate that they are not "counted" twice by different entities to benefit from the carbon offset.

Another option is to use "allowable solutions" to counteract carbon emissions with offsite measures. As explained by the Zero Carbon Hub in Figure 12 , developers can pay into a carbon fund at a defined rate per tonne of CO_2, to be invested into carbon saving projects (Allowable Solutions projects).

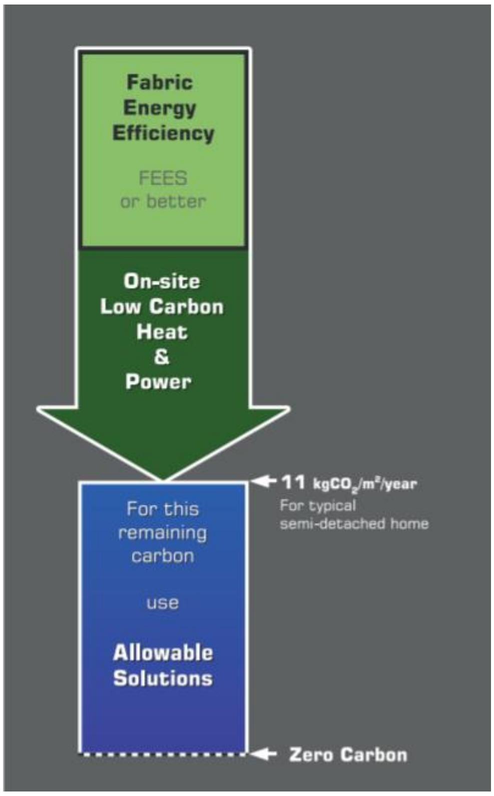


Figure 12: Balanced approach (Source: Zero Carbon Hub).

10 Conclusion and Recommendations

This study has identified preferred, low-carbon energy pathways for Hoyland South and Royston developments, in order to aid Barnsley's transition to becoming a net zero carbon borough by 2045. Hoyland South is a new residential development which will include 1,064 houses, as well as a community hub and a convenience store. The Royston development will comprise 994 new homes a community hub, a convenience store and a new primary school.

The study began by reviewing current and future energy building standards which informed the building recommendations for these new developments. This review included an assessment of buildings fabric performance and energy performance standards. The review found that standards are likely to improve throughout the development's construction period, thus two standards have been recommended. The recommendations are summarised in Table 11. Other energy performance metrics (EPC rating A, or energy use intensity) can also be used to set the energy standards in these developments.

Table 11: Recommended building standards.

Fabric performance area	Performance value	
	Recommended minimum standard	**Recommended aspirational standard**
Air permeability	$\leq$ 5 m^3/ ($h.m^2$) @50Pa	$\leq$ 1 m^3/ ($h.m^2$) @50Pa
Roof U-value	$\leq$ 0.15 W/m^2. K	$\leq$ 0.11 W/m^2. K
Wall U-value	$\leq$ 0.15 W/m^2. K	$\leq$ 0.13 W/m^2. K
Floor U-value	$\leq$ 0.15 W/m^2. K	$\leq$ 0.11 W/m^2. K
Window U-value	$\leq$ 1.2 W/m^2. K	$\leq$ 0.8 W/m^2. K

Following the building performance standards review, an energy demand assessment was conducted. The energy demand for each site was calculated based on energy benchmarks suitable for new builds. This has resulted in an estimated annual heating demand (space heating and hot water) of 5,400MWh and annual electricity demand of 3,000MWh for Hoyland South, once the development has been completed. It is estimated Royston will have an annual heating demand of 4,400MWh and an annual electricity demand of 2,400MWh, once the development has been completed.

An energy supply options appraisal was then conducted. This included the development of a longlist of distributed and centralised heating and electricity supply options. The longlist was used to create an individual shortlist energy supply options, for each site. These options were explored further through an IRM assessment based on BMBC's priorities, in order to highlight the most suitable technologies. The energy options appraisal resulted in distributed heat pumps and roof mounted PV panels to be the most suitable technologies for implementation across both sites.

The results of the IRM were used to create the following preferred pathways for each development:

Hoyland South Pathway:

- Distributed ASHPs in all dwellings
- Roof mounted PV panels with battery storage on dwellings with south-facing roofs, and grid backup
- Grid supply to all other dwellings
- Roof mounted PV panels on the shop, and grid backup

Royston Pathway:

- Distributed ASHPs in all dwellings
- Roof mounted PV panels with battery storage on dwellings with south-facing roofs, and grid backup
- Grid supply to all other dwellings
- Roof mounted PV panels on the shop, and grid backup
- Roof mounted PV panels on the school, and grid backup
- GSHP in the school with electric boiler backup

Throughout this study it has been assumed the energy supply options in the preferred pathways are replaced like for like. However, the installation of ASHPs in all dwellings will result in a wet heating system being installed as part of construction. This provides flexibility in the future to install other, lower carbon technologies in dwellings, if required.

The preferred pathways for both sites do not require any gas network infrastructure. There is sufficient spare electrical capacity at nearby substations to support the preferred pathways.

The preferred pathways would result in 7,400 tonnes CO_2e being emitted from Hoyland South and 6,100 tonnes CO_2e from Royston, between the start of construction (2021) until 2045. In 2045, it is estimated the developments will emit 250 tonnes CO_2e combined. For Barnsley to become a net zero carbon emissions Borough by 2045, the remaining carbon emissions would have to be offset. This could be done through investing in offsite renewables or rewilding and tree planting schemes.

The preferred pathways and subsequent emissions only focus on buildings within the new developments. The pathways do not include emissions from transport within the developments, street lighting or continued maintenance of the sites. It is recommended that these areas are investigated further in order to manage emissions and assist Barnsley in becoming net zero carbon emissions by 2045.

As the response to the climate emergency evolves, the low carbon technologies available may change and become more accessible. For example, hydrogen may be supplied through the gas network and hydrogen technologies may become a more suitable option. BMBC should watch emerging technologies and keep moving towards a zero-carbon future.

Appendix A

Workshop 1 slides

Energy Strategy – Hoyland South and Royston Workshop 1

16 June 2020

ARUP

1

Fabric performance standards for houses

Air Permeability ≤ 5 m³/(h.m²)@50Pa

Roof U-values ≤ 0.11 W/m².K

Wall U-values ≤ 0.15 W/m².K

Floor U-values ≤ 0.13 W/m².K

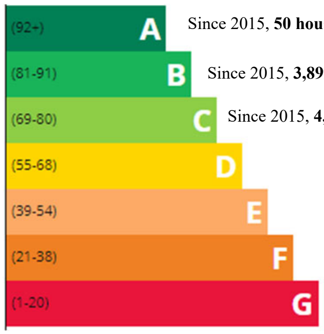
Window U-values ≤ 0.8 W/m².K

Strategy:
High standards of fabric performance

ARUP

2

Energy performance standards



Since 2015, **50 houses** in Barnsley lodged an **EPC A**

Since 2015, **3,899 houses** in Barnsley lodged an **EPC B**

Since 2015, **4,694 houses** in Barnsley lodged an **EPC C**

Question:
- Should we set an EPC target for the homes?
- If so, how ambitious should we be?

ARUP

3

Overarching energy consumption targets

Reduce energy consumption to:

35 kWh/m².yr

Energy Use Intensity (EUI) in GIA, excluding renewable energy contribution

Reduce space heating demand to:

15 kWh/m².yr

Question:
- Should we set Energy Use Intensity targets, in line with LETI?
- Should we set space heating demand targets, in line with LETI?

ARUP

4

Energy benchmarks for energy model

	Heat (kWh/m².year)	Electricity (kWh/m².year)	
Residential	77	31	*Statistics for new builds, EPC B (2017)*
School	71	74	*DfE Output Specification benchmarks (2019)*
Convenience store	-	550	*Data from CIBSE Guide F (2004)*

Long list of options

Building-integrated options:

1. Roof mounted solar PV
2. Roof mounted solar PV with battery
3. Electric radiators
4. Electric boiler and wet heating system
5. Air source heat pump
6. Ground source heat pump
7. Biomass boiler
8. Hydrogen boiler
9. Hydrogen fuel cell CHP
10. Micro gas CHP boiler
11. Solar thermal hot water

Long list of options

Centralised options:

12. Ground mounted solar PV
13. Ground mounted solar PV with battery
14. Wind turbines
15. Wind turbines with battery
16. Hydro power
17. Geothermal power
18. District heating (DH) with Electric boiler
19. DH with Biomass boiler
20. DH with WSHP
21. DH with ASHP
22. DH with GSHP
23. DH with minewater and heat pump
24. DH with Gas CHP
25. DH with Gas CHP and battery
26. DH with Biomass CHP
27. DH with Biomass CHP and battery
28. DH with Hydrogen boiler
29. DH with Hydrogen fuel cell CHP
30. DH with Hydrogen fuel cell CHP and battery
31. DH with solar thermal

Short list of options

Building-integrated

1. Roof mounted solar PV with battery
2. Electric radiators
3. Electric boiler and wet heating system
4. Air source heat pump
5. Ground source heat pump
6. Solar thermal hot water

Centralised

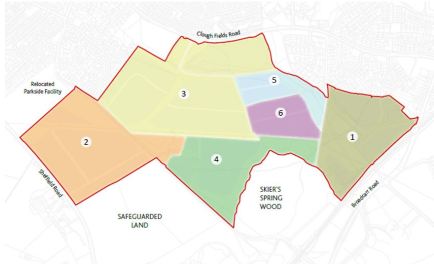
7. Ground mounted PV (Hoyland South)
8. District heating (DH) with Electric boiler
9. DH with Biomass boiler
10. DH with ASHP
11. DH with GSHP
12. DH with minewater and heat pump (Hoyland South)
13. DH with Biomass CHP
14. DH with Biomass CHP and battery
15. DH with Hydrogen boiler
16. DH with Hydrogen fuel cell CHP
17. DH with Hydrogen fuel cell CHP and battery

