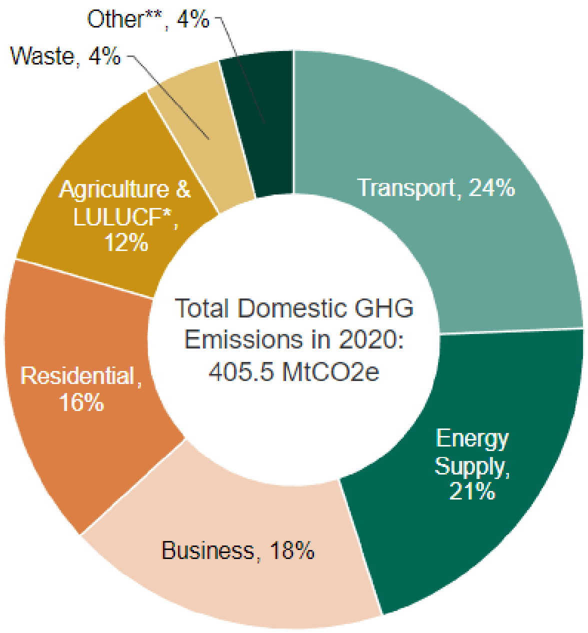
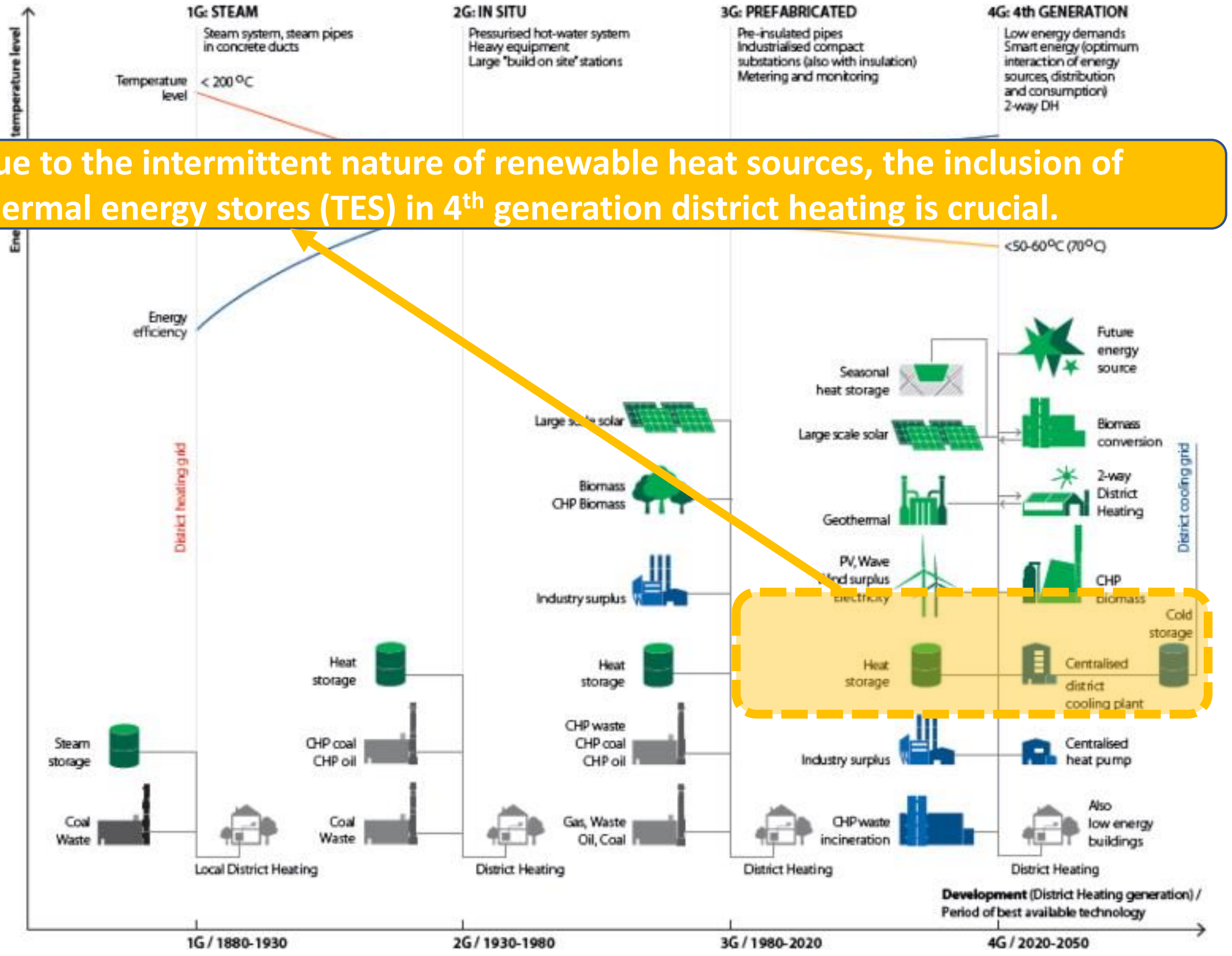
The role of distributed thermal energy storage in achieving Net Zero DHW and Space Heating

Miguel Angel Pans Castillo

Introduction

Greenhouse gas emissions by sector, 2020, by proportion (BEIS, 2022)





Due to the intermittent nature of renewable heat sources, the inclusion of thermal energy stores (TES) in 4th generation district heating is crucial.

