
# CHOICES Phase 3 Project Report

## Heat networks demonstation

clean energy prospector

icax INTERSEASONAL HEAT TRANSFER

UNIVERSITY OF BATH

eunomia

BRISTOL 2015 EUROPEAN GREEN CAPITAL

Department of Energy & Climate Change

Updated May 5, 2017

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# 1. Executive Summary

Most buildings in the UK burn natural gas in individual boilers for space and water heating. This is supplied by the gas grid which covers around 80% of UK buildings and on a winter day can deliver up to 6TWh – 5 times more energy than the electricity grid can currently deliver. Heat is responsible for around a third of the UK's greenhouse gas emissions. The replacement of the majority of this gas supply with a low carbon alternative is essential to meeting our carbon emissions reduction targets.

Two approaches represent the current state of the art for heat decarbonisation:

1. Community heat networks supplied by CHP (combined heat and power) plants;
    a. when fueled with natural gas CHP has limited carbon reduction potential (**CHP can reduce carbon by 30 percent** compared to conventional generation in individual boilers) and long-term security of supply challenges;
    b. when fueled with sustainable biomass CHP is associated with supply chain complexity, high operational costs and environmental impact from transport.
2. Electrification of heat by installing electric heat pumps in individual buildings. Research commissioned by the Energy Networks association forecast complete transition to **electric heat pumps could reduce carbon by more than 90 percent by 2050**. However, extreme peaks in heat demand that happen on a few of the coldest days each winter require significant extra investment in new power stations and electricity infrastructure[1].

In summary, electric heat pumps *have greater potential for carbon reduction* than gas CHP and simpler operation than biomass CHP but can be restricted by the cost of reinforcing the electricity grid sufficiently.

The CHOICES project is studying whether the grid impact of ground source heat pumps can be reduced economically by storing air-sourced summer heat in borehole arrays for use in winter ('active recharge'). Such an approach improves the overall efficiency of air-sourcing of heat by using direct, on-site PV generated electricity. The improved efficiency of the heat pumps in the winter months (resulting from the higher ground temperatures) reduces the grid impact – higher efficiency means lower grid draw.

The project team constructed a pilot CHOICES Energy Centre in Owen Square Park in Bristol that comprises an air-source heat capture system and ground source heat pumps rated at 140kW. Two buildings were connected to the district heat network – the Easton Community Centre (ECC) 'main' building and the ECC 'annex'. A 'private wires' system was built to source surplus PV from a 43kWp array creating a pricing differential between summer day electricity costing 4.85p/kWh and winter grid-sourced electricity costing 8.4p/kWh.

A TRNSYS software model was developed and used to predict the optimal operational parameters of the system. The model predicts that active recharge **can** relatively efficiently **shift electricity demand** for heating from the winter into summer, and that active recharge **can also reduce the cost of energy** due to the corresponding price differential. However, this impact is limited for the pilot project because the efficiency of recharge (measured in kWh of heat transferred) decreases as the charge level increases beyond the winter demand level (and the borehole temperature rises). With the current CHOICES pilot borehole configuration, optimal economic recharge levels are approximately 50 percent of heat demand.

1 Govt. modelling for 'The Future of Heating: Meeting the challenge' suggests need to meet this demand through maintaining gas back-up supply

 

The study has also identified two main areas where there is potential for improvement:

1. A Strategic Controller algorithm was developed that promises an improvement in Active Recharge by optimising when charging occurs using forward weather prediction. The Strategic Controller algorithm is predicted to improve average summer COP from 9.5 using threshold based opportunistic charging to above 10.5.
2. Additional CHOICES research will model new borehole array configurations that are predicted to improve the value of Active Recharge further by linking boreholes in series rather than parallel - this configuration is predicted to improve the charge and discharge efficiencies.

Further research is being undertaken in the coming two years to monitor real world active recharge efficiency against predicted models and implement the strategic charge control algorithm for the pilot facility.

A lifecycle assessment of the facility has been conducted, which reports that an optimised facility would have a lifetime cost of delivered energy of £167/MWh with carbon emissions of 93.7 kgCO2/MWh. Crucially, primary energy consumption is reduced by half compared to the counterfactual current gas supply. With the decarbonisation of grid electricity expected by DECC[2], the CHOICES technology offers a 25-year lifetime average 55% carbon savings over a gas counterfactual, rising to 62% if the full heat demand load is met. On this basis, the current facility is expected to create average carbon savings of 13 tonnes per year over its lifetime.

2 DECC Electricity marginal emissions factors to 2100

 

# 2. Aims and Objectives

Ground source heating depends on the fact that, below around 7 meters in depth, the earth's surface maintains a nearly constant temperature between 10 and 12 °C in the UK. Ground source heat pumps (GSHPs) can 'upgrade' this heat to useful temperatures using electricity. The first commercial ground source heat pump started operating in 1948 and by 2004 there was 12GW of thermal capacity installed worldwide[3].

When used in dense urban environments GSHP heating systems are normally only feasible with vertical borehole heat exchangers. Over multiple years the volume around these boreholes can become depleted of heat and the system efficiency will drop - the ground may become to cold for the GSHP to operate well, if the system has been incorrectly sized.

The CHOICES project is investigating the efficiencies and economics of operating electric Air Source Heat Pumps (ASHPs) in summer to 'actively charge' these ground source borehole arrays improving the system efficiencies in winter. Particularly, are there scenarios where it is valuable/economic to use excess summer PV to generate heat to borehole storage rather than 'selling' the PV to the grid at the export tariff rate?

3 https://en.wikipedia.org/wiki/Geothermal_heat_pump

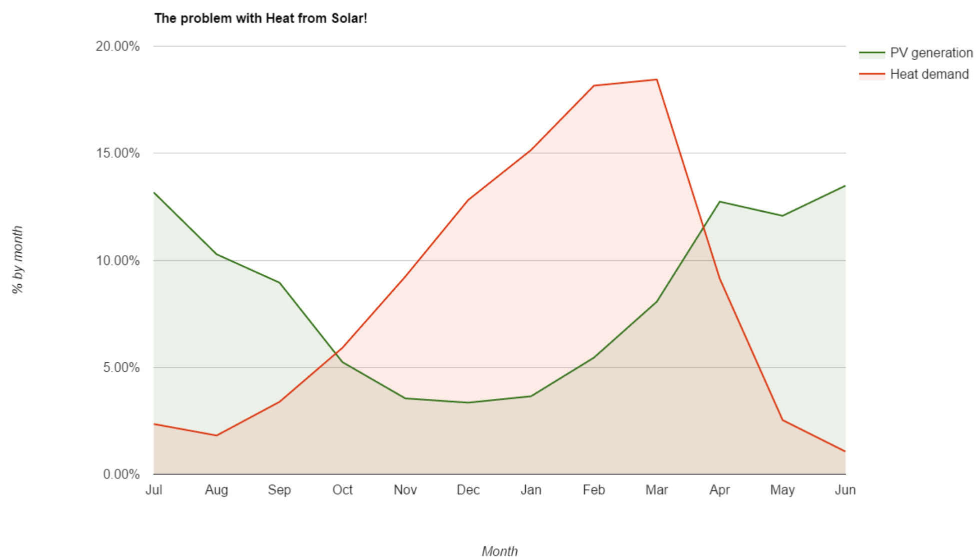


***Figure 1: The problem with generating heat from solar energy***

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*Key question - "If we 'spend' 1 kWh of summer electricity storing air sourced heat in a borehole array how much electricity can we 'save' in winter?"*

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The CHOICES project is actively recharging an array of ground source boreholes using electric air source heat pumps. This technology has the potential to improve the overall system efficiency of ground source heating as well as shift electric heat loads from winter to summer.

**Low levels of recharge. Heat is predominantly sourced from the ground in winter.**

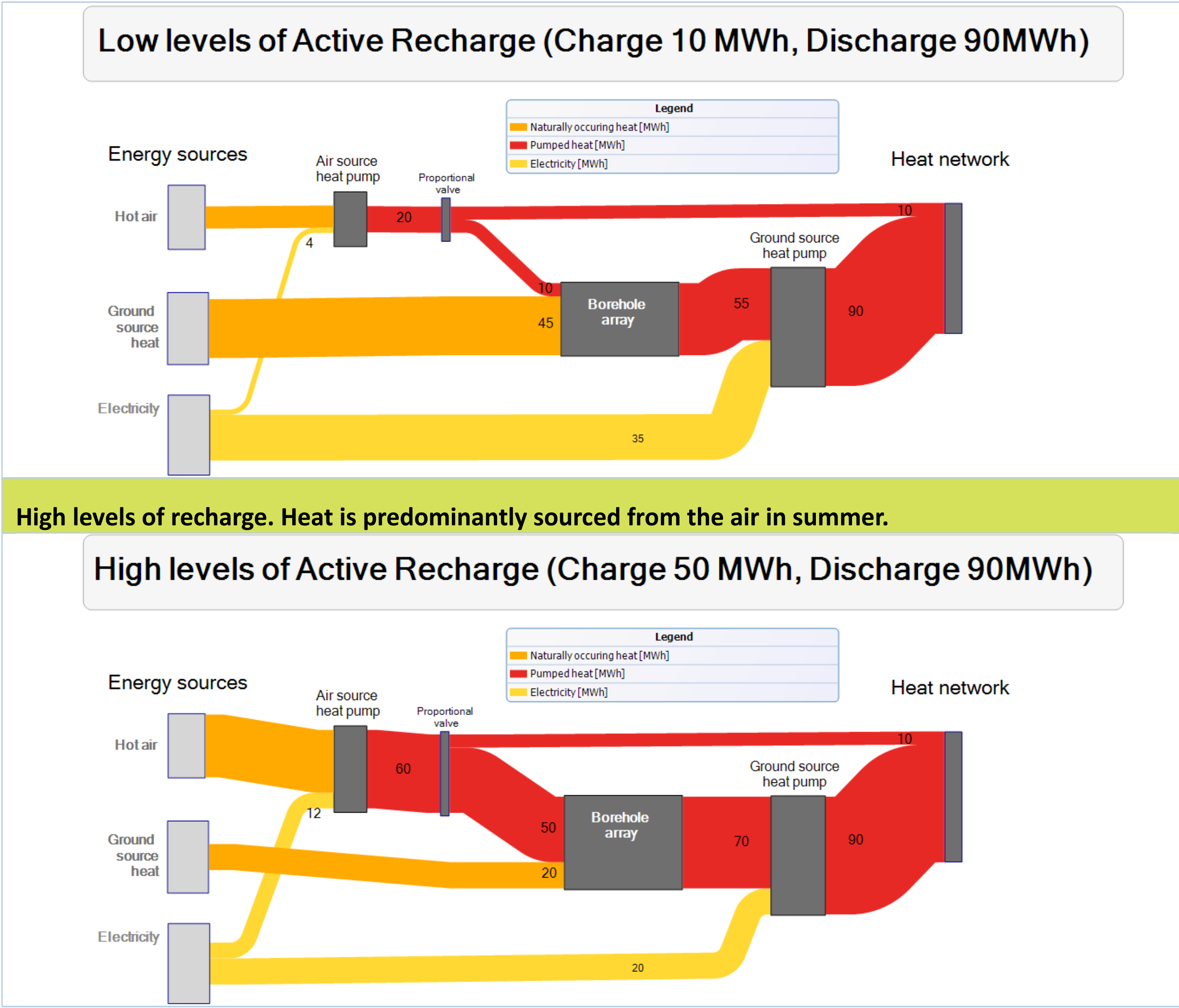



***Figure 2: Illustrative Flows of Energy at Low and High Levels of Recharge. With low recharge most heat is ground sourced and most electricity consumption is in winter. With high recharge most heat is air sourced and electricity use is shifted to summer.***

The CHOICES hypothesis, explored through this project, is that given the right system design and operational regime, the optimal level of Active Recharge can:

1. Improve the economics of ground source borehole arrays compared with natural replenishment alone;
2. Shift a significant amount of electricity load from winter to summer;
3. Remove the risk of "lock out" where the ground becomes too cold for heat pumps to operate; and
4. Improve borehole array performance over the project lifetime.

The other co-objectives of the CHOICES technology are to demonstrate:

- The potential of small-scale heat networks centred around green spaces in the urban environment;
- The development of a community-owned Energy Services Company (ESCO) to manage the facility and supply heat

# 3. Technical Solution

## Description

Our solution is the **CHOICES Energy Centre**, a small-scale, modular Combined Heat and Power (CHP) energy centre that:

1. Operates electric air source heating equipment on hot, sunny summer days and delivers the heat to an interseasonal borehole thermal storage (BTES) array.
2. Operates electric ground source heat pumps (GSHP) in winter to extract heat from the thermal store.

This process of 'active charging' of the thermal store:

1. shifts electric energy consumption in the system from times of winter peak demand to times of summer peak[4] solar generation; and
2. prevents a borehole array from exceeding its operational parameters, enabling the array to serve more properties with reduced capital costs.

The key benefit is electrification of heat while reducing the need for grid reinforcement. Distribution Network Operators (DNOs) must limit high penetrations of distributed generation due to two problems: in summer PV schemes can cause 'reverse power flow' at the transformer; in winter heat pumps increase the cold evening peak requiring transformer reinforcement. The CHOICES approach, by matching heat pump operation to surplus solar PV at the substation feeder level, mitigates both problems for the DNO.

Interseasonal thermal borehole storage is a relatively new technology, one that supports fully decarbonised heat energy pathways via the introduction of renewables such as photovoltaic-driven air source heat pumps, very low maintenance and minimal local environmental impact.

The cleverness of the **CHOICES Energy Centre** is that it 'packages' existing commercially ready technologies in a novel combination that can be constructed off-site and installed as a single unit. With further design standardisation, it therefore has the potential to scale up rapidly.

## System overview and components

The figure below is a Sankey[5] diagram illustrating forecasted energy flows in the CHOICES pilot facility. On the left energy sources are shown. A CHOICES system replaces natural gas consumption while increasing self-use of Solar PV (and reducing grid imports). Importantly, the system decreases the primary energy use by generating heat more efficiently and recovering more heat from the ground heat sink.