Evaluation criteria

Category	Criteria	Priority
Technical	Technology suitability Operational complexity	2
Economic	Capex Opex Simple payback period (building-integrated)	3
Environmental	CO2 savings Air quality impact Alignment with UK strategy for carbon neutrality Lifetime carbon savings (£/kg CO2)	1
Strategic	Security of supply Flexibility of technology	4
Planning	Development risk	

Phasing of development

- Hoyland South



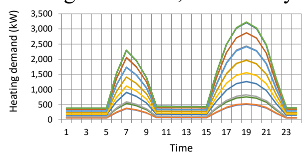
Phasing of development

- Royston

Energy demand estimates – whole site

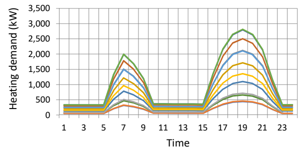
Hoyland South

Heating demand: 6,000 MWh/year

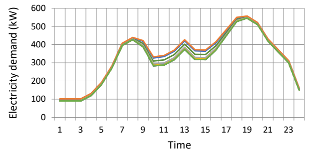


Royston (exc. Barratt Homes)

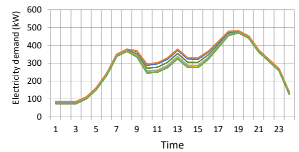
Heating demand: 5,200 MWh/year



Electricity demand: 2,800 MWh/year



Electricity demand: 2,400 MWh/year



Next steps

- Evaluation of shortlisted options
- Pathways to net zero carbon by 2045
- Workshop 2 (pathways presentation)

Appendix B

Workshop 2 slides

Energy Strategy – Hoyland South and Royston Workshop 2

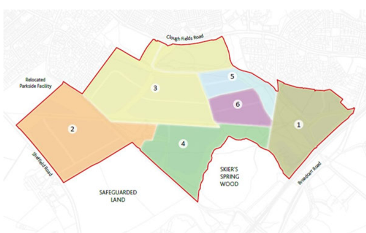
17 July 2020

ARUP

1

Heat networks

- Risks of implementation over a phased development



Hoyland South

Heat network for phases 2, 3 and 4?

Royston

No heat network investigated

2 ARUP

2

Hoyland South - Evaluation

Criteria Category	Sustainability	Technical/Operational		Economic			Total Score				
Category Weighting	40%	35%		25%							
Criteria	CO2e savings from site completion to 2045	Technology suitability	Operational complexity	Capex	Opex	Annual cost of heat	Sustainability	Technical/Operational	Economic	Total Score	Ranking
Weighting	40%	20%	15%	10%	10%	5%	40%	35%	25%		
Distributed and Centralised Systems - Phases 2, 3 and 4											
Electric radiators	3	5	5	5	1	2	1.20	1.75	0.70	3.65	3
Electric boiler with wet heating system	3	5	5	4	1	1	1.20	1.75	0.55	3.50	4
ASHP	5	5	4	3	4	2	2.00	1.60	0.80	4.40	1
GSHP	5	4	4	1	5	1	2.00	1.40	0.65	4.05	2
Solar thermal + gas boiler	1	4	4	3	5	5	0.40	1.40	1.05	2.85	7
DH + Electric/electrode boilers	2	4	3	3	1	1	0.80	1.25	0.45	2.50	10
DH + Biomass boilers	3	3	1	2	3	3	1.20	0.75	0.65	2.60	9
DH +ASHP	4	3	2	2	3	2	1.60	0.90	0.60	3.10	5
DH + GSHP	4	2	2	2	3	3	1.60	0.70	0.65	2.95	6
DH + Minewater and heat pump	4	1	2	2	3	1	1.60	0.50	0.55	2.65	8

3 ARUP

3

Hoyland South - Evaluation

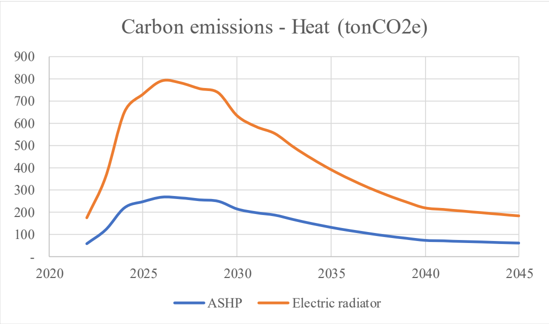
Short List

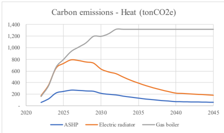
1 ASHP
2 GSHP
3 Electric radiators
4 Electric boiler with wet heating system
5 DH +ASHP
6 DH + GSHP
7 Solar thermal + gas boiler
8 DH + Minewater and heat pump
9 DH + Biomass boilers
10 DH + Electric/electrode boilers

4 ARUP

4

Hoyland South – Heat decarbonisation pathways



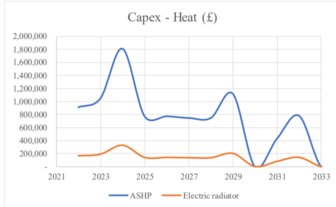


ARUP

Hoyland South – Heat decarbonisation costs

	ASHP		Electric radiators	
	Pre-2025	Post-2025	Pre-2025	Post-2025
Annual Opex (£)	500	300	1,100	600
Annual cost of heat (£)	1,050	900	1,150	700
Total Capex (£m)		9.1		1.6

**Cost of heat includes Opex and recovery of Capex over lifetime of technology*



ARUP

Royston - Evaluation

Criteria Category	Sustainability	Technical/Operational		Economic			Total Score				
Category Weighting	40%	35%		25%							
Criteria	CO2e savings from site completion to 2045	Technology suitability	Operational complexity	Capex	Opex	Annual cost of heat	Sustainability	Technical/Operational	Economic	Total Score	Ranking
Weighting	40%	20%	15%	10%	10%	5%	40%	35%	25%		
Distributed Systems											
Electric radiators	3	5	5	5	1	2	1.20	1.75	0.70	3.65	3
Electric boiler with wet heating system	3	5	5	4	1	1	1.20	1.75	0.55	3.50	4
ASHP	5	5	4	3	3	2	2.00	1.60	0.70	4.30	1
GSHP	5	4	4	1	5	1	2.00	1.40	0.65	4.05	2
Solar thermal + gas boiler	1	4	4	2	4	5	0.40	1.40	0.85	2.65	5

ARUP

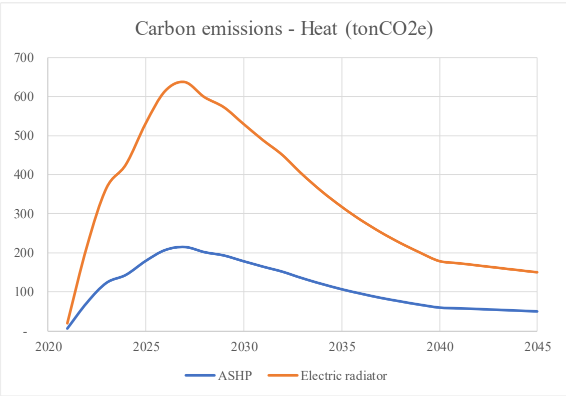
Royston - Evaluation

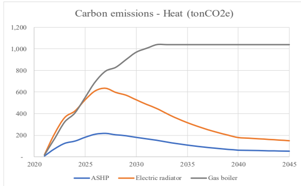
Short List

1 ASHP
2 GSHP
3 Electric radiators
4 Electric boiler with wet heating system
5 Solar thermal + gas boiler

ARUP

Royston– Heat decarbonisation pathways

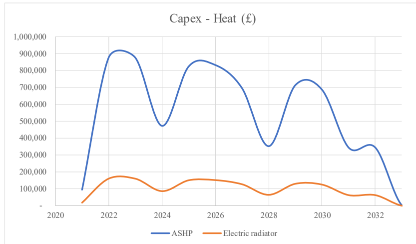




9

Royston – Heat decarbonisation costs

	ASHP		Electric radiators	
	Pre-2025	Post-2025	Pre-2025	Post-2025
Annual Opex (£)	500	300	1,100	600
Annual cost of heat (£)	1,050	900	1,150	700
Total Capex (£m)		7.1		1.3

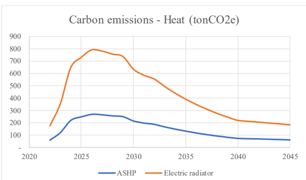


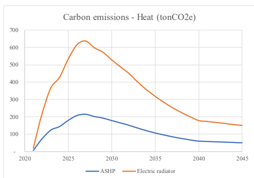
10

Solution for heat decarbonisation

…that is still economical for investor and homeowner

- 100% homes with ASHPs?
- 100% homes with electric radiators?
- Compromise?