4 Between 9-4pm July-August

5 https://en.wikipedia.org/wiki/Sankey_diagram

*Figure 3: Forecasted Energy Flows within the System*

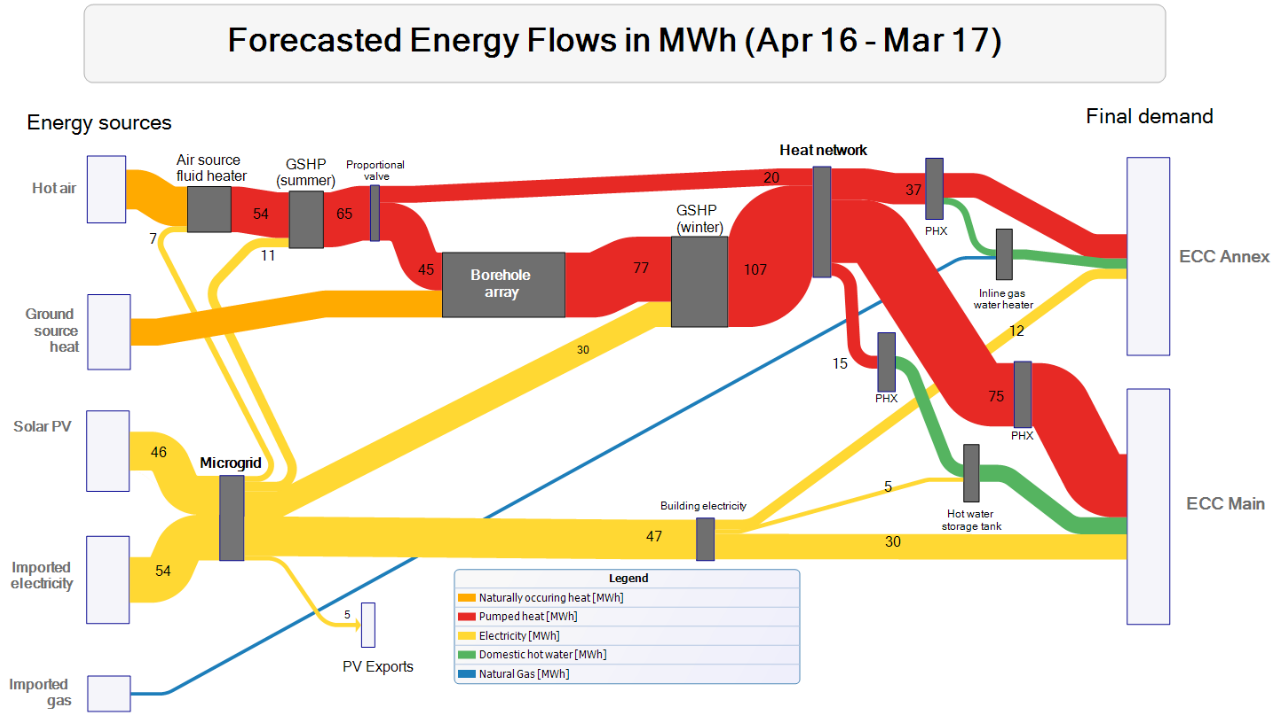



*Table 1: Components of the CHOICES Energy System*

| Component | Description | Provided by |
|---|---|---|
| **CHOICES Energy Centre** | The primary component, this includes the air and ground source heat pumps, pumps, valves, expansion vessel, controls and monitoring systems. It controls Interseasonal Heat Transfer (IHT), the heat network and the borehole array | ICAX |
| **CHOICES Strategic Controller** | The multiple energy vector charging controller is responsible for optimising when heat is generated and stored in summer based on multiple external factors | Bath University |
| **Borehole thermal store** | The array of vertical boreholes providing storage for thermal storage | ICAX |
| **Telemetry, metering, monitoring and billing platforms** | Remote data collection and analysis platforms are used by the CHOICES team to improve system efficiency, by the ESCO to monitor energy production and create bills and by customers to view/pay bills | CEPRO |
| **District heat network** | Provides heat from the Energy Centre to customer buildings | ICAX |
| **‘Private wires’ power network** | Provides electricity from the Energy Centre to customer buildings and links all the PV arrays on customer buildings. See Appendix 1.6. | CEPRO |
| **In-building equipment** | Heat Interface Units (“HIU’s”) and heat meters | CEPRO |

| | | |
|---|---|---|
| | installed in each of the customer buildings | |

## CHOICES Energy Centre

The CHOICES Energy Centre design uses a Dry Air Cooler (DAC) to source heat from the air to water then two 75kW ground source heat pumps (GSHP's) 'upgrade' the heat. The CHOICES EC supports two modes of operation, a 'recharge' mode and a 'heating' mode. In the absence of strategic control[6], the ICAX Interseasonal Heat Transfer Controller implements a default recharge control strategy based on minimising PV grid exports. This non-strategic control routine is based on instant energy values and doesn't take into account any history of recharge or any other long-term parameters to optimize the ratio of PV powered ground recharge and exported electricity.

### Winter heating mode

Customer buildings use regular building controls (in this case a Heatmiser system) to schedule space and DHW heating. The building controls open the district heat network valve when heating is required and this in turn actuates a "call for heat" signal to the Energy Centre. Each local controller is responsible for energising the correct Heat Interface Unit (HIU) motorised valves and circulation pumps in their building.

In the Energy Centre, as soon as one call for heat is received, this triggers the common "distribution pump", which is controlled on a constant differential pressure mode, to maintain the required design flow rates to each HIU. The GSHP (and ASHP at times of high demand) provides a hot water feed. These units are controlled to maintain a weather compensated setpoint. The "distribution pump" circulates hot water to each building.

Although it was outside the scope of the project, the team has developed strategies to minimise GSHP heat pump electricity consumption between 5-7pm weekdays during which "red band" peak grid charges are levied by grid distribution operators. This is an interesting evolution, as charging for electricity becomes more segmental, systems will need to be alert to optimising customer costs.

### Summer recharge mode

At times of low demand (mainly in the summer), and when surplus PV electricity is available, the ASHP is energised under a control routine whose goal is to match the instant consumption of the ASHP to the instant generation of the PV arrays. Any demand for DHW in the summer can also be met by the ASHP directly. Charging will typically occur during optimal PV generation hours, 9am-4pm, particularly avoiding 5-7pm on weekdays during which "red band" peak grid charges are levied by grid distribution operators.

### Telemetry system

The CHOICES Energy Centre relays data from internal heat and electric meters as well as algorithm control via the Modbus TCP protocol. These data streams support remote system performance monitoring and provide input feeds to the strategic controller.

6 See "CHOICES Strategic Controller, Page 9"

### Operating and maintenance requirements

The CHOICES Energy Centre requires two site visits per annum for Planned Preventative Maintenance.

## CHOICES strategic controller

The Choices Strategic Controller algorithm instructs the Energy Centre in decision making during summer recharge mode. Two approaches have been developed:

1. Maximise the temperature of the borehole array by the end of the charging season
2. Maximise the operating efficiency of the plant by only charging in the most efficient timesteps

A FEM[7] model of the borehole field was developed that calculates temperatures across the field as they evolve with time. Combined with system and environment data (in particular air temperatures), this model allows the application of a model predictive controller which is able to reach a target temperature in the most efficient control path.

A "Binpacking" algorithm was also developed to allocate a given seasonal charge (borehole policy) in the most efficient way. A two-step allocation of charge, monthly allocation based on expected seasonal site average temperature and merit order, and 5 day allocation on 3 hour timestep based on MetOffice data point API predicted site temperatures. The latter uses a rolling time horizon approach to allocate the next timestep charge monthly target based on the most up-to date weather prediction out to 5 days.

This is covered in detail in Appendix 4.2.1.

## Borehole thermal storage array

### Borehole array preliminary design

When designing a borehole storage array the key questions are:

1. can the array meet the required instantaneous/peak heat demand on the coldest winter days?
2. is the annual recharing (both active and ambient) enough to make the array sustainable, or does it become depleted with time?

The Owen Square borehole array stores heat energy in a 12-hole borehole field (to depth of 150 m). A preliminary borehole field design was undertaken with the software EED (Earth Energy Designer) using the following parameters:

***Table 2: Heat EED Modelling Data***

| Parameter | Value | Comments |
|---|---|---|
| **Average ground thermal conductivity (W/m/K)** | 2.61 | from BGS[8] report |

7 Finite Element Model
8 British Geological Survey

| | | |
|---|---|---|
| **Average ground thermal capacity (MJ/m3/K)** | 2.297 | from BGS report |
| **Average ground temperature at 1m (°C)** | 11.3 | from BGS report |
| **Number of boreholes (-)** | 12 | from EED |
| **Spacing between boreholes (m)** | 7 | based on ground area |
| **U-Pipe diameter x thickness (mm)** | 40 x 3.7 | PE 100 RC |
| **Grout thermal conductivity (W/m/K)** | 2.1 | |
| **Annual heating load (MWh)** | 180 | Based on gas meter data |
| **Peak heating load (kW)** | 115 | Based on the existing gas boilers |
| **Annual active recharge from ASHP+PV (MWh)** | 50 (1) / 100 (2) | (1) Best case with current PV generation, (2) Potential best case with doubling PV capacity |
| **Heat carrier fluid** | Water with mono-ethylene glycol at 25% | |
| **Average extraction COP (-)** | 4 | |

Parameters show the site has water saturated ground with high thermal conductivity and diffusivity.

The Borehole Thermal storage design has been modified to take into account an unexpected obstruction on site. It transpired that a major storm sewer (belonging to Wessex Water) is routed underneath Owen Square Park. In order to ensure that there would be no conflict, the boreholes were repositioned.

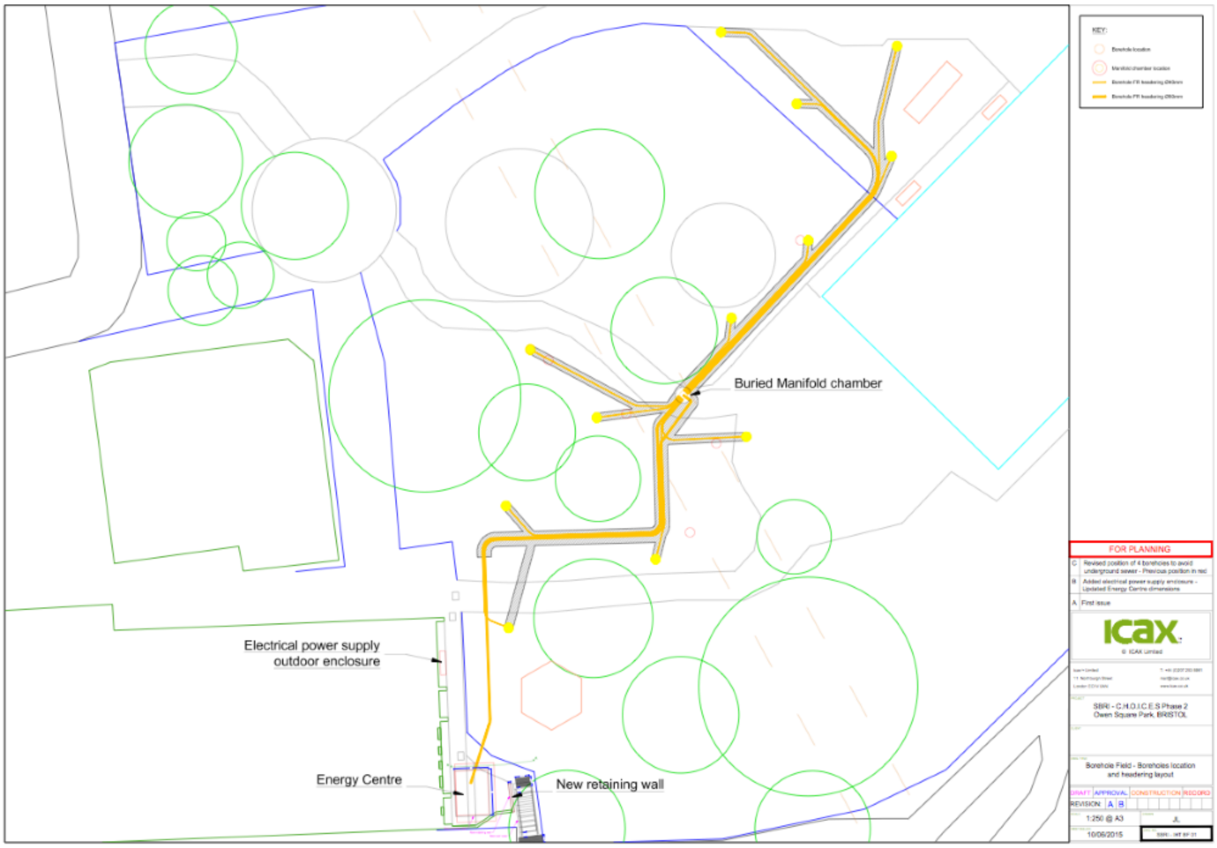



*Figure 4: Location of Revised Borehole Layout*

## 'Private wires' power network

This project implemented a 'private wires' power network to enable it to directly source local PV-generated electricity to power the CHOICES Energy Centre.

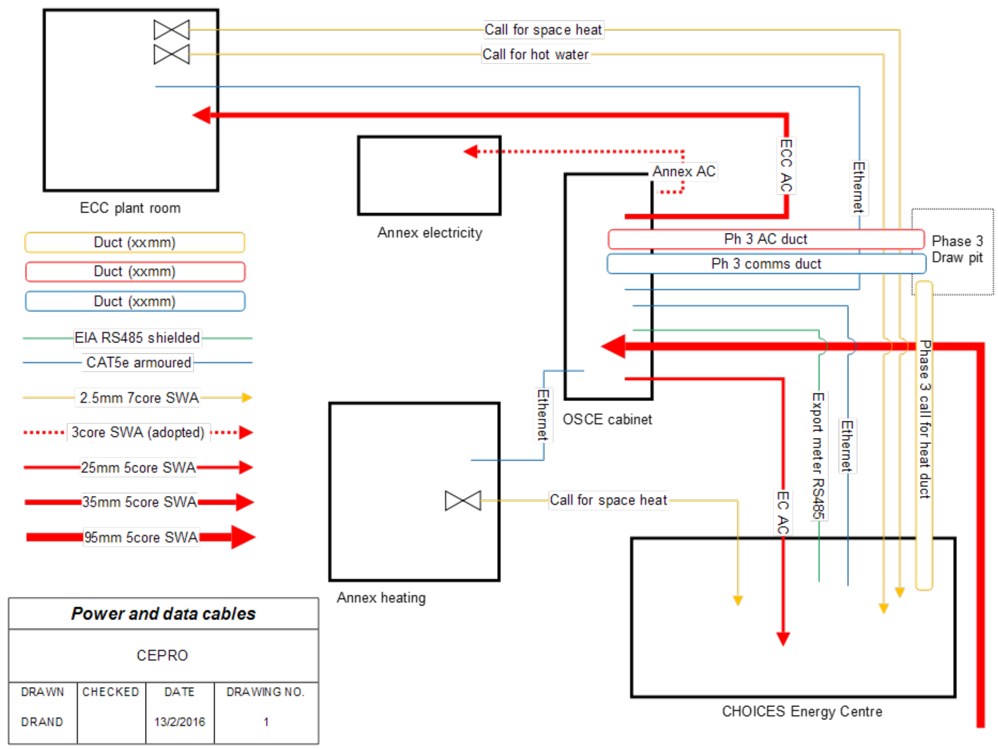



*Figure 5: Schematic showing the cable runs to provide electricity and communications*

As implemented, electricity from 43kWp of solar PV panels is used in the following priority order:

1. By loads in the ECC main building
2. By loads in the ECC annex building
3. By the CHOICES Energy Centre
4. Exported to the public grid.

## In-building equipment

Each building operates an off-the-shelf Heatmiser building controls system. The Heatmiser actuates a district heat network flow control valve which in turn sends a 'call for heat' to the Energy Centre.

# 4. Progress Against Plan

## Technical Readiness Level and test data

The CHOICES Energy Centre has been constructed in its final form in an operational environment and has now run for one full winter discharge cycle with a summer winter recharge and second winter discharge cycle to follow to March 2018. As of March 2017 the whole system has achieved TRL level 8.

Data collection from the upcoming summer recharge period will be available by November 2017 and winter discharge data will be available by March 2017.

## Land rights issues

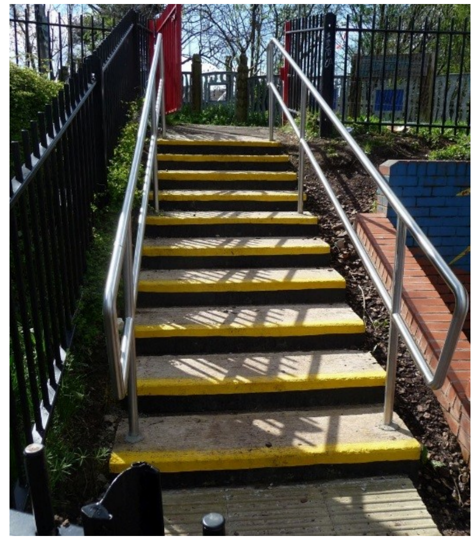


*Figure 6: New steps provided to the community as part of CHOICES Phase 2.*

The major event causing disruption to the original build programme has been the Land Rights process, which was unforeseen. It transpired that the Owen Square Park was not owned by the Council, as had been understood, but was under the control of the King George Vth Memorial Trust.

A series of meetings, formal agreements and sign-offs were required in order to achieve agreement from all parties for Land Rights consent for the project to proceed.

As part of the discussion, the CHOICES team were asked to make additional community benefits, and we have created a replacement set of steps in the park (replacing the worn timber staircase adjacent to the Energy Centre).

The consequence of sorting out the Land Rights permissions and attendant permissions sign offs was that the programme for construction and installation was significantly delayed. Originally we had anticipated a September start on site, but in fact the start was delayed to January. This created significant pressure in the delivery programme:

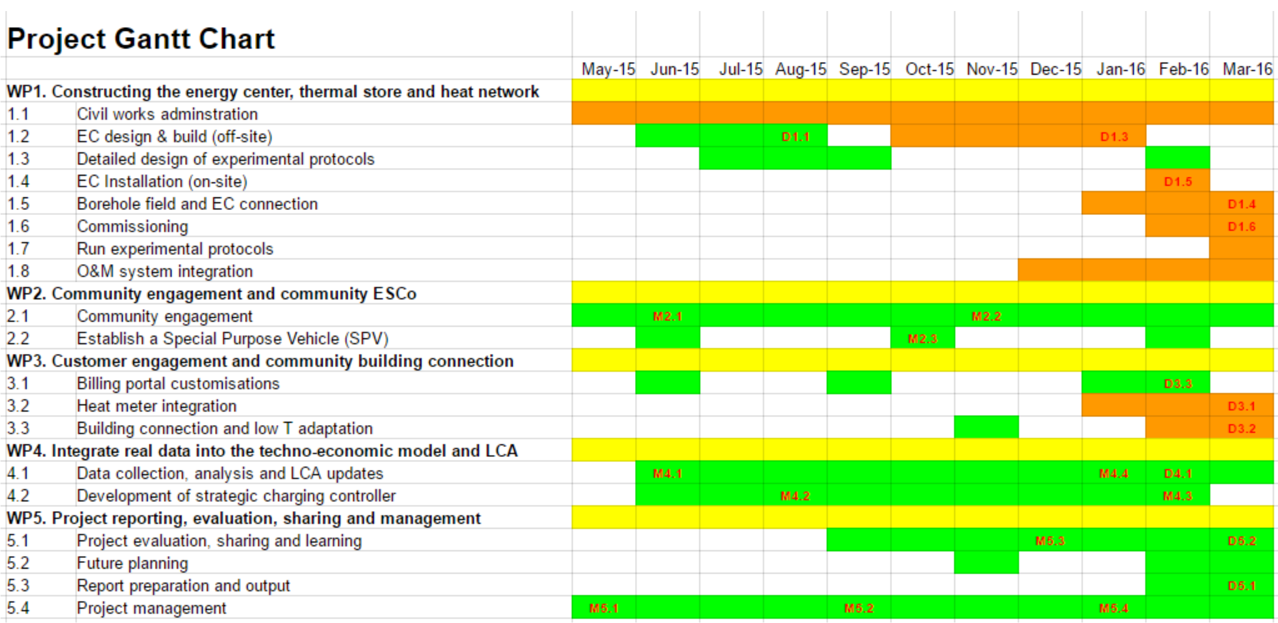



*Figure 7: Project Gantt Chart*

However, the delivery team were able to accommodate this, and the construction programme was able to complete within overall programme time. Park re-instatement activities and some testing activities continued into April. Controls (VPN) access works and delayed plant commissioning both in the Energy Centre and on the client building side continued until December 2016, meaning that we are able to report now on the winter data set, and a preliminary summer recharge, but will report on the full summer charge set in November 2017.

**Learning.** Full site land rights investigation needs to be undertaken as soon as possible, as this can have a catastrophic impact on the project programme if not addressed early enough.

## Site vandalism

The secure store was “tagged” almost immediately following its placing for the construction works.

It became clear that this would be a risk to the Energy Centre, which is intended to be a visual benefit to the park, not an invitation for tagging.

Our response has been to commission a site specific artwork for the Energy Centre, which is intended to add to the visual quality of the installation, and also prevent random tagging. The artwork references the local park, cycling, and solar energy.

***Figure 8: Vandalism to secure store***


***Figure 9: Skid Art (by Zoe Power)***

## Borehole field drilling


*Figure 10: Drill rig set up on site*

The Borehole Thermal storage design was modified to take into account a major storm sewer under the park. Once this was done, the drilling proceeded smoothly. Despite the reduced time window, we were able to deliver the 12 boreholes in a shorter time span than programmed, partly as a result of working long days, and partly by designing a very precisely tailored drill regime for the site.

## Additional PV capacity for charging the borehole field

At Phase 1, it was anticipated that there would be 18KW peak power generation from the PV array on the roof of the Community building. During the project, additional PV capacity was added , funded separately by Bristol Energy Cooperative. This meant that there was additional surplus PV electricity available in summer to the CHOICES Energy Centre. We have adapted the design and installation of the equipment to enable the additional PV capacity to be harvested by the Energy Centre. Original summer recharge capacity of 75kW (Aquaciat ASHP) was increased to 114kW (Guntner dry air cooler).

### TRNSYS Modelling

In order to understand how to create a framework within which the team could seek ways to optimise the future performance of the system, and influence current decisions (such as whether or not to divert electrical energy into the borehole charging protocol at any particular point in time) we developed a model of the Energy Centre and borehole field using the TRNSYS simulation tool (ICAX). This tool was used to analyse the strategic control algorithm (Bath University) and financial and life cycle model consequences (Eunomia) in a fast and accurate modelling environment.

TRNSYS allows the linking of block components (eg. Heat pump compressor, borehole field) which all come with their appropriate set of fixed parameters, variable inputs and outputs. The outputs of one component are linked to the inputs of the next component. The TRNSYS engine runs dynamic simulations by going through an iterative process in order to converge on a solution that fits the variables for each component. The simulation timestep is also configurable to suit the simulation requirements.

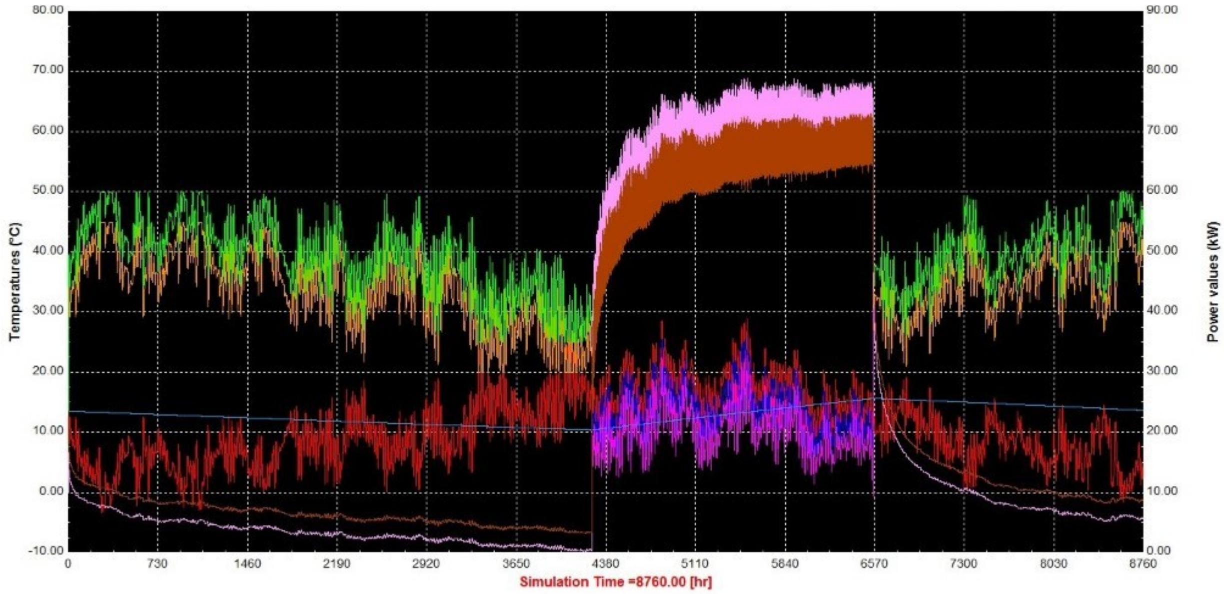



***Figure 11: Example TRNSYS graphical output showing simulation run over one year (January to December).***
***Brown/pink is borehole flow/return T***
***Green/brown is heat network flow/return T.***
***Purple/blue is DAC air source capture T***
***Red is air temperature***

## Energy Centre Controls development and delivery

The controls capability has been delivered as described above. Evolutions and refinements include the inclusion of a ruggedised PC within the ICAX IHT controller, to carry the Bath algorithm functionality.

The summary list of data inputs and outputs from the IHT controller to the cloud platform (for data monitoring purposes) is outlined in Table 3 below.

***Table 3: List of Data Inputs and Outputs from IHT Controller to Cloud Platform***

| Inputs | Outputs |
|---|---|
| • GSHP 1 and 2 energy/power output,<br>• GSHP 1 and 2 energy/power input,<br>• GSHP 1 and 2 electrical energy/power consumption,<br>• GSHP 1 and 2 instant COP for heating and recharge,<br>• Pump 1 and Pump 2 electrical energy / power consumption<br>• Dry Air Cooler electrical energy / power consumption<br>• Electricity import/export energy/power | • Override call for heat<br>• Cancel (if for example, the algorithm decides it would be better to recharge than to heat the building for a time window in mild outside conditions)<br>• Recharge mode ON/OFF<br>• Recharge power consumption setpoint (kW)<br>• Heating using thermal store only -> Force (when not used, ICAX code will chose the best source or a mix of the |

| | |
|---|---|
| flow<br>• Dry air cooler energy/power output<br>• Borehole extracted energy/power, recharged energy/power<br>• Outdoor air temperature<br>• ECC building call for heat<br>• ADC building call for heat | two)<br>• Heating using dry air cooler only -> Force (when not used, ICAX code will chose the best source or a mix of the two) |

# 5. Key Findings

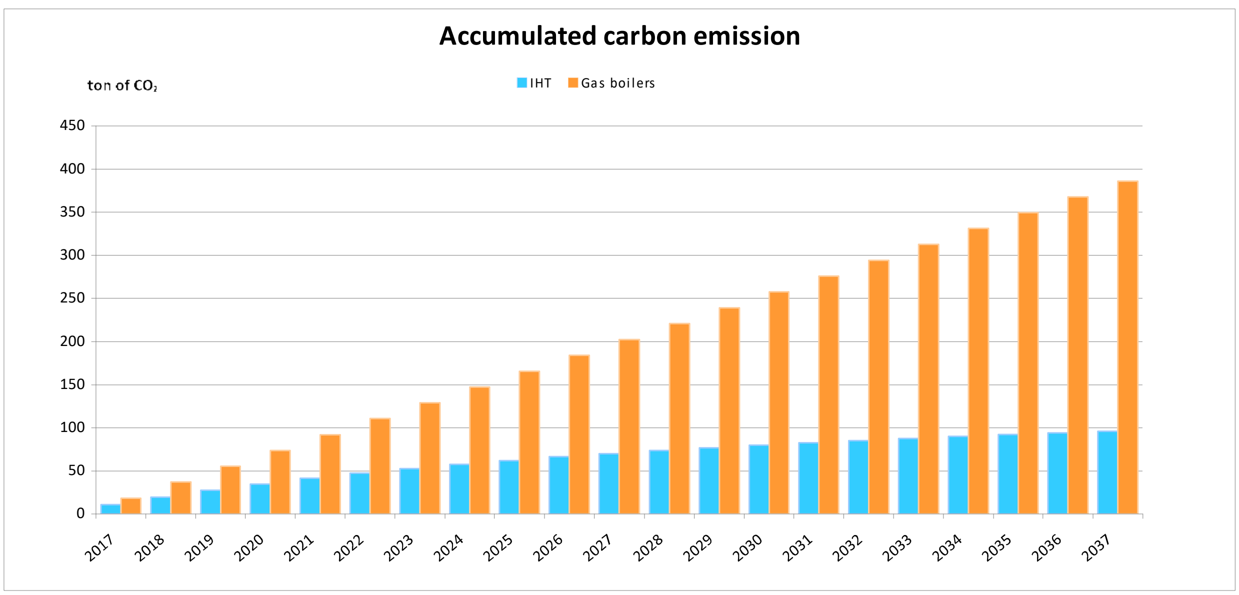
## Life-Cycle Assessment

Detailed technical modelling has been undertaken on the pilot facility both for a realistic heating load from the currently connected buildings (90MWh), and the 'design load' of 180MWh, in order to model as accurately as possible the anticipated energy use of the facility over its lifetime, and the potential performance of the pilot facility under a more optimal heat load. Core assumptions used within the modelling are outlined in Table 1 in Appendix 4.1.1.