11

Royston school – Heat decarbonisation

Criteria Category	Sustainability	Technical/Operational		Economic			Total Score				
Category Weighting	40%	35%		25%							
Criteria	CO2e savings from site completion to 2045	Technology suitability	Operational complexity	Capex	Opex	Annual cost of heat	Sustainability	Technical/Operational	Economic	Total Score	Ranking
Weighting	40%	20%	15%	10%	10%	5%	40%	35%	25%		
Centralised Systems											
Electric boilers	3	5	5	5	1	1	1.20	1.75	0.65	3.60	3
ASHP	5	5	4	3	4	3	2.00	1.60	0.85	4.45	1
GSHP	5	4	4	1	5	3	2.00	1.40	0.75	4.15	2

12

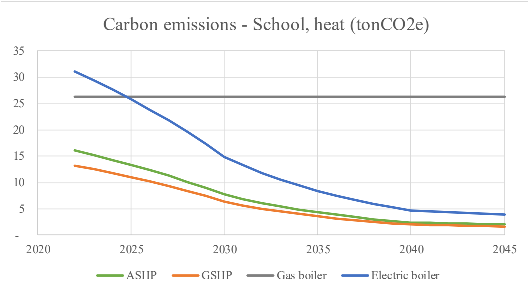
Royston school – Heat decarbonisation

Short List

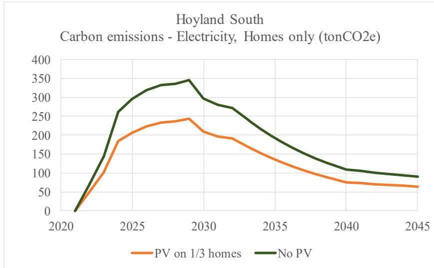
1 ASHP

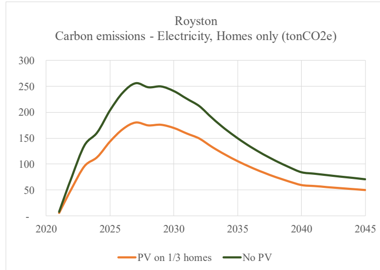
2 GSHP

3 Electric boilers



Electrical demand decarbonisation (PV & battery)





Save 30% grid imports by installing PV & batteries in 1/3 of total homes
Save 30% carbon emissions (against no PV)

Electrical demand decarbonisation - Costs

	No PV	PV + battery	
Annual Opex (£)	450	50	
Annual cost of electricity (£)	450	850	
Total Capex Hoyland (£m)	-	4.5	355 homes
Total Capex Royston (£m)	-	3.5	276 homes

Requirement or suggestion to install PV panels in a x% of homes?

Other carbon reduction measures

- Smart devices at home
- LED street lighting
- EV chargers at home
- Vehicle to grid charging
- Demand side management
- Purchase of renewable electricity
- Hydrogen?

Other information required

- PV in school for electricity generation
- PV in shops
- Council decision on:
  - ➢ housing standards
    - fabric performance ✓
    - EPC rating A?
    - energy consumption targets (LETI or other)?
  - ➢ school performance: net zero? DfE design guidance?

Next steps

- Draft report – w/c 27 July
- Council review period – *2 weeks?*
- Final Issue - August
- Sustainability and Energy Use input to Masterplan framework documents

  (4 September, with Masterplan Framework Documents Draft)

Appendix C

Assumptions

C1 Phased build-out

The following assumptions were made regarding the phasing of the two sites:

Hoyland South	Phase							Total
	1	2	3a	3b	4	5	6	
Year	2021-2022	2022-2024	2023-2026	2026-2028	2028-2029	2030-2031	2031-2032	2021-2032
Number of buildings per type								
Dwellings	106	243	270	174	130	50	91	1,064
Convenience store	0	0	1	0	0	0	0	1
Heating energy demands (kWh)								
Dwellings	655,000	1,500,000	1,670,000	615,000	460,000	175,000	320,000	5,400,000
Convenience store	0	0	0	0	0	0	0	0
Electricity energy demands (kWh)								
Dwellings	265,000	605,000	675,000	435,000	325,000	125,000	225,000	2,700,000
Convenience store	0	0	275,000	0	0	0	0	275,000

Royston	**Phase**									**Total**
	1a	1b	1c	1d	2	3	4	5	6	
Year	2021	2021-2022	2021-2023	2021-2023	2023-2026	2024-2027	2026-2029	2028-2030	2029-2032	2021-2032
Number of buildings per type										
Dwellings	11	0	118	86	166	122	124	81	120	828
Convenience store	0	0	0	0	0	1	0	0	0	1
Primary school	0	1	0	0	0	0	0	0	0	1
Heating energy demands (kWh)										
Dwellings	70,000	0	730,000	530,000	1,025,000	755,000	440,00	285,000	425,000	4,300,000
Convenience store	0	0	0	0	0	0	0	0	0	0
Primary school	0	105,000	0	0	0	0	0	0	0	105,000
Electricity energy demands (kWh)										
Dwellings	30,000	0	295,000	215,000	415,000	300,000	310,000	200,000	300,000	2,100,000
Convenience store	0	0	0	0	0	275,000	0	0	0	275,000
Primary school	0	95,000	0	0	0	0	0	0	0	95,000

The total number of dwellings has been divided between 2, 3 and 4 beds using the % splits below:

Housing type	**Percentage of dwellings (%)**
2-bed house	20
3-bed house	41
4-bed house	39

C2 Cost assumptions

The following assumptions were made in the development of the energy model costs:

- No contingency has been added to the costs of distributed options.
- No incentives applied to heat generating options (distributed or centralised)
- Coefficient of performance for distributed heat pumps is the same for dwelling pre- and post- fabric improvement.
- GSHP systems are based on closed loop, vertical boreholes.
- Centralised technologies use electric boilers as peaking plant as back-up, to maximise carbon savings. While it is expected that they will operate for a small part of the year, the electrical connection to the energy centre will need to be sized to satisfy the peak electric boiler's demand in case of main plant failure.
- Capex and cost of heat for centralised heat options assumes that the heat network (trench and pipework, energy centre and plant) is fully built-out in the first year.
- The heat network owner/operator would recover the Capex and Opex (and fuel) investment from consumers via a heat tariff. This heat tariff (used for comparison purposes) does not include profit, grants or funding.
- Carbon emissions factors for biomass and gas carbon is constant in time.
- Unit price for gas and electricity is constant in time.

C3 Energy Benchmarks

The energy benchmarks and sources are presented below.

Hoyland South & Royston			
Item	**Value**	**Unit**	**Reference**
Housing heating	77	kWh/m^2	BEIS Energy consumption in new domestic buildings 2015 to 2017 (England and Wales)
Housing electric	31	kWh/m^2	BEIS Energy consumption in new domestic buildings 2015 to 2017 (England and Wales)
Housing DHW	30	kWh/m^2	Arup estimate
Improved housing heating	44	kWh/m^2	Energy Performance of Buildings Directive, Second Cost Optimal Assessment for the UK (2019)
Improved housing electric	31	kWh/m^2	BEIS Energy consumption in new domestic buildings 2015 to 2017 (England and Wales)
Improved housing DHW	23	kWh/m^2	Arup estimate
Small food shop heating	0	kWh/m^2	CIBSE Guide F (2004)
Small food shop electric	550	kWh/m^2	CIBSE Guide F (2004)
Primary school heating	71	kWh/m^2	Department for Education Output Specification, Annex 2H Energy (2019)
Primary school electric	64	kWh/m^2	BMBC energy data for primary and secondary schools

C4 Generation technologies

Distributed heating options

Gas boilers			
Item	**Value**	**Unit**	**Reference**
Gas boiler efficiency	85	%	Arup project experience
CAPEX	5,607	£/dwelling	Energy Performance of Buildings Directive, Second Cost Optimal Assessment for the UK (2019)
O&M	70	£/year	Arup project experience
Lifetime	15	Years	Energy Performance of Buildings Directive, Second Cost Optimal Assessment for the UK (2019)

Roof mounted PV and Battery			
Item	**Value**	**Unit**	**Reference**
Dwellings with panel installation	33	% of site	Based on south facing roofs in Barratt planning documents
PV size	3	kWp/ dwelling	Average installation for 3-bed house
PV annual electrical output	2,788	kWh/year	Global Solar Atlas
3-bed house electrical demand	2,387	kWh/year	Benchmarks
Grid import in winter	11	% house demand	Global Solar Atlas
Export to grid in summer	23	% house demand	Global Solar Atlas
CAPEX PV panel (all inclusive)	1,562	£/kWp	Solar photovoltaic cost data (BEIS 2020)
CAPEX Inverter	800	£	Arup project experience
O&M cost	15	£/kWp.year	Arup project experience
PV lifetime	25	Years	
Inverter lifetime	8	Years	Energy Saving Trust
Smart export guarantee (SEG)	3	p/kWh	Expected average value

Electric radiators			
Item	**Value**	**Unit**	**Reference**
Efficiency	100	%	Arup project experience
CAPEX	1,540	£/dwelling	Based on 7 radiators per home
O&M cost	0	£/year	Arup project experience
Lifetime	20	Years	CIBSE Guide M

Electric boiler with wet heating system			
Item	**Value**	**Unit**	**Reference**
Electric boiler efficiency	99	%	Arup project experience
CAPEX	5,620	£/ dwelling	Energy Performance of Buildings Directive, Second Cost Optimal Assessment for the UK (2019)
O&M cost	0	£/year	Arup project experience
Lifetime	20	Years	CIBSE Guide M

Distributed ASHP			
Item	**Value**	**Unit**	**Reference**
COP	2.95	#	Energy Performance of Buildings Directive, Second Cost Optimal Assessment for the UK (2019)
CAPEX	8,593	£/dwelling	Energy Performance of Buildings Directive, Second Cost Optimal Assessment for the UK (2019)
O&M cost	110	£/year	Energy Performance of Buildings Directive, Second Cost Optimal Assessment for the UK (2019)
Lifetime	15	Years	Energy Performance of Buildings Directive, Second Cost Optimal Assessment for the UK (2019)

Distributed GSHP			
Item	**Value**	**Unit**	**Reference**
COP	3.5	#	BSRIA
CAPEX	23,458	£/dwelling	Arup project experience
O&M cost	0	£/year	No regular maintenance required
Heat pump lifetime	20	Years	CIBSE Guide M
Borehole lifetime	60	Years	Arup project experience