The modelling was conducted using the TRNSYS software described in the previous section. The software has been tuned to the thermal properties of the ground at the pilot site.

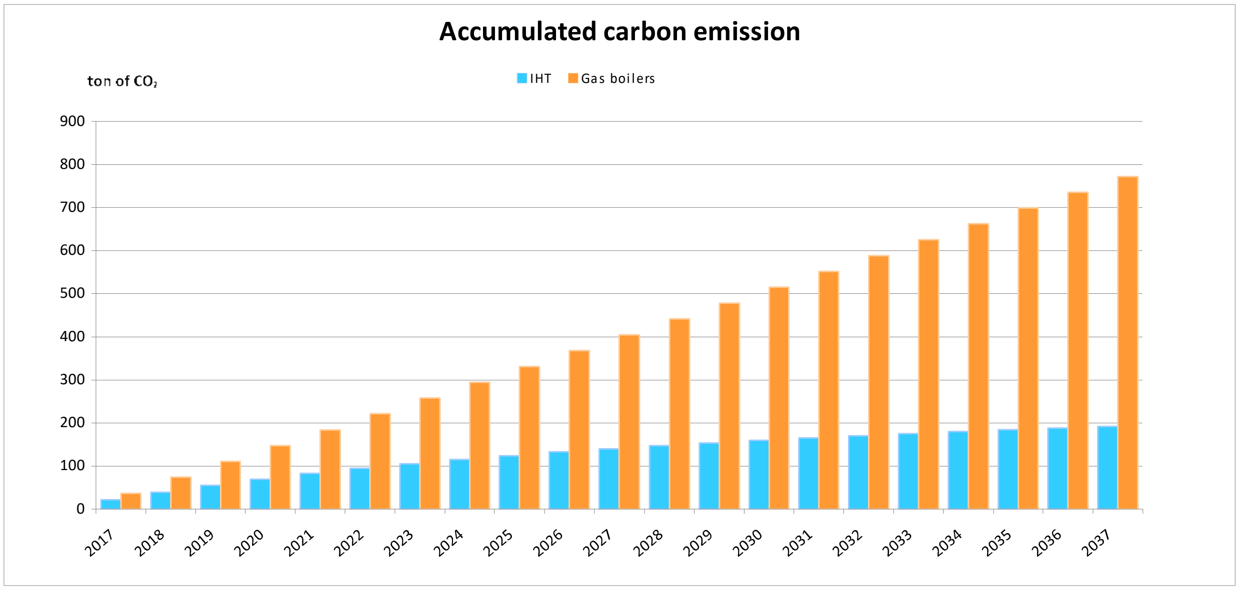
The results of the life-cycle assessment (LCA) indicate that:

- With the decarbonisation of grid electricity expected by DECC[9], the CHOICES technology offers a 25-year lifetime average 55% carbon savings over a gas counterfactual, rising to 62% if the full heat demand load is met.




90 MWh: 290 tonnes of CO2 saved

9 DECC Electricity marginal emissions factors to 2100




180 MWh: 580 tonnes of CO2 saved over 20 years

- On this basis, the current facility is expected to create average carbon savings of 13 tonnes per year over its lifetime.
- The technology also offers 52% primary energy savings against the gas counterfactual over its lifetime. The high initial primary energy costs are more than offset by lower energy use during operation.
- These savings are largely maintained under the sensitivity analysis undertaken, with the carbon impact ranging from 82 - 101 kgCO2e per MWh heat delivered, compared with 282 kgCO2e in the gas counterfactual.

## Assumptions

A number of assumptions support the LCA and financial modelling of the facility. The most important of these are outlined in Table 4 below.

Detailed technical modelling has been undertaken on the pilot facility both for a realistic heating load from the currently connected buildings (90MWh), and the 'design load' of 180MWh, in order to model as accurately as possible the anticipated energy use of the facility over its lifetime, and the potential performance of the pilot facility under a more optimal heat load.

The counterfactual considered (for the calculation of savings in energy, carbon or cost) is that of the same demand heat load being met by the baseline gas boiler heat supply. This is the real-life counterfactual for our pilot project, and realistic one for comparative projects set in similar urban-park locations. For the real-life counterfactual, we assume the current boiler efficiency of 75%. For the design heat load counterfactual, we assume boilers are properly maintained, replaced after twelve years, and operate at 85% efficiency.

***Table 4: Assumptions for LCA and Financial Modelling***

| | Pilot Facility | Scaled Facility, where different |
|---|---|---|
| **Heat Demand** | Approximated based on historic data. This is approximately half the full design load of the facility. Therefore, the embodied carbon and energy of the products per MWh of delivered energy are twice as high as they would be with a heat demand matching the design load. | Scaled to the design load of 180 MWh. This heat load is assumed to be 50% small-scale commercial/public and 50% domestic. Heat loads have been profiled according to a degree day calculation over the year, and profiled based on estimated daily profiles for community and domestic loads. |

| | Pilot Facility | Scaled Facility, where different |
|---|---|---|
| **Heat Demand Profile** | Degree-day calculation and estimated daily useage profile for heating and hot water. | Separate domestic load profiles for heating and hot water are assumed. |
| **Price of Electricity** | Pilot electricity costs obtained on the PICLO tariff (Good Energy). This tariff is broadly in line with DECC central energy prices, assuming a broadly standard electricity use profile between time periods. | |
| **Price of Solar PV** | The opportunity cost of that electricity, namely the value received from exporting it to the grid (the export tariff). This reflects the current arrangement with supplier Bristol Energy Cooperative for the pilot facility. | |
| **Price of Gas (Counterfactual)** | DECC central estimate, using the half-waypoint between commercial and domestic price. | DECC central estimates, using the half-waypoint between commercial and domestic prices for the 'community building' load and domestic prices for the domestic network. |
| **Availability of on-site Solar PV** | The amount available to the facility is calculated based upon historic export data from a comparable site, re-scaled and adjusted to account for the difference in generation and self-use expected at the pilot facility site. | |
| **Capital Costs of the Technology** | The costs incurred for the project management, design, construction, installation and commissioning of the CHOICES system, not including R&D and research costs. | These do not include the costs of construction of a domestic heat network. It is assumed that the facility would supply an existing or new-build heat network. |
| **Operating and Billing Costs** | A cost of £120/customer/year is assumed, through a subscription to billing and customer management software supplied by Clean Energy Prospector. | |
| **Maintenance Costs** | Annual maintenance costs of £1200 are assumed to cover annual checks and routine maintenance. Additionally, it is assumed some capital outlay will be needed to replace components of equipment, equating to 3% of the cost of the energy centre over the project lifetime. | |
| **End-of-life** | End-of-life disposal is assumed to largely consist of scrap metal, plastic and WEEE to be disposed of via open-loop recycling processes. | |

In assessments including revenue assumptions, heat charge revenues are set to deliver 5% savings against a gas counterfactual.

## Carbon Impact of Delivered Energy

Under the design heat load, the CHOICES technology as installed at the pilot site would have a lifetime carbon impact of 93.7 kgCO2/MWh. The breakdown of this carbon impact between different life-cycle stages and aspects of operation is shown in Figure 12 below. The manufacture and construction account for approximately 32% of the lifetime impact.

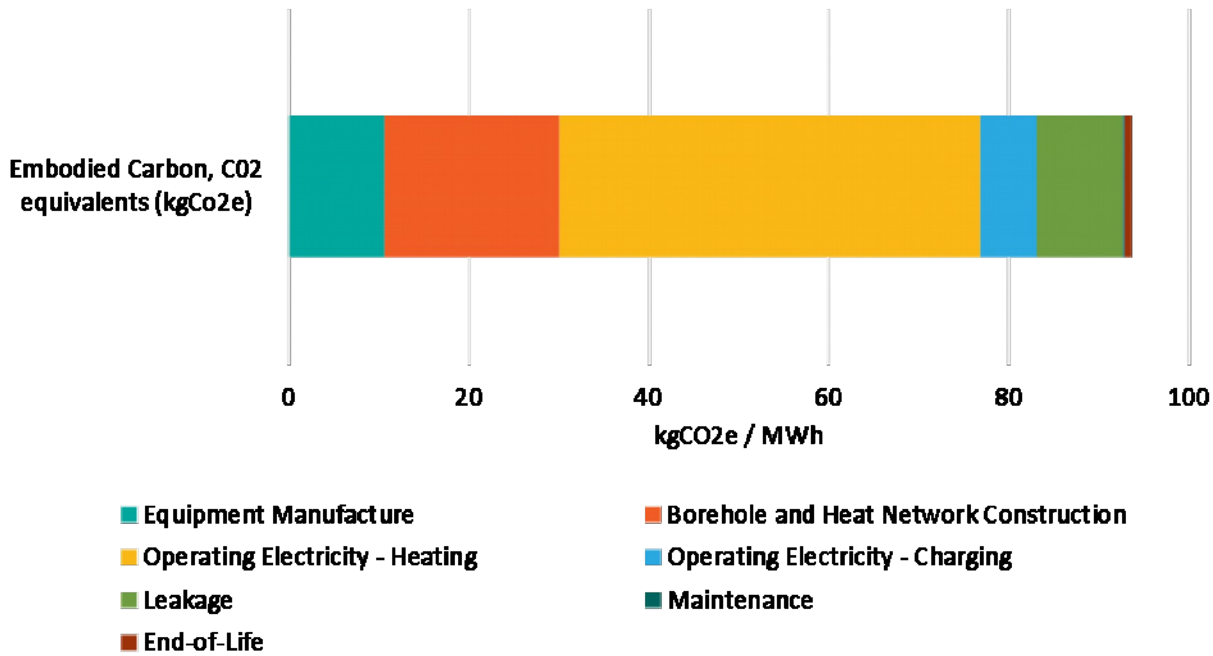



*Figure 12: Central LCA Results for Design Heat Load, kgCO2e/MWh delivered heat*

The carbon impact ranging from 82 - 101 kgCO2e per MWh heat delivered under the modelled set of sensitivities (see appendix 4.1.1). Carbon impacts are most impacted by embodied energy within the construction of the heat network (reflecting uncertainties regarding large transport impacts), uncertainties regarding the carbon intensity of grid electricity, availability of electricity from solar PV, and uncertainties remaining in the embodied carbon in products and materials.

*Table 5: Lifetime Carbon Impact of Delivered Energy Against Counterfactual, kgCO2e/kWh delivered*

| | CHOICES | Counterfactual | Saving |
|---|---|---|---|
| **Pilot Project** | 0.126 | 0.282 | 0.156 (55%) |
| **Design Heat Load** | 0.094 | 0.248 | 0.154 (62%) |

## Primary Energy in Delivered Energy

Under the design heat load, the primary energy usage of the facility is approximately 2,650 MJ/MWh delivered (or .735 KWh/KWh delivered). Manufacture and construction accounts for 13% of this primary energy, and operating electricity accounts for 86% of this energy.

***Table 6: Lifetime Primary Energy Useage Delivered Energy Against Counterfactual, kWh/kWh delivered***

| | CHOICES | Counterfactual | Saving |
|---|---|---|---|
| **Pilot Project** | 0.73 | 1.52 | 0.79 (52%) |
| **Design Heat Load** | 0.74 | 1.33 | 0.60 (45%) |

## Cost of Delivered Energy

The lifetime cost of delivered energy for the pilot project calculated takes into account initial capital, operational and end-of-life costs, excluding research and development costs incurred during the project. Over a 25-year lifetime, assuming a 3% discount rate, the levelised cost of delivered energy at scale is estimated at £166/MWh (£282/MWh for the pilot facility with its current heat load). This is primarily due to the high capital costs of the technology, accounting for £123/MWh.

Under a modelled set of sensitivities (see appendix 4.1.1), the cost of delivered energy ranged from £155-180/MWh - the higher cost illustrating the impact of delivering 10% less than the design heat load. The cost of delivered energy is most sensitive to the capital costs of the facility, the actual heat demand met by the facility, and the price of electricity (whilst being comparatively less sensitive to inaccuracies in the modelled efficiencies of the facility).

***Table 7: Lifetime Cost of Delivered Energy Against Counterfactual, £/kWh delivered***

| | CHOICES | Counterfactual | Saving |
|---|---|---|---|
| **Pilot Project** | 0.282 | 0.043 | N/A |
| **Design Heat Load** | 0.166 | 0.045 | N/A |

There are possibilities for future reductions in the cost of delivered energy:

- The operational lifetime of the facility may be increased to thirty years, and the borehole array may have a residual capital value after that time.
- The capital costs of the technology can be significantly reduced, through standardising some highly bespoke elements of the CHOICES pilot design (plausibly reducing the cost of delivered energy to £125/MWh).

### Financial Performance of the CHOICES Pilot

Without taking into account capital costs of the technology, for the pilot facility CHOICES technology offers marginal (approximately 5%) savings compared to a gas heat supply, due to lower energy bills but higher management and maintenance requirements.

The heat load of the building is met by electricity, rather than gas. The CHOICES technology therefore offers a relatively stable alternative to uncertain gas prices. If the costs of gas rise, the savings offered by CHOICES technology could significantly increase.

Without subsidy, these cost savings are not sufficient to cover additional maintenance bills, management charges, and to repay the capital investment over its lifetime, let alone at sufficient interest rates or payback time for corporate investment. This is, of course, common to many renewable technologies, and the gap which incentives such as the RHI are designed to address.

With RHI payments, additional reductions in capital costs are necessary to achieve more broadly viable rates of return. The consortium expect to be able to reduce capital costs by up to 36% in a commercialised version of the facility, which brings the (pre-finance) payback period to 18 years, within the project lifetime. To achieve above an IRR of 5%, at which social and community finance might be obtainable, a subsequent 30% reduction in capital costs would be required. The market potential of the technology is more fully explored in a subsequent section of this report.

## Active Recharge

Borehole-based ground-source heat pumps are recognised as effective sources of heat especially when there is a an existing 'cooling' load which allows the borehole to provide an additional value, whilst also, simply phrased, putting heat back into the ground.

Charging the borehole with heat during the summer maintains or increases the temperature of the borehole array over time, and increases the energy-efficiency of the GSHP operation during winter.

Where there is no cooling load, there are a number of existing sites which use solar thermal panels to actively 'charge' the ground. The CHOICES technology is the first site in the UK to demonstrate an array which is actively 'charged' with heat from the air, extracted by a combination of a dry-air cooler and reversible GSHP.

Figure 13 below illustrates the change in average borehole temperature over the operational lifetime as predicted by the TRNSYS model, comparing the results if no summer charging occurs (only natural replenishment) compared with an summer active recharge input of 90MWh (half of the design heat load). Without active recharge, as illustrated in the figure below, the borehole array becomes depleted over time.

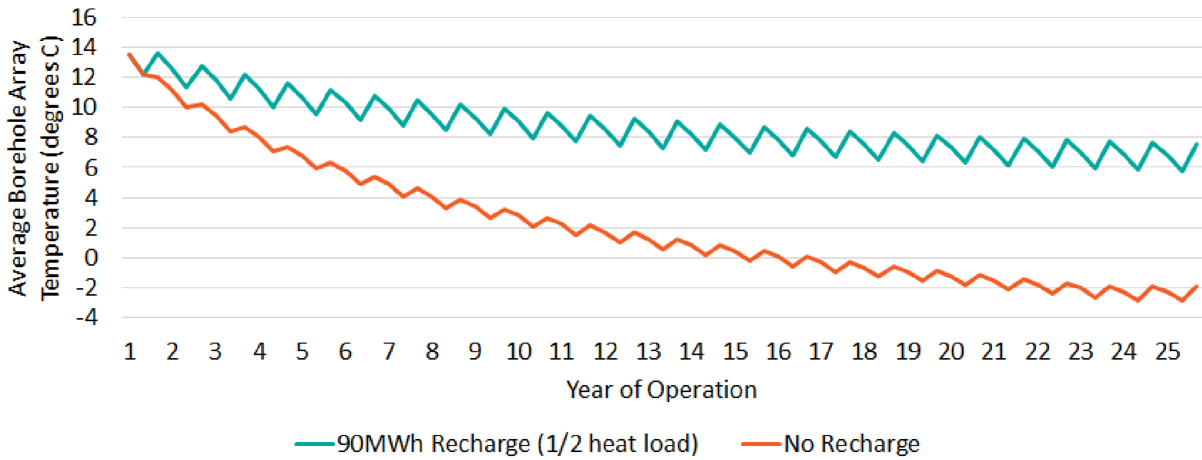



***Figure 13: Average Temperature of the Borehole Array over Time, Degrees***

A detailed modelling exercise was undertaken to understand the optimal level of charge for the pilot facility modelled (assuming the design heat demand). In this modelling:

- Stepped annual levels of charge were modelled with the TRANSYS model, using detailed half-hourly profiles and hourly timestep profiles to extend the modelling over 25 years.

## Electricity Savings from Active Recharge

The figure below depicts the lifetime 'electricity balance' of charging the ground for different levels of recharge (as a fraction of the delivered heat load). The teal bars represent the electricity used in summer to charge the ground over 25 years, and the orange bars depict electricity saved in winter over the same period.

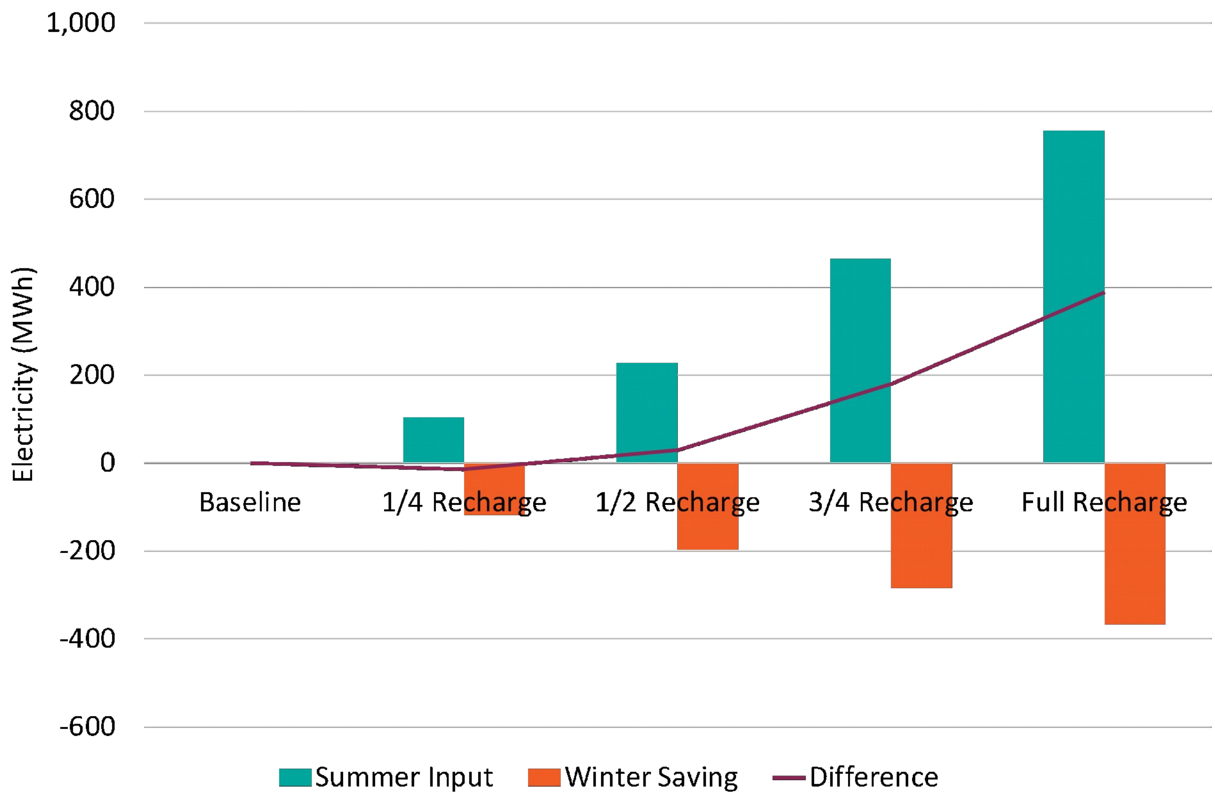



*Figure 14: Electricity Spent in Active Recharge vs Electricity Saved in Heating (MWh)*

The figure above illustrates the key findings:

- A charge of 90MWh, half of the delivered heat load, is expected to save approximately the same amount of electricity in winter as it uses in summer over its lifetime;
- Increasing the levels of charge, more electricity is used in summer than is saved in winter. However, there may still be a cost saving depending on the price difference between electricity sourced from on-site solar PV (or electricity in summer) and electricity in winter.
- A charge of 90MWh still results in a decreasing ground temperature over time.

The table below displays the cumulative 'efficiency' of active recharge: how much the electricity saved 'costs' in electricity input. A number of 1 indicates that for every kWh of electricity used in charging the array, one kWh is saved. A number of 0.5 indicates that it takes 2 kWh input in summer to save 1 in winter.

*Table 8: Cumulative Efficiency of Active Recharge*

| | After 2 Years | After 10 Years | Overall |
|---|---|---|---|
| **Recharge of 45MWh** | 0.22 | 0.67 | 1.14 |
| **Recharge of 90MWh** | 0.19 | 0.52 | 0.87 |
| **Recharge of 135 MWh** | 0.15 | 0.38 | 0.61 |
| **Recharge of 180 MWh** | 0.12 | 0.31 | 0.49 |

Since the impact each MWh charge is felt in raised ground temperatures over each following year, the cumulative energy input in earlier years contribute to larger 'savings' obtained in later years, when there is a more pronounced difference in ground temperature. Hence, the savings of recharge are only fully realised over the lifetime of the facility, and each year that passes, the cumulative 'cost' of the electricity saved decreases.

This analysis relies on the TRANSYS modelling and obtaining high charging efficiencies in the summer. A key priority for the next phase of the project will be to assess real charging efficiencies to be able to update the analysis presented here.

## Cost Savings from Active Recharge

Table 8 above acts as a guide to the potential cost savings available through low levels of active recharge. For instance, since 1 kWh of summer electricity can save 0.87 units of winter electricity, if summer electricity in the long-term can be sourced for under 0.87 x the average cost of winter electricity, then there are net savings from inputting up to 90MWh of heat (1/2 of the design heat load) into the ground.

The cost savings are primarily experienced in the later years of operation, as the ground has been prevented from cooling. So the extent of the savings will depend on:

- the extent of electricity price rises over time (and the differential between electricity prices in summer and winter); and
- any discount rate applied to electricity costs incurred in future years.

Applying the current electricity prices obtained by the CHOICES facility under the PICLO tariff, under the central scenario of a 90MWh recharge, without taking into account changes in electricity prices or discount rates, the lifetime saving on winter electricity is estimated at approximately £30k, compared to a summer cost of £23k. This does not take into account the additional capital costs of installing the capacity to recharge, and depends also on high summer charging efficiencies modelled by the TRANSYS tool.

Figure 15 below illustrates the relative costs and savings from active recharge, with teal bars representing the cost of charging electricity in summer, and orange bars representing the corresponding winter savings. Active recharge initially reduces the lifetime cost of electricity, but subsequently increases the lifetime cost of energy as the level of charge increases.

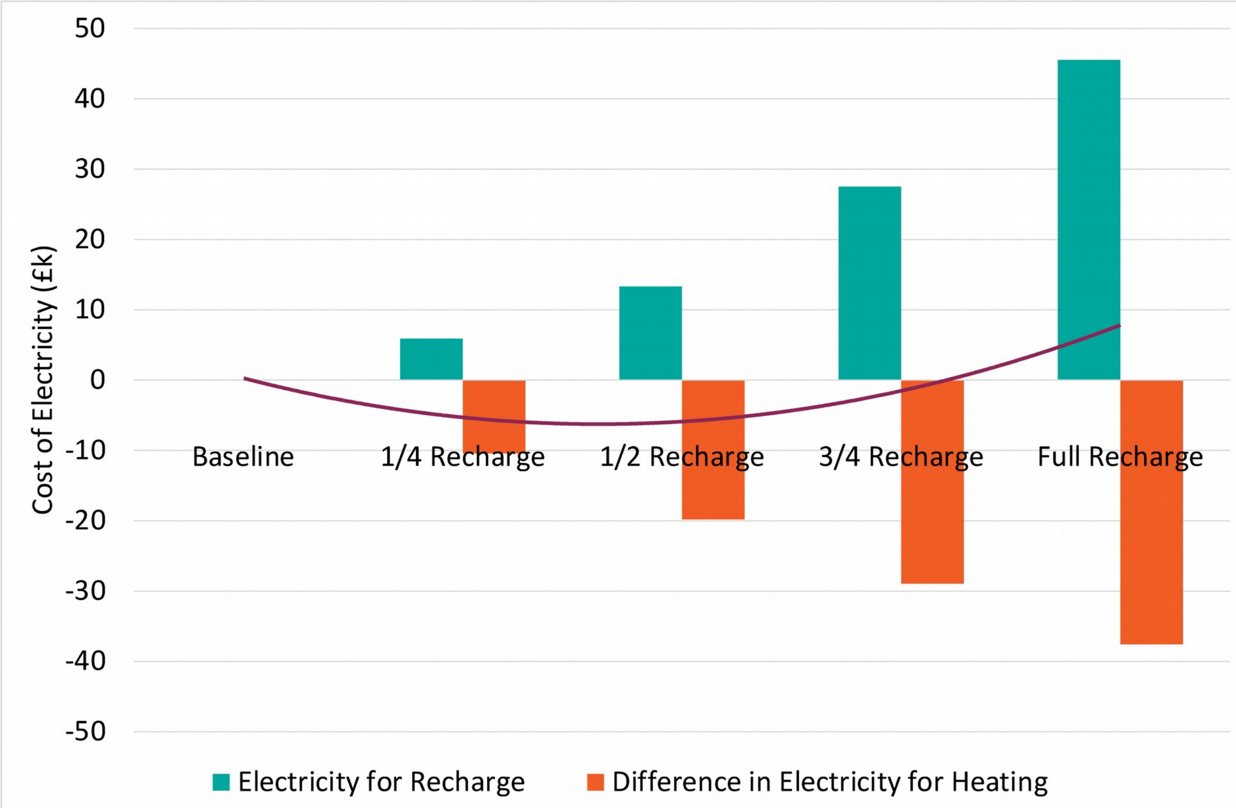



***Figure 15: Cost of Electricity for Active Recharge vs Savings in Electricity for Heating (MWh)***

For the pilot facility, the additional savings incurred by much higher levels of charge are outweighed by the costs of transferring heat into the ground. The CHOICES facility however, offers the opportunity to take advantage of low-cost off-peak electricity. The two sources currently available used by the CHOICES facility are:

- Solar PV generated on-site, which would otherwise be exported to the grid, available at the export tariff rate; and
- Prices available through the Good Energy PICLO pilot tariff, which provides cheaper summer night-time electricity.

Trials such as PICLO demonstrate the potential for smart buying of electricity in the future. PICLO offers the ability for energy buyers to directly access electricity from solar farms, wind turbines and hydro plants, a process called 'sleeving'. Most importantly for CHOICES, PICLO and other similar services are de-bundling the DNO Use of System Charges (DUoS) as well as promising (in the future) to provide direct access to the wholesale half hourly electricity rate. In the future this will enable CHOICES to buy electricity during half hourly blocks when excess generation from surplus PV or wind is depressing the national wholesale price.