Solar Thermal Hot Water			
Item	**Value**	**Unit**	**Reference**
Heat contribution	50	% of DHW	Arup project experience
CAPEX	10,237	£/ dwelling	Energy Performance of Buildings Directive, Second Cost Optimal Assessment for the UK (2019)
O&M cost	160	£/year	Energy Performance of Buildings Directive, Second Cost Optimal Assessment for the UK (2019)
Lifetime solar panel	25	Years	Energy Performance of Buildings Directive, Second Cost Optimal Assessment for the UK (2019)

Battery Storage (Domestic)			
Item	**Value**	**Unit**	**Reference**
Battery size	6	kWh/ dwelling	Spirit Energy
CAPEX	7,290	£/system	Spirit Energy
O&M cost	0	£/year	Arup project experience
Lifetime	15	Years	Solar Harvester

Centralised heating options

Gas boilers			
Item	**Value**	**Unit**	**Reference**
Efficiency	90	%	Arup project experience
CAPEX	50	£/kW	Arup project experience
O&M cost	3	£/kWth.year	(Poyry) DECC 2009
Lifetime	20	years	CIBSE Guide M

Electric Boiler			
Item	**Value**	**Unit**	**Reference**
Electrode boiler efficiency	99	%	Supplier data (Parat, Flexiheat)
Direct electric boilers	100	£/kW	Supplier quotes (Parat, Flexiheat)
O&M	2.5	£/MWh.year	Arup project experience
Lifetime	20	years	CIBSE Guide M

Biomass Boiler			
Item	**Value**	**Unit**	**Reference**
Thermal efficiency	85	%	Arup project experience
Capacity	20	% of peak heat requirement	Arup project experience
Heat generation	80	% of annual heat produced	Arup project experience

Thermal store capacity	25	% of boiler capacity (kW), m^3	Arup project experience
Biomass boiler	350	£/kWth	Arup project experience
O&M cost	15	£/kWth.year	(Poyry) DECC 2009
Lifetime	20	years	CIBSE Guide M

ASHP			
Item	**Value**	**Unit**	**Reference**
ASHP COP	2.5	#	BSRIA
Capacity	20	% of peak heat requirement	Arup project experience
Heat generation	80	% of annual heat produced	Arup project experience
Thermal store capacity	25	% of heat pump capacity (kW), m^3	Arup project experience
CAPEX	470	£/kW	Arup project experience
O&M cost	9	£/kWth.year	(Poyry) DECC 2009
Lifetime	15	years	CIBSE Guide M

GSHP			
Item	**Value**	**Unit**	**Reference**
GSHP COP	3.5	#	BSRIA
Heat capacity per 150m borehole	6	kW	Arup project experience
Capacity	20	% of peak heat requirement	Arup project experience
Heat generation	80	% of annual heat produced	Arup project experience
Thermal store capacity	25	% of heat pump capacity (kW), m^3	Arup project experience
GSHP CAPEX	1,000	£/kW	(Poyry) DECC 2009
Borehole CAPEX	45	£/m.borehole	Arup project experience
Header pipes CAPEX	1,100	£/borehole	Arup project experience
O&M	3.1	£/MWh.year	Arup project experience
Lifetime GSHP	20	years	CIBSE Guide M
Lifetime boreholes	60	years	Arup project experience

Minewater			
Item	**Value**	**Unit**	**Reference**
COP with minewater	4	#	Coal Authority
Borehole CAPEX	1,500	£/m.borehole	Arup project experience
Other CAPEX	250,000	£	Arup project experience

Biomass CHP			
Item	**Value**	**Unit**	**Reference**
Electrical efficiency	16	%	Arup project experience
Thermal efficiency	70	%	Arup project experience
Capacity, thermal	20	% of peak heat requirement	Arup project experience
Capacity, electrical	5	% of peak heat requirement	Arup project experience
Heat generation	80	% of annual heat produced	Arup project experience
Electricity generation	19	% of annual heat produced	Arup project experience
Thermal store capacity	25	% of CHP capacity (kW), m^3	Arup project experience
CAPEX	1,526	£/kWe	Arup project experience
O&M cost	35	£/MWhe	Arup project experience
Lifetime	15	years	CIBSE Guide M

Heat network assumptions

Heat Network			
Item	**Value**	**Unit**	**Reference**
CAPEX			
Trench	1,200	£/m	Arup project experience
Energy centre building	1,000	£/m^2	Arup project experience
Energy centre utilities	190	£/m^2 energy centre	Arup project experience
Energy centre electrical connection	20	£/kW	Arup project experience
HIU and heat meter	1,654	£/dwelling	Assessment of the Costs, Performance, and Characteristics of UK Heat Networks (DECC, 2015)
Thermal store	800	£/m^3	Assessment of the Costs, Performance, and Characteristics of UK Heat Networks (DECC, 2015)
Prelims, contingency and extra fees for	65	%	Arup project experience

energy centre and plant			
OPEX			
Heat network Maintenance	0.6	£/MWh	Assessment of the Costs, Performance, and Characteristics of UK Heat Networks (DECC, 2015)
Metering and billing	110	£/dwelling	Arup project experience
Pumping cost	3.6	£/MWh of heat conveyed	Arup project experience
Lifetime, trench and energy centre	60	years	Arup project experience
Lifetime, HIU and heat meters	20	years	Arup project experience

School

ASHP with electric boiler back up			
Item	**Value**	**Unit**	**Reference**
COP	2.5	#	BSRIA
CAPEX	725	£/kW	Arup project experience
O&M cost	0.5	% of CAPEX per annum	Arup project experience

GSHP with electric boiler backup			
Item	**Value**	**Unit**	**Reference**
COP	3.5	#	BSRIA
CAPEX	1500	£/kW	Arup project experience
O&M cost	1	% of CAPEX per annum	Arup project experience

PV			
Item	**Value**	**Unit**	**Reference**
No. stories school	2	#	Arup assumption
Useable roof area	50	%	Arup assumption
Capacity to area ratio	150	W/m^2	Arup project experience
Grid import	65	% of electrical demand	Global Solar Atlas
Export to grid	11	% of electrical demand	Global Solar Atlas

Shop

PV			
Item	**Value**	**Unit**	**Reference**
No. stories shop	1	#	Arup assumption
Useable roof area	50	%	Arup assumption
Capacity to area ratio	150	W/m^2	Arup project experience
Grid import	90	% of electrical demand	Global Solar Atlas
Export to grid	0	% of electrical demand	Global Solar Atlas

C5 Energy prices

Energy prices			
Item	**Value**	**Unit**	**Reference**
Gas purchase price, homes	4.3	p/kWh	BEIS retail fuel prices, domestic
Electricity purchase price, homes	18.2	p/kWh	BEIS retail fuel prices, domestic
Gas purchase price, Council	3.07	p/kWh	BEIS retail fuel prices, public sector
Electricity purchase price, Council	14	p/kWh	BEIS retail fuel prices, public sector
Biomass cost	4.38	p/kWh	Arup project experience
Grid export price	4	p/kWh	Arup project experience

C6 Carbon emission factors

The following electricity carbon emissions projections figures have been taken from supporting tables 1 to 19 of the Green Book supplementary appraisal guidance for valuation of energy use and greenhouse gas emissions (BEIS).

Year	Electricity carbon factor (kgCO2e/kWh)
2020	0.2956
2021	0.2828
2022	0.2693
2023	0.2550
2024	0.2399
2025	0.2240
2026	0.2071
2027	0.1893
2028	0.1705
2029	0.1507
2030	0.1296
2031	0.1155
2032	0.1029
2033	0.0917
2034	0.0817
2035	0.0728
2036	0.0649
2037	0.0578
2038	0.0515
2039	0.0459
2040	0.0409
2041	0.0396
2042	0.0382
2043	0.0369
2044	0.0356
2045	0.0342
2046	0.0329
2047	0.0316
2048	0.0303
2049	0.0289
2050	0.0276

The following carbon emission factors have been taken from UK Government GHG Conversion Factors for Company Reporting for 2020 (BEIS).

Fuel	Scope no.	Carbon factor (kgCO2e/kWh)
Natural gas	1	0.18387
	3	0.02391
Biomass	1	0.01545
	3	0.00792