Further modelling found that the borehole configuration influences and potentially increases the business case for Active Recharge at higher levels of recharge. Simulations run on reducing the distance between boreholes suggest that savings may be obtained with a higher level of active recharge if the price differential between winter and summer electricity remains above approximately 1.5 (i.e. the price of electricity in winter is more than 1.5 times the cost paid for electricity in summer).

In the pilot example the level of savings modelled do not clearly provide a secure business case for the inclusion of the 'active recharge' technology alongside a borehole array, however there are a number of promising indications:

- The pilot model does show that it is possible to significantly shift portions of the electricity load of a GSHP from winter into summer, at an ‘efficiency’ approaching 1-1.
- Emerging time-of-use tariffs (for instance through the PICLO platform) could allow CHOICES to take advantage of low grid prices at times of over-supply, for instance local solar-farms in the afternoon.

Additionally, the technology has other benefits which are not modelled, including the ability to use the DAC to supply heat as an air-source at times of peak load in winter, or to act as an air-source heat supply to the buildings in the summer.

Actual system performance is being closely monitored to establish the accuracy of the underlying model.

## TRNSYS Model Validation: Monitoring Update March 2017

### Methodology

One month’s worth of full monitoring data (covering the period of February 2017) was available with which to conduct the update. The following approach was taken:

- A new set of modelling inputs for the period was created based on monitored heat demand and air temperatures over the period.
- TRNSYS model outputs and resulting calculations were then compared with the equivalent actual performance, both overall and for each timestep, covering:

Electricity usage of GSHPs and pumps;

  - Overall Energy Centre electricity usage;
- COP of GSHPS and overall COP of heat produced;

Flow and return temperatures from the borehole; and

  - COP of heat supplied (taking into account pipework losses).
- To account for the period of charging the ground in the summer, the ‘initial surface temperature’ variable in the TRNSYS model was adjusted to account for the resulting increase in ground temperature, so that the average inlet temperature from the borehole within the model matched the average monitored value.

The system is operating significantly below its design heat load, and below the scaled estimate used to assess the business case above. Other operational and system differences impact on the results:

- In the period of February 2017, the building radiators had not been upgraded as initially anticipated. As a result, the system has run the network at higher temperatures than the TRNSYS model assumes, to deliver the same level of occupier comfort.
- The distribution pump has been running at full capacity for much of February, leading to a higher energy use than would be expected with a more intelligent BMS.

The results from TRNSYS are interpreted in this context, and key results are summarised below.

Results

The model run demonstrated a close match on a half-hourly basis between TRNSYS and modelled outputs, showing a very similar profile. However, there were two key differences observed:

The electricity used for pumping (in particular by the distribution pump) was significantly higher than that predicted by the TRNSYS for the same heat load (more than 400kWh compared to 40kWh modeled in TRNSYS. As noted above, this is partly due to operating the pump at levels beyond what is required. Additionally, the energy used by the distribution pump would not scale up with increased heat demand, but is dependent on the extent of pressure loss through the client building heat exchangers. With a scaled heat load, TRNSYS models an annual pumping electricity demand of 4,750 kWh, or 395kWh/month, very similar to the observed value of 400kWh during February.

- As expected due to higher heat load, the CoP of the GSHP units are lower (excluding pumping electricity, 3.86 rather than 4.84 as predicted by TRNSYS). The temperature in the heat network is also returning 10 degrees higher and output 9 degrees higher than 10 degrees higher on average than TRNSYS predicts. In calculations derived from manufacturers data and used within the TRNSYS model, this 10 degree outlet temperature change more than accounts for the 1 unit difference in CoP. A very similar system installed by ICAX elsewhere is operating at the performance as indicated by TRNSYS.

Figure below compares the actual CoP of the Ground Source Heat Pumps in orange with the modelled TRSNSYS CoP for the same half-hourly periods in teal. It also shows in purple a measure of how depleted the borehole is (showing heat extracted in the previous 6-hour stretch). High CoP values can be observed, as expected, when the ground has had time without heat extraction. In this graph, the consistent difference can be seen in the CoP, though the profiles show a close match.

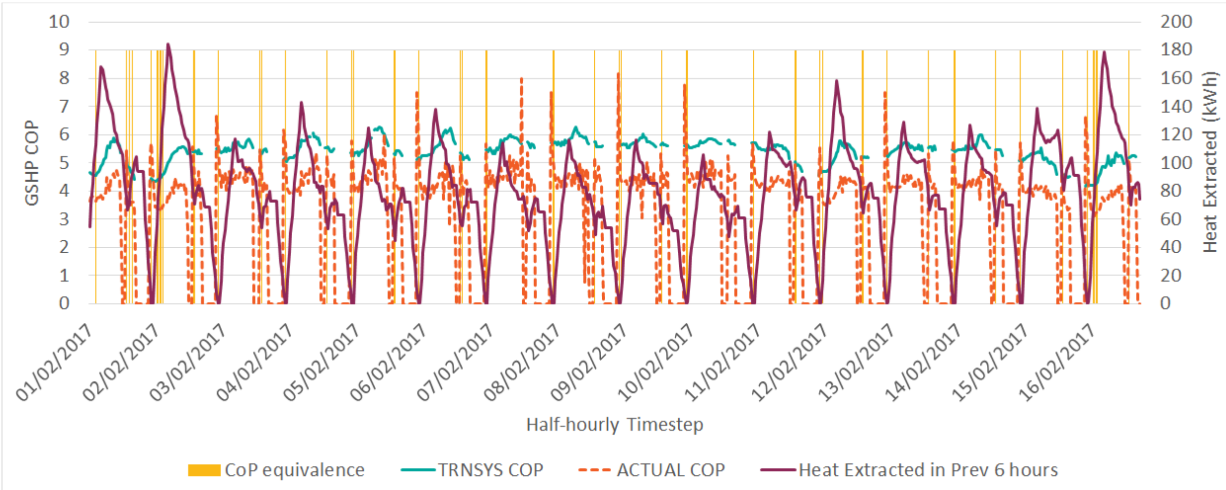



***Figure 15: Timestep Comparison of GHSP CoP, Actual vs Modelled***

In light of this correlation and the explanation for the difference in observed CoP, there is reason to have confidence in the original projections, particularly the performance of the system at design heat load (with radiator upgrades). There is a possibility that distribution pumping loads are underestimated in TRNSYS, but operationally the pumps are being used at the levels TRNSYS would expect under a higher heat load, and the actual values seen match the TRNSYS predictions for higher heat loads.

- Due to the limited scope of data available, we have not been able to yet assess or validate:
- Performance of the system in charging mode;
- The accuracy of TRNSYS modelling of long-term changes in ground temperature; or
- The extent of true heat losses in the network, since the heat meter in the client building has had a error.

It is hoped that a further update in November will be able to address these issues with greater confidence.

Borehole Configurations: Impact of Shallow Series Arrangements

Methodology

A revised version of the TRNSYS model was created to allow for modelling performance under different borehole configurations.

Configurations were run on the TRNSYS model to explore the relative benefit of alternative borehole arrangements, in which the boreholes are:

- spaced at three metre rather than seven metre intervals;
- arranged in series (in strings of four) rather than in parallel; and

shallower and more numerous (48 boreholes rather than 12, and a quarter of the depth).

In all configurations modelled, the total borehole length is maintained.

Additionally, we were interested in exploring the comparison at a higher level of summer recharge. Therefore for some boreholes we also compare scenarios where the full winter heat load is replenished in the summer.

The outputs where assessed on the basis of:

- whole system CoP
- whole system cost of energy (taking into account current)
- required average price differential

Scenarios

| Scenario | Borehole Configuration | Recharge Level |
|---|---|---|
| **7m Parallel** | Current borehole configuration | ~90MWh (Equal to half of heat demand) |
| **3m Parallel** | Reduced borehole spacing to 3m | ~90MWh |
| **3m Series, Shallow** | 48 boreholes of 37.5m depth, series strings of four | ~90MWh |
| **7m Parallel, Full Recharge** | Current borehole configuration | ~180MWh (Equal to heat demand) |
| **3m Series Shallow, Full Recharge** | 48 boreholes of 37.5m depth, series strings of four | ~180MWh |

## Results

Figure shows the whole-system CoP achieved for each scenario, including all energy used prior to heat extraction at client buildings. Straight lines indicate parallel arrangements and dotted lines indicate series arrangement.

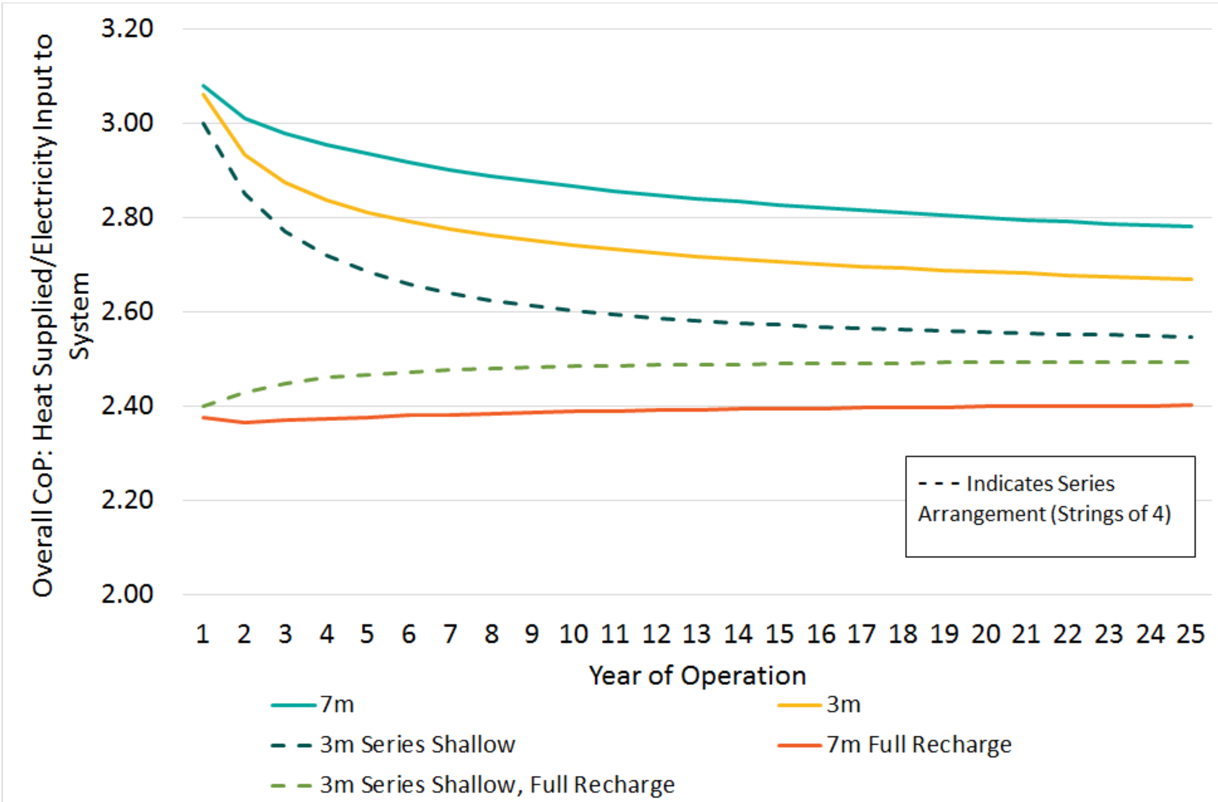



*Figure 15: System CoP (system boundary at heat output from EC)*

Firstly, it is noted that the current 7m arrangement (whether in series or parallel) performs the best in energy terms. Changing the borehole configuration to 3m and then to 3m series shallow reduces the overall system CoP.

Secondly, for each of the scenarios on a 'half' recharge, the CoP reduces over time as the ground temperature falls. However, for the full recharge scenarios, the CoP stays broadly stable over time, with a slight increase, as the temperature of the ground stays stable and increases. On a full recharge, changing the borehole configuration to 3m and/or 3m shallow appears to increase overall system performance.

The benefit of active recharge as noted above does not come from a reduction in the overall amount of energy required to deliver heat, but rather the use of surplus/cheap and renewable PV electricity in the summer to raise the ground temperature and to offset winter heating electricity – and, in doing so, reduce the pressure on the grid caused by electrification of heat.

The figure below shows the average borehole temperature fluctuation as modelled by TRNSYS. Changing the configuration to 3m creates a greater amount of fluctuation in ground temperatures as the area covered by the borehole is more concentrated. In the half recharge scenario, configuring the boreholes in series further depletes ground temperatures. However, in the full recharge scenario, ground temperatures fluctuate around (and slightly higher than) the equivalent 7m parallel arrangement.