Appendix D

Longlist analysis

			Technical option	Possible variants	Building requirements	Technology suitability Hoyland South	Technology suitability Royston	Spatial requirement	Utility infrastructure considerations	Development risk	Renewable energy contribution	CO2 reductions on site 2020-2033	CO2 saving potential 2033 - 2080	Incentives and grant funding potential	Capital cost	Ownership risk	Opportunities	Summary	Arup's proposed options to take forward to shortlist	Agreed shortlisted options with Council	Comments (Arup post-workshop)
Counterfactual			Gas boilers for space heating and DHW Electricity from the grid		Wet heating system				Gas connection Grid connection												
Building - integrated technologies	ELECTRICITY	1	Roof mounted solar PV		PV system Connection to grid or to building	MEDIUM Sufficient irradiaton Suitable for south-facing roof Topography sloping south	MEDIUM Sufficient irradiaton Suitable for south-facing roof	LOW Roof space, inverter and other units	LOW Grid reinforcement	LOW Installed regularly around the UK	MEDIUM Depends on irradiance and day light hours (low in winter)	MEDIUM Can cover 100%electricity demand of a house (where heating is non-electric) with zero carbon emissions , but not at night when needed most	MEDIUM Can cover 100%electricity demand of a house (where heating is non-electric) with zero carbon emissions , but not at night when needed most	MEDIUM Smart export guarantee	MEDIUM	HIGH Any decentralised technology will have to be installed by the owner or developer	LOW No expansion possible beyond the house Not flexible to swap technologies	✓ Low space requirement and development risk ✓ CO2 savings and incentives available ✗ Electricity available only during daytime	No	No	
		2	Roof mounted solar PV with battery		PV system Connection to grid or to building Battery	HIGH Same as above Battery provides flexibility to use electricity in own home Can meet 100% of the house electricity demand	HIGH Same as above Battery provides flexibility to use electricity in own home Can meet 100% of the house electricity demand	LOW Roof space, inverter and other units, battery	LOW Grid reinforcement	LOW Installed regularly around the UK	HIGH Depends on irradiance. Battery will allow it to contribute to most/all of the house demand annually	HIGH Can cover 100%electricity demand of a house from zero carbon source (where heating is non-electric)	HIGH Can cover 100%electricity demand of a house from zero carbon source (where heating is non-electric)	MEDIUM Smart export guarantee	MEDIUM		LOW No expansion possible beyond the house Not flexible to swap technologies	✓ Low space requirement and development risk ✓ CO2 savings and incentives available ✓ Battery provides flexibility of use ✓ Enables use of DSR and microgrid	Yes	Yes	
	HEATING	3	Electric radiators		Electric radiators	HIGH Suitable anywhere Can meet 100% of the house heating demand	HIGH Suitable anywhere Can meet 100% of the house heating demand	LOW	MEDIUM Grid reinforcement to cover heat demand	NONE	MEDIUM Depends on grid energy mix at the time	LOW Decarbonisation of the grid is marginally better than gas system	HIGH Grid average is very low compared to gas counterfactual	NONE	LOW		MEDIUM Can be flexible to swap for more efficient electric radiators, or to take out and install a wet heating system (any temperature) at end of life	✓ Low capital cost ✓ CO2 savings (long term) ✗ No wet heating system ✗ Grid reinforcement	Yes	Yes	
		4	Electric boiler with wet heating system		Wet heating system (similar to gas boilers)	HIGH Suitable anywhere Can meet 100% of the house heating demand	HIGH Suitable anywhere Can meet 100% of the house heating demand	LOW Similar to gas boiler cupboard	MEDIUM Grid reinforcement to cover heat demand	LOW Installed regularly around the UK	MEDIUM Depends on grid energy mix at the time	LOW Decarbonisation of the grid is marginally better than gas system	HIGH Grid average is very low compared to gas counterfactual	NONE	LOW		MEDIUM Flexible to increase or decrease capacity. Heat source can be replaced with another, but must work at the (high) temperature of the wet heating system already installed.	✓ Low capital cost ✓ CO2 savings (long term) ✗ Grid reinforcement	Yes	Yes	Discounted due to Capex 3 times higher than electric radiators (no additional carbon savings), with higher cost of heat to customer
		5	ASHP		Low temperature wet heating system Immersion heater (back-up/top up)	HIGH Ideal for new homes with low heating rqts Variable SCOP (low CoP in winter) ASHP in all homes can generate a lot of noise Dispersion of cool air issue Can meet 100% heating demand with immersion heater	HIGH Ideal for new homes with low heating rqts Variable SCOP (low CoP in winter) ASHP in all homes can generate a lot of noise Dispersion of cool air issue Can meet 100% heating demand with immersion heater	LOW Installed outdoors with suitable clearances for air flow	LOW Grid reinforcement	LOW Installed regularly around the UK	MEDIUM Depends on grid energy mix at the time	MEDIUM	HIGH	HIGH Domestic RHI	MEDIUM		MEDIUM Flexible to increase or decrease capacity. Heat source can be replaced with another, but must work at the (low) temperature of the wet heating system already installed	✓ Low space requirement and development risk ✓ CO2 savings and incentives available ✗ Variable seasonal performance ✗ Noise issues	Yes	Yes	
		6	GSHP (Shoebox) with vertical boreholes		Low temperature wet heating system Immersion heater (back-up/top up)	HIGH Requires land available at each home for boreholes (land can be reinstated) Dependant on thermal energy of the site Risk of depleting the ground heat if used only for heating Can meet 100% heating demand with immersion heater for dhw	HIGH Requires land available at each home for boreholes (land can be reinstated) Dependant on thermal energy of the site Risk of depleting the ground heat if used only for heating Can meet 100% heating demand with immersion heater for dhw	HIGH Boreholes area. Typically own garden. Use can be reinstated.	LOW Grid reinforcement	MEDIUM Ground investigations	HIGH Ground and grid energy mix	HIGH	HIGH	HIGH Domestic RHI	HIGH		LOW Capacity linked to boreholes in the ground. Would not be suitable to stop using boreholes for another technology. Another tech must work at the (low) temperature of the wet heating system already installed.	✓ High coefficient of performance ✓ High CO2 savings and incentives available ✗ Boreholes - space and cost	Yes	Yes	
		7	Biomass boiler		Buffer storage tank Biomass fuel delivery access and fuel storage space required	HIGH Preferable for base load Can meet 100% of the house heating demand with storage tank	HIGH Preferable for base load Can meet 100% of the house heating demand with storage tank	HIGH Fuel store, fuel access, storage tank. Garage or shed.	MEDIUM Fuel supply strategy	MEDIUM Consider supply chain, sustainability, and fuel emissions - particularly if installed in all houses in a development. Requires fuel delivery strategy	NONE Biomass is not considered a renewable source	HIGH Lowest carbon emission factor	HIGH Biomass carbon factor is smaller than grid factor	MEDIUM Domestic RHI	MEDIUM		MEDIUM Flexible to increase or decrease capacity. Heat source can be replaced with another, but must work at the (high) temperature of the wet heating system already installed.	✓ High CO2 savings and incentives available ✗ High space requirement ✗ Fuel supply strategy ✗ Air quality issue, if installed in all homes	Yes	**No**	
		8	Hydrogen boiler		Not currenlty available in the market to buy (will be designed to work with natural gas network)	NO Not available in the market	NO Not available in the market	LOW Similar size to gas boiler	MEDIUM Fuel supply strategy	HIGH The hydrogen supply chain is not yet developed New technology Fuel storage and delivery	HIGH Depends on supply chain. Assume electrolysis from excess renewable energy	HIGH Assume hydrogen has zero carbon emission factor	HIGH Assume hydrogen is zero carbon	NONE	MEDIUM		MEDIUM Hydrogen boilers will be made to work with natural gas Heat source can be replaced with another, but mustwork at the (high) temperature of the wet heating system already installed Can use H2 from future H2 network	✓ High CO2 savings ✗ Not available in the market ✗ Fuel supply strategy	No	No	
		9	Hydrogen fuel cell CHP		Natural gas supply Connection to grid or to home for electricity produced	HIGH Can provide 100% of the house heating demand, and some electricity Uses gas, but lower local emissions as it burns hydrogen	HIGH Can provide 100% of the house heating demand, and some electricity Uses gas, but lower local emissions as it burns hydrogen	MEDIUM Containarised solution indoors	LOW Gas fuel Grid reinforcement	MEDIUM	NONE Fuel is natural gas	NONE Heating from gas Electricity displaced by gas CHP will have worse carbon factor than grid average for this period	NONE Heating from gas Electricity displaced by gas CHP will have worse carbon factor than grid average for this period	HIGH SEG micro CHP tariff PACE funding scheme	MEDIUM		MEDIUM Heat source can be replaced with another, but must work at the (high) temperature of the wet heating system already installed.	✓ Incentives available ✓ Air quality ✗ No carbon savings - gas as fuel	No	No	
		10	Micro gas CHP boiler (internal combustion)		Natural gas supply Connection to grid or to home for electricity produced	HIGH Can provide 100% of the house heating demand, and some electricity	HIGH Can provide 100% of the house heating demand, and some electricity	LOW Containarised solution, similar to domestic gas boiler	LOW Gas fuel Grid reinforcement	LOW Installed across the UK	NONE Fuel is natural gas	NONE Heating from gas Electricity displaced by gas CHP will have worse carbon factor than grid average for this period	NONE Heating from gas Electricity displaced by gas CHP will have worse carbon factor than grid average for this period	MEDIUM SEG micro CHP tariff	HIGH		MEDIUM Heat source can be replaced with another, but must work at the (high) temperature of the wet heating system already installed.	✓ Incentives available ✗ No carbon savings - gas as fuel	No	No	
		11	Solar thermal hot water (flat solar collector)		Buffer storage tank with heat exchanger Needs to be coupled with another heat source (heat pump or boiler), as solar thermal can only supplement heat.	MEDIUM Suitable for south-facing roofs, which is only a proportion of total houses. Can provide DHW, and preheat central heating Will require backup throughout winter	MEDIUM Suitable for south-facing roofs, which is only a proportion of total houses. Can provide DHW, and preheat central heating Will require backup throughout winter	MEDIUM Roof space and heat exchanger space	NONE	LOW Installed regularly around the UK	LOW Depends on irradiance and day light hours (low in winter)	MEDIUM	HIGH Better than having only electric boiler, but not as good as a heat pump	HIGH Domestic RHI	MEDIUM		LOW No expansion possible beyond the house Not flexible to swap technologies	✓ CO2 savings ✓ Incentives available ✗ Can only supplement another heat technology	Yes	Yes	
Centralised technologies	ELECTRICITY	12	Ground mounted PV	Microgrid	Connection from building to microgrid	MEDIUM Barnsley - sufficient irradiaton/specific yield for PV to work Topography to the south Clash with area needed for house allocation	MEDIUM Barnsley - sufficient irradiaton/specific yield for PV to work Clash with area needed for house allocation	HIGH	MEDIUM Grid reinforcement Microgrid	LOW Installed across the UK	LOW Directly dependant on space available	LOW Little/no space available to contribute significantly to carbon savings	LOW Little/no space available to contribute significantly to carbon savings	MEDIUM SEG up to 5 MW	MEDIUM	LOW Council-led	HIGH Can be expanded to nearby sites outside red line boundary	✗ Not suitable for housing development with no spare land ✗ Grid reinforcement	No	**Yes - Hoyland South (Wentworth land outside red line boundary) + private wire**	Discounted - Green belt across Wentworth land available near the site, which is unlikely to be released for PV site
		13	Ground mounted PV and battery	Microgrid	Connection from building to microgrid	MEDIUM Same as above Battery needed if microgrid is installed - to modulate supply/demand	MEDIUM Same as above Battery needed if microgrid is installed - to modulate supply/demand	HIGH	MEDIUM Grid reinforcement Microgrid	LOW Installed across the UK	MEDIUM Battery will allow it to contribute more to site's demand	LOW Little/no space available to contribute significantly to carbon savings	LOW Little/no space available to contribute significantly to carbon savings	MEDIUM SEG up to 5 MW	MEDIUM		HIGH Can be expanded to nearby sites outside red line boundary	✗ Not suitable for housing development with no spare land ✗ Grid reinforcement	No	No	
		14	Wind turbines	Microgrid	Connection from building to microgrid	LOW Suitable wind speed for installation Not suitable for a housing development - visual impact locally and to landscape Avoid existing pylon	LOW Suitable wind speed for installation Not suitable for a housing development - visual impact locally and to landscape	HIGH	MEDIUM Grid reinforcement Microgrid	HIGH Complex planning permission Requires a lot of space/visual impact	LOW Compared to solar, will provide lower % of site's demand per m2	LOW Little/no space available to contribute significantly to carbon savings	LOW Little/no space available to contribute significantly to carbon savings	MEDIUM SEG up to 5 MW	HIGH		MEDIUM Can be expanded to nearby sites Clearance to be respected	✗ Not suitable for housing development with no spare land / visual impact ✗ Grid reinforcement	No	No	
		15	Wind turbines with battery	Microgrid	Connection from building to microgrid	LOW Same as above Battery needed if microgrid is installed - to modulate supply/demand	LOW Same as above Battery needed if microgrid is installed - to modulate supply/demand	HIGH	MEDIUM Grid reinforcement Microgrid	HIGH Complex planning permission Requires a lot of space/visual impact	LOW Compared to solar, will provide lower % of site's demand per m2	LOW Little/no space available to contribute significantly to carbon savings	LOW Little/no space available to contribute significantly to carbon savings	MEDIUM SEG up to 5 MW	HIGH		MEDIUM Can be expanded to nearby sites Clearance to be respected	✗ Not suitable for housing development with no spare land / visual impact ✗ Grid reinforcement	No	No	
		16	Hydro power	Microgrid	Connection from building to microgrid	NO No main rivers are within or near to the site.	NO No rivers nearby. Watercourse within red line boundary appears to have very low water level.	HIGH	MEDIUM Grid reinforcement Microgrid	HIGH Requires sufficent water conditions Complex planning permission	NONE No resources available	NONE No resources available	NONE No resources available	MEDIUM SEG up to 5 MW	HIGH		LOW Dependant on the source	✗ No water resources ✗ Not suitable for housing development with no spare land / visual impact ✗ Grid reinforcement	No	No	
		17	Geothermal power	Microgrid	Connection from building to microgrid	NO Requires high-temperature resource from deep underground (2-5km fro 3MW project) Not suitable for a small housing development	NO Requires high-temperature resource from deep underground (2-5km fro 3MW project) Not suitable for a small housing development	HIGH	MEDIUM Grid reinforcement Microgrid	HIGH Requires ground investigations and viability depends on results of investigation Complex planning permission	LOW Renewable, but a large installation will be required to meet a small demand	LOW Little/no space available to contribute significantly to carbon savings	LOW Little/no space available to contribute significantly to carbon savings	MEDIUM SEG up to 5 MW	HIGH		LOW Dependant on the source	✗ Not suitable for housing development with no spare land ✗ Boreholes 2-5km deep ✗ Grid reinforcement	No	No	
	TING	18	District heating with Electric/electrode boilers		Any wet heating system DHN connection to building and Heat Interface unit	HIGH Easy to modulate Need to check that enough spare capacity is available from DNO for peak demand	HIGH Easy to modulate Need to check that enough spare capacity is available from DNO for peak demand	LOW Energy centre	MEDIUM Grid reinforcement to cover heat 100% demand Trenching and underground pipework	MEDIUM Planning permission for underground network and energy centre. Large electrode boilers are relatively new	MEDIUM Dependant on grid energy mix	LOW Decarbonisation of the grid is marginally better than gas system	HIGH Grid carbon factor is very low. Use electric backup, not gas boilers	MEDIUM HNIP (up to March 2022) HNDU (unknown closeout date)	HIGH		HIGH Can be futureproofed for larger capacity Extra heat sources and consumers can be added Can swap heat source technology for lower emissions	✓ CO2 savings (long term) ✓ Can be futureproofed, and heat source can be replaced ✗ Grid reinforcement	Yes	Yes	
		19	District heating with Biomass boiler	Peak/backup plant: Gas boiler Electric/electrode boiler	Any wet heating system DHN connection to building and Heat Interface unit	HIGH Works with high temperature heating systems Need fuel delivery strategy, fuel access, fuel storage. Larger EC than other fossil fueled technologies	HIGH Works with high temperature heating systems Need fuel delivery strategy, fuel access, fuel storage. Larger EC than other fossil fueled technologies	MEDIUM Energy centre Requires large storage space for fuel	HIGH Fuel delivery strategy Trenching and underground pipework	MEDIUM Planning permission for underground network and energy centre. Fuelsupply strategy	NONE Biomass is not a renewable source.	HIGH Biomass carbon factor is the lowest and can meet most of the demand all year round	HIGH Biomass carbon factor is the lowest and can meet most of the demand all year round. Use electric backup/peaking plant, not gas boiler	HIGH Non-domestic RHI HNIP (up to March 2022) HNDU (unknown closeout date)	HIGH		HIGH Can be futureproofed for larger capacity Extra heat sources and consumers can be added Can swap heat source technology for lower emissions	✓ High CO2 savings ✓ Incentives available ✓ Can be futureproofed, and heat source can be replaced ✗ Fuel supply strategy ✗ Larger energy centre	Yes	Yes	
		20	District heating with WSHP	Peak/backup plant: Gas boiler Electric/electrode boiler	Low temperature wet heating system DHN connection to building and Heat Interface unit	NO No watercourses nearby	NO No rivers nearby. Watercourse within red line boundary appears to have very low water level.	MEDIUM Energy centre Requires connection to body of water	MEDIUM Grid reinforcement Trenching and underground pipework	HIGH Planning permission for underground network and energy centre Complex planning permission related to water source	NONE No resources available	NONE No resources available	NONE No resources available	HIGH Non-domestic RHI REGO HNIP (up to March 2022) HNDU (unknown closeout date)	HIGH		LOW Dependant on the source	✗ No water resources	No	No	
		21	District heating with ASHP	Peak/backup plant: Gas boiler Electric/electrode boiler	Low temperature wet heating system DHN connection to building and Heat Interface unit	MEDIUM Noisy and cold air exhaust issues in a residential area House heating systems will need to be medium/low temperature (longer radiators, underfloor heating) - ideal during development phase Need larger EC than other fossil fueled technologies + clearance for free flow of air	MEDIUM Noisy and cold air exhaust issues in a residential area House heating systems will need to be medium/low temperature (longer radiators, underfloor heating) - ideal during development phase Need larger EC than other fossil fueled technologies + clearance for free flow of air	MEDIUM Energy centre Requires space for heat pump and air flow	MEDIUM Grid reinforcement Trenching and underground pipework	MEDIUM Planning permission for underground network and energy centre	HIGH Ground energy and grid energy mix	MEDIUM CoP affected seasonally.	HIGH Grid carbon factor is very low. Use electric backup, not gas boilers	HIGH Non-domestic RHI HNIP (up to March 2022) HNDU (unknown closeout date)	HIGH		HIGH Can be futureproofed for larger capacity Extra heat sources and consumers can be added Can swap heat source technology for lower emissions	✓ High CO2 savings ✓ Incentives available ✓ Can be futureproofed, and heat source can be replaced ✗ Noise and cool air issues ✗ Larger energy centre ✗ Grid reinforcement	Yes	Yes	
		22	District heating with GSHP (closed loop, vertical boreholes)	Peak/backup plant: Gas boiler Electric/electrode boiler	Low temperature wet heating system DHN connection to building and Heat Interface unit	HIGH Possible areas for boreholes: archery ground, green areas in sports facility, school playing fields. Add boreholes as you extend district heating. House heating systems will need to be medium/low temperature (longer radiators, underfloor heating) - ideal during development phase	HIGH Possible areas for boreholes: school playing fields, recreational area, and other greens spaces. Add boreholes as you extend the network to the north of the site. House heating systems will need to be medium/low temperature (longer radiators, underfloor heating) - ideal during development phase	HIGH Energy centre Requires space and clearance for communal boreholes	MEDIUM Grid reinforcement Trenching and underground pipework	HIGH Planning permission for underground network and energy centre Ground investigations Complex planning permission	HIGH Ground energy and grid energy mix	HIGH Higher CoPs than ASHP, so uses less electricity	HIGH Grid carbon factor is very low. Use electric backup, not gas boilers	HIGH Non-domestic RHI HNIP (up to March 2022) HNDU (unknown closeout date)	HIGH		MEDIUM Can be futureproofed for larger capacity Extra heat sources and consumers can be added	✓ High CO2 savings ✓ Incentives available ✓ Can be futureproofed ✗ Communal borehole area required ✗ High development risk ✗ Grid reinforcement	Yes	Yes	
		23	District heating with Minewater and heat pump	Peak/backup plant: Gas boiler Electric/electrode boiler	Low temperature wet heating system DHN connection to building and Heat Interface unit	HIGH Viable - Mine water levels estimated at the appropriate depth for pumping to surface. Temperature obtained is 12-20C. Requires heat pump to elevate temperature	NO No identified mine entries within or near the red line boundary	HIGH Energy centre 2 new boreholes to access groundwater, and pipework from there to EC	MEDIUM Grid reinforcement Trenching and underground pipework	HIGH Planning permission for underground network and energy centre. Complex planning permission. Coal Authority and minewater treatment issues.	HIGH Depends on availability of mine water Water and ground energy + grid energy mix	HIGH Similar to GSHP system	HIGH Similar to GSHP system	HIGH Non-domestic RHI HNIP (up to March 2022) HNDU (unknown closeout date)	HIGH		MEDIUM Can be futureproofed for larger capacity Extra heat sources and consumers can be added	✓ Mine water levels estimated at the appropriate depth for economic pumping to surface ✓ High CO2 savings ✓ Incentives available ✗ High development risk - requires Coal Authority's early involvement ✗ Grid reinforcement	Yes - Houland South No - Royston	Yes - Houland South No - Royston	
		24	District heating with Gas CHP (as base heat load)	Peak/backup plant: Gas boiler Electric/electrode boiler	Any wet heating system DHN connection to building and Heat Interface unit	HIGH Works with high temperature heating systems May not align with climate emergency unless replaced by low carbon tech later Electricity generated can be used onsite or sold to grid	HIGH Works with high temperature heating systems May not align with climate emergency unless replaced by low carbon tech later Electricity generated can be used onsite or sold to grid	LOW Energy centre	HIGH Grid reinforcement Gas supply to energy centre Trenching and underground pipework	MEDIUM Planning permission for underground network and energy centre.	NONE	NONE Electricity generated/displaced by gas CHP will have worse carbon factor than grid average for this period	NONE Electricity generated/displaced by gas CHP will have worse carbon factor than grid average for this period	MEDIUM HNIP (up to March 2022) HNDU (unknown closeout date)	HIGH		HIGH Can be futureproofed for larger capacity Extra heat sources and consumers can be added Can swap heat source technology for lower emissions	✓ Can be futureproofed, and heat source can be replaced ✗ No carbon savings	No	No	