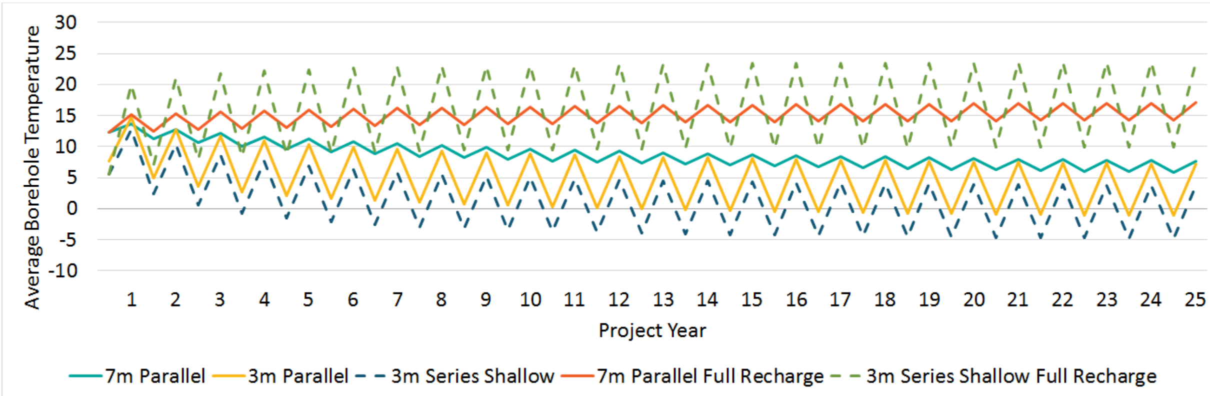
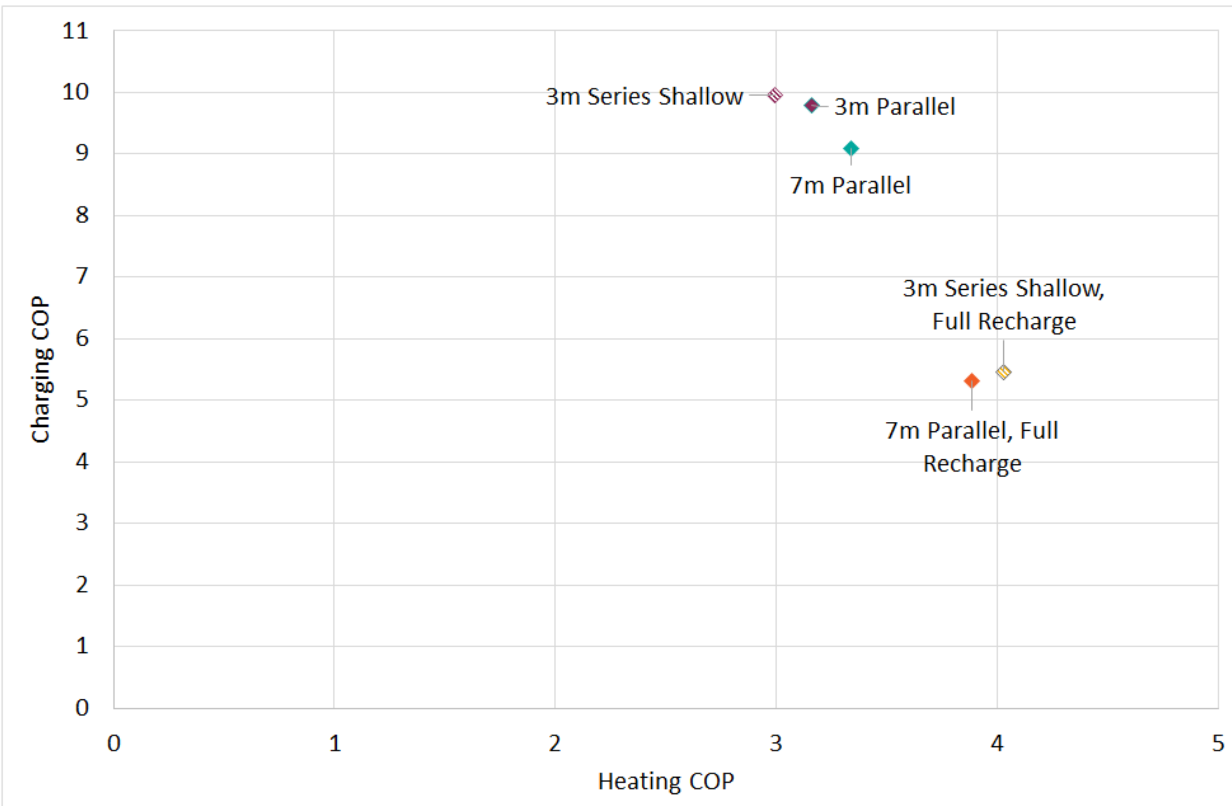



Figure: Average Borehole Temperature Change over Time

The following figure shows the resulting differences in Charging and Heating CoP in each scenario




***Charging vs Heating CoP, Average Over 25 Years, Average Over 25 Years***

***Whereas the series arrangement under half recharge results in a decrease in heating CoP alongside an increase in the charging efficiency (due to the lower average ground temperatures alongside greater borehole temperature fluctuation), the series arrangement at a higher level of active recharge results in an increase in the efficiency of both charging and heating.***

Comparing the 7m parallel current configuration with a recharge of half the heat load, with the 3m series shallow on full recharge, the average winter CoP is improved by 0.7 from 3.3 to 4, and the summer recharge CoP decreases by 3.6 from 9.0 to 5.4.

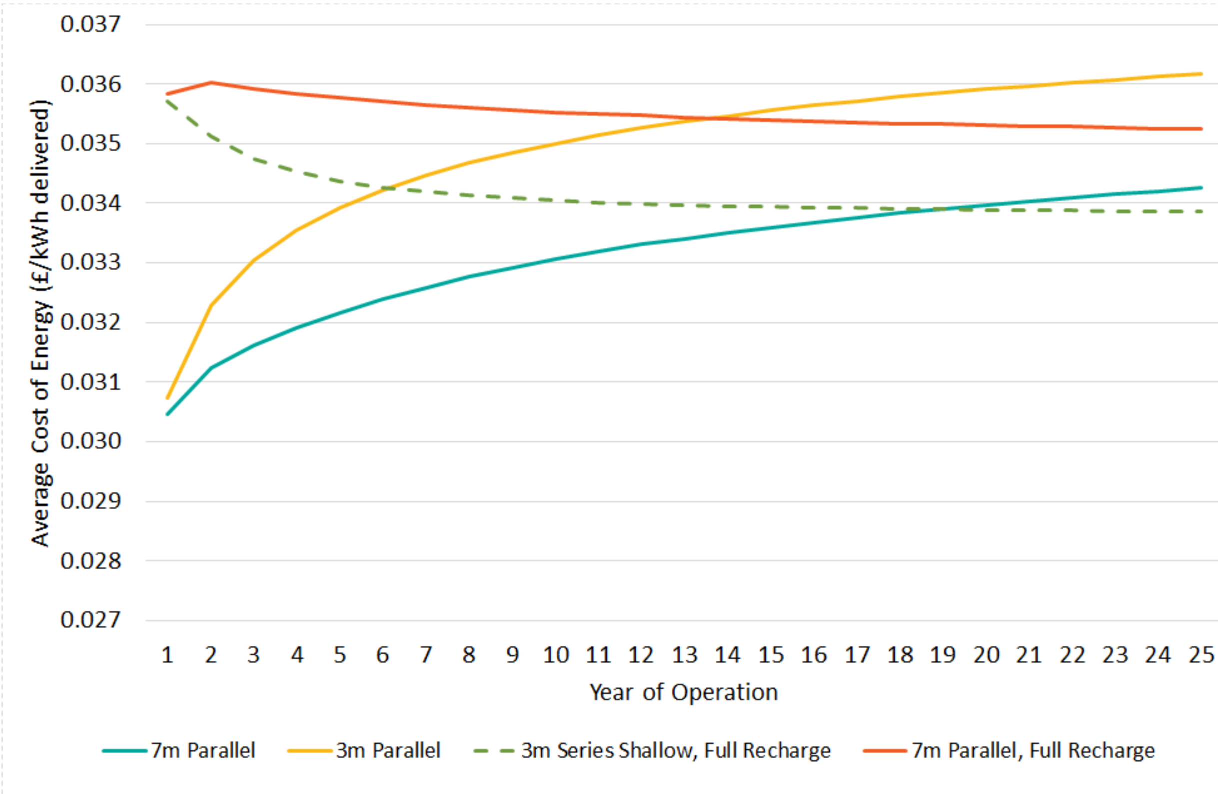



***Figure: Average Cost of Energy Over 25 Years***

Figure x above shows that when the cost of energy is taken into account (at the current expected level of differential between solar PV and winter price electricity), by the end of the project lifetime, rough cost equivalence is reached between the 3m full recharge scenarios and the current 7m set-up. This is because, though they use more energy overall, the 3m series recharge scenarios use a higher proportion of cheaper solar electricity. However, for most of the project lifetime, at the current project differential between charging and winter electricity, the cost is still significantly higher, and the dynamic of the graph suggests it is unlikely even over an extended project lifetime to result in net financial benefit.

Finally, considering the implications for the project parameters in which different borehole arrangements could offer an improvement over the baseline case, the following graph presents the additional input (in teal) and the corresponding saving (in orange) compared to the current set-up and recharge scenario.

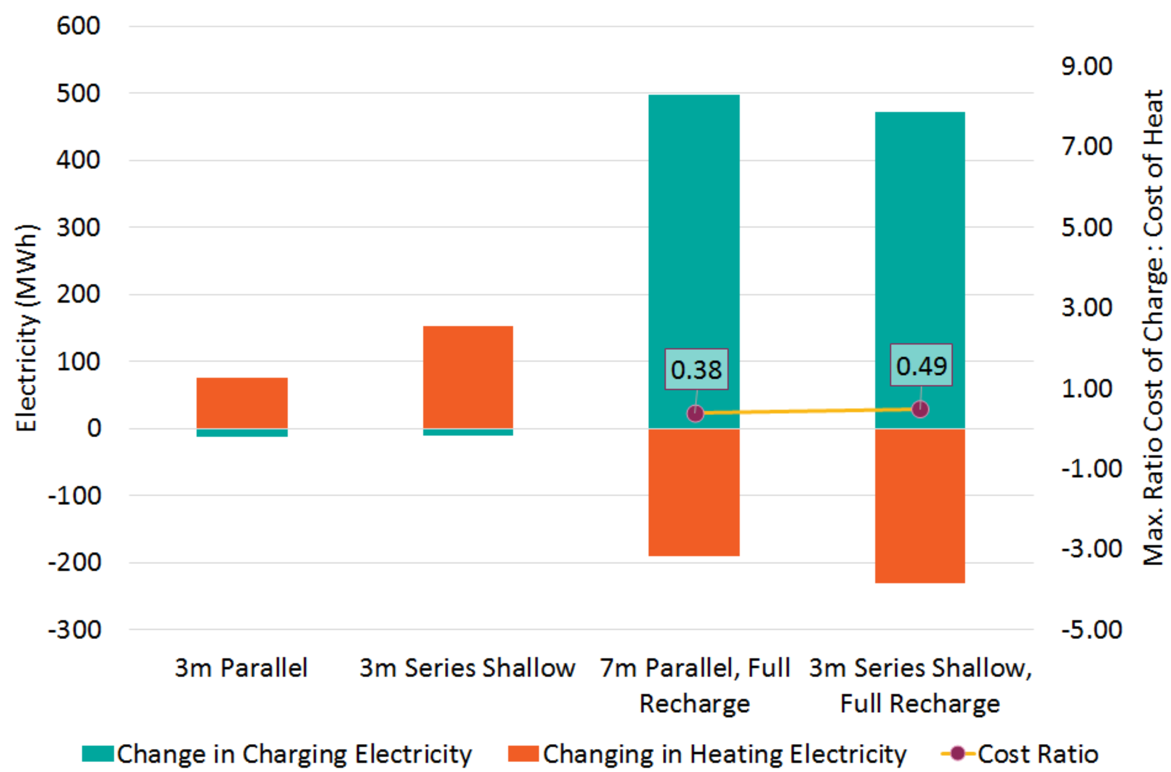



***Figure: Additional Charge vs Winter Saving and Cost Ratio, All Scenarios Over 25 Years***

Whereas when the borehole operates under a ‘half recharge’ strategy, borehole reconfiguration increases winter electricity consumption for minimal reduction in summer usage (as seen in scenarios 3m parallel and 3m series shallow), a full recharge uses additional charging to offset more heating electricity costs. Also displayed is the ‘maximum ratio’: a guideline ratio for determining when the scenario would represent a cost improvement over the baseline case: if charging electricity can be sourced at this proportion of the cost of heating electricity, the scenario in question will represent an improvement over the baseline case.

Currently, the minimum ratio for full recharge on the current set-up is 0.38 (meaning that full recharge is viable when summer charging electricity can be sourced at 38% of the cost of winter electricity). The 3m series arrangement with full recharge uses less charging electricity to save more heating electricity, increasing this ratio: if low-cost solar PV can be expected to be sourced for under half of the cost of heating electricity, the this scenario is likely to offer improved financial performance in the long term.

## Active Recharge: Potential Benefits at Scale

Given that by the last year of the project lifetime, the borehole reconfiguration with full recharge could be expected to be cost-equivalent with the half recharge strategy, outside of the framing of the immediate economics of the project and in the context of the electrification of heat, it is clear that active recharge strategy is preferable:

- One, approach designed to optimise project finances over a single project lifetime, depletes ground source heat reserves over time, results in a GSHP efficiency of 3.2 by the end of the project timeframe.

- The second, in which ground source heat is replenished and built up over time, keeps the GHSP operating at a CoP of 4.1, saving 22% of the winter heating electricity that would otherwise be required year on year.

At scale, this technology clearly has the potential to support the use of ground source heat pumps in contexts where there is no parallel cooling requirement. Active recharge is able to maintain or improve GSHP efficiencies through summer charging, giving a clear economic value to solar PV electricity that might otherwise be considered surplus.

Whilst even business customers face minimum seasonal difference in electricity prices and are protected from energy price fluctuation, this community-scale system is likely to depend on such fluctuation in the energy prices (or through an appropriate storage incentive mechanism) to justify the business case. Because of the relatively low system power and slow response times, unless it reached considerable scale it is less well suited to fit into any existing grid services. However, if the economics can be established, then at scale these systems could effectively ‘soak up’ electricity at times of excess generation, not to time-shift power loads to later in the day, but reduce the electricity demand from heat across the whole of the winter heating season.

# 6. Issues Encountered, Lessons Learned

The key issues encountered during the CHOICES project were all related to the real world issues with construction projects.

## Land rights and construction in urban parks.

Owen Square Park was Charity Commission protected land so we had to 'replace' land lost to the Energy Centre. This was a difficult process fraught with risk and only succeeded because Easton Community Centre had replacement land available to release.

**Recommendation.** Where possible seek to place the Energy Centre module itself on land owned by a project beneficiary NOT the public park. It is much easier to get an easement/wayleave for a subterranean borehole array than an above ground Energy Centre.

Key planning issues were good local resident engagement, careful tree protection methodology, discrete positioning of the Energy Centre (avoiding loss of amenity in the park) and noise restrictions on the sound levels from Air Source Heat pumps.

Key installation challenges were access routes to site for drilling rigs, access to sufficiently high pressure water from Bristol Water and avoiding existing services (a large sewer in this case).

**Recommendation.** A complete set of deep and shallow survey documents should always be reviewed in advance. The distribution of the Borehole Thermal storage is very flexible, and can adapt to site obstructions (even major ones) easily.

## Issues with technology development

It is interesting and worth noting that the project team didn't encounter any significant issues in any aspect of the individual technology components during the pilot CHOICES installation. The project installed technologies including:

- 1x Guntner dry air cooler
- 2x Ecoforest ground source heat pumps
- 1x Havell microgrid distribution panel
- An ICAX IHT controls system
- 23 electricity and heat meters (system wide)
- Three modbus control networks
- Heatmiser building control systems
- Piclo electricity supply platform
- Simtricity billing platform
- Thinkspeak telemetry platform

Assembling these technologies is not without challenges but proceeded smoothly. It is certainly now the case that the major opportunities for streamlining projects such as this one arise from streamlining the physical construction deployment aspects including planning, permitting, trenchworks, construction and remediation.