HEA	25	District heating with Gas CHP with battery	Peak/backup plant: Gas boiler Electric/electrode boiler	Any wet heating system DHN connection to building and Heat Interface unit	HIGH Same as above Battery allows electricity to be used on-site when needed instead of exported. May not offer benefits.	HIGH Same as above Battery allows electricity to be used on-site when needed instead of exported. May not offer benefits.	LOW Energy centre	HIGH Grid reinforcement Gas supply to energy centre Trenching and underground pipework	MEDIUM Planning permission for underground network and energy centre.	NONE	NONE Electricity generated/displaced by gas CHP will have worse carbon factor than grid average for this period	NONE Electricity generated/displaced by gas CHP will have worse carbon factor than grid average for this period	MEDIUM HNIP (up to March 2022) HNDU (unknown closeout date)	HIGH	HIGH Can be futureproofed for larger capacity Extra heat sources and consumers can be added Can swap heat source technology for lower emissions	✓ Can be futureproofed, and heat source can be replaced ✗ No carbon savings	No	No	
	26	District heating with Biomass CHP	Peak/backup plant: Gas boiler Electric/electrode boiler	Any wet heating system DHN connection to building and Heat Interface unit	HIGH Works with high temperature heating systems Need fuel delivery strategy, fuel access, fuel storage. Larger EC than other fossil fueled technologies Electricity generated can be used onsite or sold to grid	HIGH Works with high temperature heating systems Need fuel delivery strategy, fuel access, fuel storage. Larger EC than other fossil fueled technologies Electricity generated can be used onsite or sold to grid	MEDIUM Energy centre Requires large storage space for fuel	HIGH Grid reinforcement Fuel delivery strategy to energy centre Trenching and underground pipework	MEDIUM Planning permission for underground network and energy centre. Fuelsupply strategy	NONE Biomass is not a renewable source.	HIGH Biomass carbon factor is very low. Electricity generated from this will have low carbon factor	HIGH Biomass carbon factor is very low. Electricity generated from this will have low carbon factor	HIGH Non-domestic RHI HNIP (up to March 2022) HNDU (unknown closeout date)	HIGH	HIGH Can be futureproofed for larger capacity Extra heat sources and consumers can be added Can swap heat source technology for lower emissions	✓ High CO2 savings ✓ Incentives available ✓ Can be futureproofed, and heat source can be replaced ✗ Fuel supply strategy ✗ Larger energy centre ✗ Grid reinforcement	Yes	Yes	Discounted - phased demand will make a biomass CHP very difficult to operate effectively. Small biomass CHP are not efficient
	27	District heating with Biomass CHP with battery	Peak/backup plant: Gas boiler Electric/electrode boiler	Any wet heating system DHN connection to building and Heat Interface unit	HIGH Same as above Battery allows electricity to be used on-site when needed instead of exported. May not offer benefits.	HIGH Same as above Battery allows electricity to be used on-site when needed instead of exported. May not offer benefits.	MEDIUM Energy centre Requires storage space for fuel	HIGH Grid reinforcement Fuel delivery strategy to energy centre Trenching and underground pipework	MEDIUM Planning permission for underground network and energy centre. Fuelsupply strategy	NONE Biomass is not a renewable source.	HIGH Biomass carbon factor is very low. Electricity generated from this will have low carbon factor. Battery would allow electricity to be used on-site, improving the carbon savings	HIGH Biomass carbon factor is very low. Electricity generated from this will have low carbon factor	HIGH Non-domestic RHI HNIP (up to March 2022) HNDU (unknown closeout date)	HIGH	HIGH Can be futureproofed for larger capacity Extra heat sources and consumers can be added Can swap heat source technology for lower emissions	✓ High CO2 savings - battery allows electricity to be used on-site ✓ Incentives available ✓ Can be futureproofed, and heat source can be replaced ✗ Fuel supply strategy ✗ Larger energy centre ✗ Grid reinforcement	Yes	Yes	Discounted - phased demand will make a biomass CHP very difficult to operate effectively. Small biomass CHP are not efficient
	28	District heating with Hydrogen boilers	Peak/backup plant: Gas boiler Electric/electrode boiler	Any wet heating system DHN connection to building and Heat Interface unit	HIGH Requires hydrogen delivered (tanks). Viability depends on method of production of hydrogen.	HIGH Requires hydrogen delivered (tanks). Viability depends on method of production of hydrogen.	MEDIUM Energy centre Requires large storage space for fuel if it is tankered in	HIGH Fuel delivery strategy to energy centre Trenching and underground pipework	HIGH Planning permission for underground network and energy centre. Hydrogen supply chain	HIGH Depends on supply chain. Assume electrolysis from excess renewable energy	HIGH Assume hydrogen has zero carbon emission factor (electrolysis)	HIGH Assume hydrogen has zero carbon emission factor. Opportunity to use a hydrogen network by then.	MEDIUM HNIP (up to March 2022) HNDU (unknown closeout date)	HIGH	HIGH Can be futureproofed for larger capacity Extra heat sources and consumers can be added Can swap heat source technology for lower emissions Can connect to future H2 network	✓ High CO2 savings ✓ Can be futureproofed, and heat source can be replaced ✓ Potential to connect to H2 network ✗ Fuel supply strategy (H2)	Yes	Yes	Discounted - hydrogen boilers suppliers are low in numbers/ non existent
	29	District heating with Hydrogen fuel cell CHP (electricity with heat as byproduct)	Peak/backup plant: Gas boiler Electric/electrode boiler	Any wet heating system DHN connection to building and Heat Interface unit	HIGH Requires hydrogen delivered (tanks). Viability depends on method of production of hydrogen.	HIGH Requires hydrogen delivered (tanks). Viability depends on method of production of hydrogen.	MEDIUM Energy centre Requires large storage space for fuel if it is tankered in	HIGH Grid reinforcement Fuel delivery strategy to energy centre Trenching and underground pipework	HIGH Planning permission for underground network and energy centre. Hydrogen supply chain	HIGH Depends on supply chain. Assume electrolysis from excess renewable energy	HIGH Assume hydrogen has zero carbon emission factor (electrolysis)	HIGH Assume hydrogen has zero carbon emission factor. Opportunity to use a hydrogen network by then.	MEDIUM HNIP (up to March 2022) HNDU (unknown closeout date)	HIGH	HIGH Can be futureproofed for larger capacity Extra heat sources and consumers can be added Can swap heat source technology for lower emissions Can connect to future H2 network	✓ High CO2 savings ✓ Can be futureproofed, and heat source can be replaced ✓ Potential to connect to H2 network ✗ Fuel supply strategy (H2) ✗ Grid reinforcement	Yes	Yes	Discounted - cost of plant and of tankered-in hydrogen make this option very expensive. This translates into an annual cost of heat (£/year) to homeowner at least 3 times more expensive than minewater scheme
	30	District heating with Hydrogen fuel cell CHP w. battery	Peak/backup plant: Gas boiler Electric/electrode boiler	Any wet heating system (high temp or low temp) Requires connection to home (including heat exchangers/HIU)	HIGH Same as above Battery allows electricity to be used on-site when needed instead of exported. May not offer benefits.	HIGH Same as above Battery allows electricity to be used on-site when needed instead of exported. May not offer benefits.	MEDIUM Energy centre Requires large storage space for fuel if it is tankered in	HIGH Grid reinforcement Fuel delivery strategy to energy centre Trenching and underground pipework	HIGH Planning permission for underground network and energy centre. Hydrogen supply chain	HIGH Depends on supply chain. Assume electrolysis from excess renewable energy	HIGH Assume hydrogen has zero carbon emission factor (electrolysis) Battery would allow electricity to be used on-site, improving the carbon savings	HIGH Assume hydrogen has zero carbon emission factor. Opportunity to use a hydrogen network by then.	MEDIUM HNIP (up to March 2022) HNDU (unknown closeout date)	HIGH	HIGH Can be futureproofed for larger capacity Extra heat sources and consumers can be added Can swap heat source technology for lower emissions Can connect to future H2 network	✓ High CO2 savings - battery allows electricity to be used on-site ✓ Can be futureproofed, and heat source can be replaced ✓ Potential to connect to H2 network ✗ Fuel supply strategy (H2) ✗ Grid reinforcement	Yes	Yes	Same as above
	31	District heating with Solar thermal farm	Peak/backup plant: Gas boiler Electric/electrode boiler	DHN connection to building and Heat Interface unit	LOW Can provide DHW, and preheat central heating Will require backup throughout winter. Will need to be coupled with another low-carbon technology	LOW Can provide DHW, and preheat central heating Will require backup throughout winter. Will need to be coupled with another low-carbon technology	HIGH Energy centre Solar collectors	MEDIUM Grid reinforcement Trenching and underground pipework	MEDIUM Planning permission for underground network and energy centre	LOW Depends on irradiance and land available	Little/no space available to contribute significantly to carbon savings	Little/no space available to contribute significantly to carbon savings	HIGH Non-domestic RHI HNIP (up to March 2022) HNDU (unknown closeout date)	HIGH	LOW Can be expanded by adding collectors nearby Cannot be swaped with another technology	✗ Requires large space to make a significant contribution to heat. Not suitable for housing development with no spare land. ✗ Seasonal performance	No	No	

Appendix E

Hoyland South
Integrated Risk Matrix (IRM)

E1 Distributed heating options IRM

The following table documents the calculated IRM values for each distributed heating shortlisted option. These values have been estimated based on technology assumptions listed in Appendix C.

Technology option	Carbon emissions 2030-2045 (phases 2, 3 and 4)	Carbon savings 2030-2045 (phases 2, 3 and 4)	Capex (phases 2, 3 and 4)	OPEX (phases 2, 3 and 4)	Annual cost of heat (pre-2025)	Annual cost of heat (post-2025)
	Tonnes CO2e	Tonnes CO2e	£	£/year	£/dwelling	£/dwelling
Gas boiler (counterfactual)	17,000	-	-	-	-	-
Electric radiators	5,000	12,000	1,500,000	750,000	1,200	700
Electric boiler with wet heating system	5,000	12,000	5,000,000	750,000	1,400	900
ASHP	2,000	15,000	7,500,000	350,000	1,100	900
GSHP	2,000	15,000	19,500,000	250,000	1,200	1,100
Solar thermal + gas boiler	9,000	8,000	8,500,000	300,000	800	700

This study assumes dwellings built from 2025 will have a higher fabric performance standard, with lower space heating demand and lower annual cost of heat. The majority of homes at this site are built post-2025.

E2 Centralised heating options IRM

The following table documents the calculated IRM values for each centralised heating shortlisted option, applied to phases 2, 3 and 4 only. These values have been caudated based on technology assumptions listed in appendix C.

Technology option	Carbon emissions 2030-2045 (phases 2,3 and 4)	Carbon savings 2030-2045 (phases 2,3 and 4)	Capex (phases 2,3 and 4)	OPEX (phases 2,3 and 4)	Annual cost of heat (pre-2025)	Annual cost of heat (post-2025)
	Tonnes CO2e	Tonnes CO2e	£	£/year	£/dwelling	£/dwelling
Electric/electrode boilers	5,000	12,000	10,000,000	800,000	1,500	1,000
Biomass boilers	3,000	14,000	10,500,000	450,000	1,100	700
ASHP	3,000	14,000	11,000,000	500,000	1,200	800
GSHP	2,000	15,000	12,000,000	450,000	1,100	800
Minewater and heat pump	3,000	14,000	13,000,000	450,000	1,200	800

E3 IRM scoring

The calculated IRM values have been converted to scores using the scoring ranges documented below.

Score	CO2e savings from site completion to 2045		CAPEX		OPEX		Annual cost of heat	
	Tonnes CO2e		£		£/year		£/dwelling	
	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
5	15,000	16,000	0	2,000,000	0	300,000	700	800
4	14,000	15,000	2,000,000	5,000,000	300,000	400,000	800	900
3	12,000	14,000	5,000,000	10,000,000	400,000	500,000	900	950
2	10,000	12,000	10,000,000	15,000,000	500,000	600,000	950	1000
1	0	10,000	15,000,000	20,000,000	600,000	800,000	1,000	2000

Appendix F

Royston
Integrated Risk Matrix (IRM)

F1 Distributed heating IRM

The following tables document the calculated IRM values for each distributed heating shortlisted option for both dwellings and schools. These values have been estimated based on technology assumptions listed in Appendix C.

Dwellings

Technology option	Carbon emissions 2032-2045	Carbon savings 2032-2045	Capex	OPEX	Annual cost of heat (pre-2025)	Annual cost of heat (post-2025)
	kgCO2e/dwelling	kgCO2e/dwelling	£/dwelling	£/year	£/dwelling	£/dwelling
Gas boiler (counterfactual)	17,000	-	-	-	-	-
Electric radiators	4,000	13,000	2,000	900	1,200	700
Electric boiler with wet heating system	4,000	13,000	6,000	900	1,400	900
ASHP	1,000	16,000	9,000	500	1,100	900
GSHP	1,000	16,000	24,000	300	1,200	1,000
Solar thermal + gas boiler	13,000	4,000	11,000	400	900	700

This study assumes dwellings built from 2025 will have a higher fabric performance standard, with lower space heating demand and lower annual cost of heat. The majority of homes at this site are built post-2025.

Schools

Technology option	Carbon emissions 2022-2045	Carbon savings 2022-2045	Capex	OPEX	Annual cost of heat
	Tonnes CO2e	Tonnes CO2e	£	£/year	£
Gas boiler (counterfactual)	650	-	-	-	-
Electric/electrode boilers	350	300	50,000	17,000	18,000
ASHP	200	450	75,000	9,000	11,500
GSHP	150	500	110,000	8,000	10,500

F2 IRM scoring

The calculated IRM values have been converted to scores using the scoring ranges documented below for both dwellings and schools.

Dwellings

Score	CO2e savings from site completion to 2045		CAPEX		OPEX		Annual cost of heat	
	kgCO2e		£/dwelling		£/year		£/dwelling	
	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
5	15,000	16,000	0	2,000	0	300	600	800
4	14,000	15,000	2,000	6,000	300	400	800	900
3	12,000	14,000	6,000	10,000	400	500	900	950
2	10,000	12,000	10,000	15,000	500	600	950	1,000
1	0	10,000	15,000	25,000	600	1,000	1,000	1,500

Schools

Score	CO2e savings from school completion to 2045		CAPEX		OPEX		Annual cost of heat	
	Tonnes CO2e		£		£/year		£/dwelling	
	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
5	450	600	0	50,000	0	8,000	0	10,500
4	350	450	50,000	60,000	8,000	9,000	10,500	11,000
3	200	350	60,000	75,000	9,000	11,000	11,000	12,000
2	100	200	75,000	90,000	11,000	13,000	12,000	15,000
1	0	100	90,000	115,000	13,000	18,000	15,000	18,000

Appendix G

Pathway assumptions

G1 Pathway assumptions

The following general assumptions have been made throughout the development of all pathways:

- All capital costs incurred from the installation of technologies in dwellings is assumed to be passed on to the homeowner through the increased price of the dwelling.
- The carbon emissions for each pathway are based on energy supply options being replaced like for like once they reach their end of life.

Dwellings

ASHP assumptions:

- All dwellings will be fitted with an ASHP as part of the construction process which will meet 100% of the dwellings' space heating and hot water demands.

PV assumptions:

- A 3kWp PV systems will be installed on all south facing dwellings (approximately 33% of total dwellings in each development).
- The PV system is sized based on an average installation in the UK, occupying an area of 20-25m^2.
- It is estimated that the PV system will be able to provide approximately 90% of a dwelling's annual electrical demand, exporting excess to the grid throughout the summer and importing some grid electricity during winter.
- Homeowners will receive payments through the Smart Export Guarantee (SEG) scheme when exporting electricity to the grid, which contributes to their O&M savings.
- The operation of the PV does not account for electricity required for heating solutions.

Shops

The following assumptions relate to the shop's pathway:

- 35kWp roof mounted PV system will be installed on the shop's roof, based on assumptions of roof space available.
- PV system will supply approximately 10% of the shops electricity demand. The rest is to be provided by grid electricity.

School

The following assumptions relate to the Royston's school electricity and heating solutions:

- 50kWp roof mounted PV system will be installed on the school roof.
- The PV system will supply approximately 45% of the school's annual electricity demand. This does not include any electricity required for the GSHP or electric boiler backup. The balance is met by 65% supply from the grid and 10% export to the grid, throughout the year.
- The school's PV system will export to the grid during the summer.
- The school's heating demand will be met by a GSHP and backup electric boiler.
- The GSHP system will produce approximately 80% of the school's heating demand. The remaining 20% will come from the electric boiler backup.