# 7. Costs: Budget vs Actuals

The project completed £12,061 over budget on an original budget of £694,439. The following areas were most significant in this cost increase.

Negotiating land rights and permission to construct was significantly underestimated during feasibility stage and was significantly over budget during construction phase. Unfortunately this was the hardest part of the project to estimate as this work was mostly in the hands of third parties, external to the project, with their own priorities.

Separation of power and heat enclosures. Originally it was planned that the upgraded public grid connection (required to support the heat pumps) and 'Private Wires' microgrid panel (used to source local PV) would share space in the CHOICES Energy Centre enclosure. As it turned out the footprint available for the CHOICES Energy Centre was extremely constrained and the decision was made to separate the power components into a separate GRP enclosure. This resulted in an overall cleaner, tidier solution but additional enclosure and construction costs were involved.

Park re-instatement and improvement costs were underestimated during feasibility stage. The contribution of the project to the community through the provision of new steps into the park was a key enabler for the project (as discussed above). Additionally, the standards of remediation required for a well-used public park were beyond those estimated originally.

To stay as close to budget as possible the decision was made to postpone plans to install new radiators in the two customer buildings.

To mitigate the potential negative impact of running the lower temperature water through the existing radiators, ICAX personnel undertook a re-balancing exercise on the existing system which has resulted in good levels of reported comfort for users of the ECC over the winter of 2016/7.

# 8. Dissemination activities and Peer Review

## Journals, presentations, demonstrations

The principal focus for CHOICES dissemination in Phase 2 was to engage with the local community to ensure a smooth construction process and acceptance of the project happening in a local park. Additionally several media engagements and events were run to spread knowledge of the project to the wider Bristol energy community. The team had hoped to promote the project as part of Bristol's year as European Green Capital but the late start to the project made this difficult.

OSCE/CHOICES in the media:

- Ujima radio interview - Jul 29th, 2015
- ITV Points West - Jan 28, 2016
- Made In Bristol TV – 6 and 9 news, Jan 8th, 2016
- Radio 4 - Recorded Feb, 2016 (broadcast in May)
- Bristol Post article - Sep, 2015

Events held at Easton Community Centre:

- Community consultation meetings – June 2015
- Renewables Day - Sep 2015
- Behind-the-scenes of CHOICES - March 30, 2016
- Shift Bristol (community energy field trip) - April 27, 2016
- Bristol Big Green week June, 2016.

# 9. Conclusions

## Construction learnings

- Having a project "champion" within the landowning body is essential to overcome inertia and barriers.
- An extensive borehole drilling programme in urban, council owned, charity commission protected parks can be successful through good engagement with stakeholders on the environmental benefits! **However, thorough understanding of any land ownership issues is critical.**
- Planning permission for a CHOICES Energy Centre was relatively straightforward. Bristol City Council policies state that "the use of combined heat and power (CHP) will be 'encouraged'[10]. Key issues were good local resident engagement, careful tree protection methodology, discrete siting of the Energy Centre (avoiding loss of amenity in the park) and noise restrictions on the sound levels from Air Source Heat pumps.
- The approach to completing the Energy Centre build off-site then delivering it to site as final step is a very effective strategy that saved time and allowed for late design changes.
- A full set of deep and shallow survey documents should be created in advance of primary works. Cable detection tools, test digs and comprehensive collection of services documents from utilities are the key techniques.
- The distribution of the Borehole Thermal storage is very flexible, and can adapt to site obstructions (even major ones) easily, a strength of the technology. Also with a streamlined process deployment can be very quick.
- The marginal cost of installing electricity cables (and comms cables) is relatively low and worthwhile.

## Operational learnings

- A 'private wires' microgrid is an effective technology to deploy alongside a micro heat network. This technology solves the problem of sourcing PV power without incurring grid distribution charges and provides significant reductions in electricity costs where demand response can be used to avoid DUoS peak periods.
- Solutions like Piclo that track the provenance of grid electricity are coming to market and easily support 'sleeving', the purchase of renewable electricity from local sources.

## Lifecycle and techo-economic analysis learnings:

- The CHOICES technology combination is modelled to deliver, in the central case, a 62 percent reduction in $CO_2$ emissions and savings of half the primary energy use, compared to a gas boiler counterfactual.

10 See Appendix 1.1

- The high capital costs of CHOICES pilot facility contribute to a relatively high cost of delivered energy for this CO2 reduction.

- Active recharge using heat pumps can displace winter electricity demand with distributed summer electricity use at efficiencies of 2:1 - 1:1. This can reduce energy costs, and also delivers grid benefits over the long term. Further work needs to be done to understand how these benefits can be monetised.
- Active Recharge **can** reduce the cost of energy, but this impact is limited for the pilot project, because active recharge efficiency declines as the charge level approaches the winter demand level. This is primarily because charging is less efficient as the borehole temperature rises. With the current CHOICES pilot borehole configuration, optimal economic recharge levels are approximately 50 percent of heat demand.
- Solar PV, unlike alternatives[11], is always marketable and will fetch the 'wholesale price' when sold to the grid. At the moment this limits the differential between summer and winter buy price. With CHOICES pilot pricing from PICLO that differential is currently 1:1.7 (5p vs 8.4p)
- The business case for active recharge improves with higher winter demand. It may improve further with more advanced 'series-based' borehole designs which will be studied in Phase 3.
- A bean packing algorithm is an effective mechanism for distributing a desired level of recharge over a summer period.

11 Typical summer recharge heat sources such as air conditioning processes, solar thermal panels, industrial waste heat and asphalt collectors have no alternative avenues for resale so are effectively 'free' in the sense that the energy will be vented if it not stored.

# 10. Future Plans, Market Potential and Roll-out

## CHOICES IP ownership and licensing model

ICAX have developed IP in the controls evolution and coding for the ICAX controller installed in the CHOICES Energy Centre. This is protected by encryption and cannot be accessed except by ICAX. The controls evolution here specifically adds PV charging to the state of the art Interseasonal Heat Transfer (IHT) capability delivered by ICAX in its products.

ICAX retains ownership and copyright of the design of the CHOICES Energy Centre including ownership of the ICAX controller. ICAX have licensed the use of the CHOICES Energy Centre design and ICAX controller to CEPRO for use in the Owen Square Community Energy Project.

CEPRO has developed a microgrid metering and billing platform (Simtricity) that provides for revenue collection from thirdparty ownership of microgrid assets including CHP Energy Centres. CEPRO is operating this platform under contract to the Owen Square Community Energy project.

Bath University has developed an algorithm for strategic operation of a CHOICES Energy Centre to recharge a borehole thermal array and is licensing that algorithm for use in the Owen Square Community Project.

## Further Research into Borehole thermal storage

We are modelling significantly higher summer vs winter COP with CHOICES equipment of around 10 vs 5: however, this is only translating to a marginal benefit in terms of winter electricity cost savings, and is not economically viable at higher levels of active recharge. The team plan to use TRNSYS to model alternate borehole configurations. Particularly, following the lead of projects like Braedstrup in Denmark[12] that use a series configuration with closer boreholes to provide a higher winter temperature.

Also, we will investigate the economics of deploying a CHOICES system into an existing district heat network where there is a fuel based heat source such as a biomass boiler. In such a scenario a Merit Order[13] will be in place in terms of which heat source will provide load but higher heat loads may improve the economics.

## Market Approach

The CHOICES team has identified the opportunity to supply renewable heat to small-scale heat network, with seasonal storage that are fully electric but that mitigate grid constraints.

12 https://www.rehau.com/download/785808/braedstrup-project-case-study.pdf
13 https://en.wikipedia.org/wiki/Merit_order

The CHOICES technology has applications at different scales. It could be replicated at similar or larger scales as the CHOICES pilot (anchor community heat loads with houses bordering a green space), but also could be connected up as a heat supply to an existing or new heat network.

As in the model established in the pilot project, the CHOICES technology can be owned and operated by a third party ESCO supplier. This third party can:

- Bring investment in to fund the installation of CHOICES technology (and solar photovoltaic, if required), paid back through energy bills;
- Operate a private wire network amongst connected buildings, to route surplus PV through the facility 'behind the meter' and access retail energy prices;
- Manage billing and communication with users, supporting with energy efficiency measures.

Additionally, if the borehole array itself can be funded through prudential borrowing over a longer lifetime, the business case for the facility improve.

The CHOICES platform is a good physical demonstrator for the innovation contained in the project. Project partners intend to use this as a lever to develop customer interest in CHOICES technology.

Once the data stream is developed over the course of the next year, we will have an evidence base to assist us in promoting this technology to suitable customers. We will then be able to propose the CHOICES linking of PV to borehole charging to suitable customers as appropriate.

The route to market for CHOICES is as follows:

- Add PV sharing as an option to existing and new Interseasonal Heat Transfer customer streams (ICAX IP)
- Add Predictive algorithm control (Bath IP) as an option
- Add Cloud-based monitoring and billing (CEPRO IP) as an option

ICAX will promote this technology actively and in collaboration with other partners in the following ways:

- Use the ICAX website to identify and promote the CHOICES technology (following the delivery of the appropriate evidence data stream).
- Target specific customers who would benefit from the CHOICES technology offer.

## Market Potential

Eligibility for the RHI, or another future support mechanism for renewable heat, remains an essential precondition for the financial attractiveness of the technology. From conversations with DECC officials, we judged that there is a strong likelihood that the RHI Regulations will be amended to allow the facility to be eligible to receive payments under the RHI. This remains a key recommendation to DECC to ensure that the inter-seasonal supply of renewable heat is properly supported.

*Project Recommendation: We proposed that a change to Regulation 8(c) should be made to allow heat to be generated from renewable sources. For heat pumps, we* *recommended that in order to be defined as a renewable source, they achieve at least a Coefficient of Performance of 2.9 and a Seasonal Performance Factor of 2.5, thereby satisfying Regulation 8(d) and 8(e) of the RHI Amendment Regulations 2014.*

Even assuming RHI eligibility, the central business case for the pilot facility remains marginal against an individual gas boiler counterfactual, though more competitive against oil.

However, there should be opportunities to reduce the bespoke design and build cost of the whole system. The individual products used are relatively mature technologies, but the bespoke nature of the CHOICES project design raises the cost of the whole package significantly compared to the installation of a borehole-based ground source heat pump. Applying the capital costs estimated by the project team of a replicable commercial facility, an equivalent facility might obtain an IRR approaching 3%. However, it would take a further 15% reduction in capital costs of the system to obtain an IRR of 5%, the level at which social and community finance might become attainable.

Additionally, if the borehole array itself could be funded through prudential borrowing over a longer lifetime, the business case for the facility would improve.

The extent of the potential market depends upon developing the technology as a competitive option to:

- A standalone GSHP heating supply (with a larger borehole field);
- An equivalent borehole array recharged with solar thermal;
- Gas, Biomass CHP heat supply to a heat network.

Table 9 below outlines at a very high level the main comparisons between CHOICES and its alternatives.

***Table 9: Comparison of CHOICES technology to Alternatives***

| | CHOICES | GSHP | Solar-Thermal Recharge | Gas/CHP Supply |
|---|---|---|---|---|
| **Capital Cost** | High | Medium-High | High | Low |
| **Space Requirement** | Medium | Higher | Medium | Low |
| **Carbon** | Low | Medium | Low | High |
| **'Soft' Grid Benefits** | Electricity Demand Reduction (Winter), Grid Balancing (Summer) | None | Electricity Demand Reduction (Winter), | N/A |

## Micro-Networks

For comparable non-domestic clusters, CHOICES offers a low-carbon source of heat that utilises excess PV and provides some level of security from energy price rises. At the micro-network level, buildings without access to surplus PV will find it harder to obtain savings from active recharge, although the emergence of tariffs which pass time-of-service charges through with greater transparency, along with the continued growth in regional PV generation, may yet provide opportunities to access cheap, 'solar-rich' grid electricity during the afternoons. The additional costs of developing a domestic heat-network alongside a lower-temperature heat supply to core buildings present a further challenge.

### Fuel Supply into Heat Networks

As a fuel source to a larger domestic network, to meet design requirements of current domestic heat networks, an additional energy centre would be needed to upgrade the heat from 45 to 55 or 60 degrees. This would require additional input electricity, decreasing the system efficiency. The CHOICES system however would be especially suited to a low-temperature heat network connecting new-build houses designed to receive lower-temperature heat.

As a fuel source into a heat network, the CHOICES technology potentially offers a low-carbon source of heat that doesn't have the air quality concerns of biomass or CHP, or the traffic concern associated with large-scale biomass fuel supply.

The same comment applies regarding the availability of surplus photovoltaic electricity or reduced price summer electricity. The delivered cost of energy is higher than for lower-temperature networks, making it less competitive against a CHP gas supply.

Installing distributed, cleaner technologies may be more attractive than fossil-fuel sources of energy. CHOICES technology does not face the air quality risks of local fossil-fuel heat generation, nor the transport impact of biomass generation.

## Potential Benefits

*Air and Ground Source Heat Pumps are likely to be strategically important in the long term decarbonisation of heat.*

Recent Impact Assessment accompanying the consultation on changes to the RHI.

CHOICES technology supports the decarbonisation of heat by offering a solution which enables users to utilise excess PV to decrease the grid demand in winter. Utilising excess PV enables the same heat to be delivered on a lower-carbon, more renewable basis – especially when combined as part of the same investment.

The capacity to recharge the ground also maintains GSHP efficiencies, decreasing the risk of GSHP performance dropping below levels deemed renewable under the RHI. It enables a greater heat load to be met from a given array size where there are space constraints.

If the additional benefits of CHOICES technology were to convince 5 additional community building energy users (average annual heat demand of 100MWh) to install CHOICES technology, and LAs convinced of the benefits were to uptake the technology in 30 parks and green spaces across the UK (with an average annual system heat demand of 250MWh), then the results from the LCA suggest lifetime impact would be, over 25 years, in the region of:

- over 30,000 tonnes of avoided $CO_2e$ emissions; and
- over 120,000 MWh of primary energy use avoided;

If CHOICES technology were to be connected to 10 mid-scale domestic extensions in place of CHP supply, the indicative results suggest lifetime savings in the order of 35,000 tonnes of $CO_2e$ and 126,000 MWh of primary energy.