Objectives

i. A novel model was used to simulate a theoretical ultra-low carbon district heating network (ULC-DHN) located at Holywell Park, Loughborough University (Loughborough, UK).

ii. The proposed ULC-DHN system includes heat pumps (HPs), evacuated-tube solar thermal collectors (ETSTCs) and seasonal thermal energy storage (STES) to provide heat to buildings.

iii. Both a) real historic half-hourly CO_2 emissions per kWh of electricity and b) real historic half-hourly heat demands for Holywell Park are used in the simulations.

iv. The effect of:

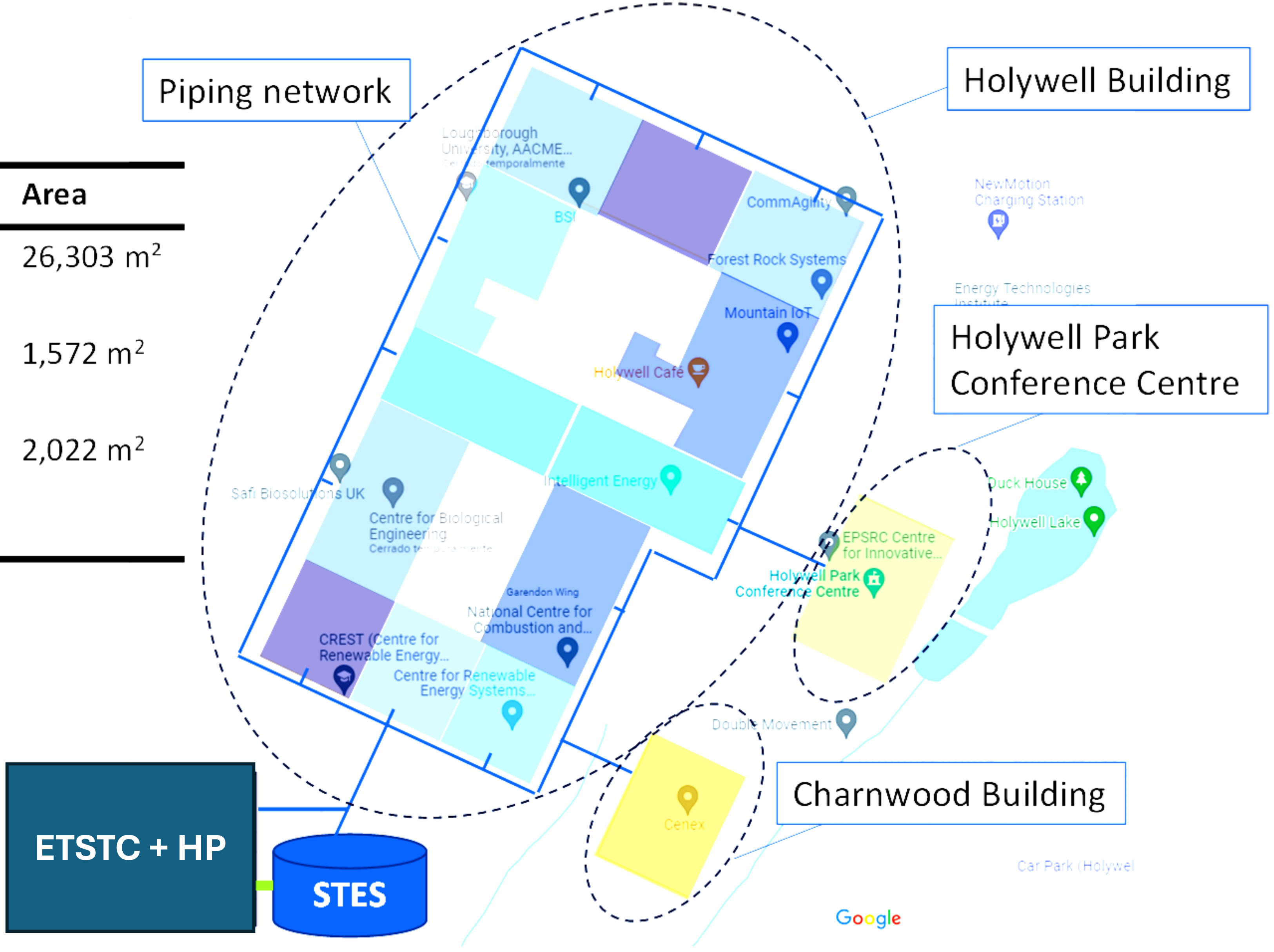
   a. Using onsite Wind-generated electricity vs. using onsite PV-generated electricity to power the HPs;

   b. The location of the ULC-DHN - three locations were assumed: Loughborough, Bournemouth and Glasgow -

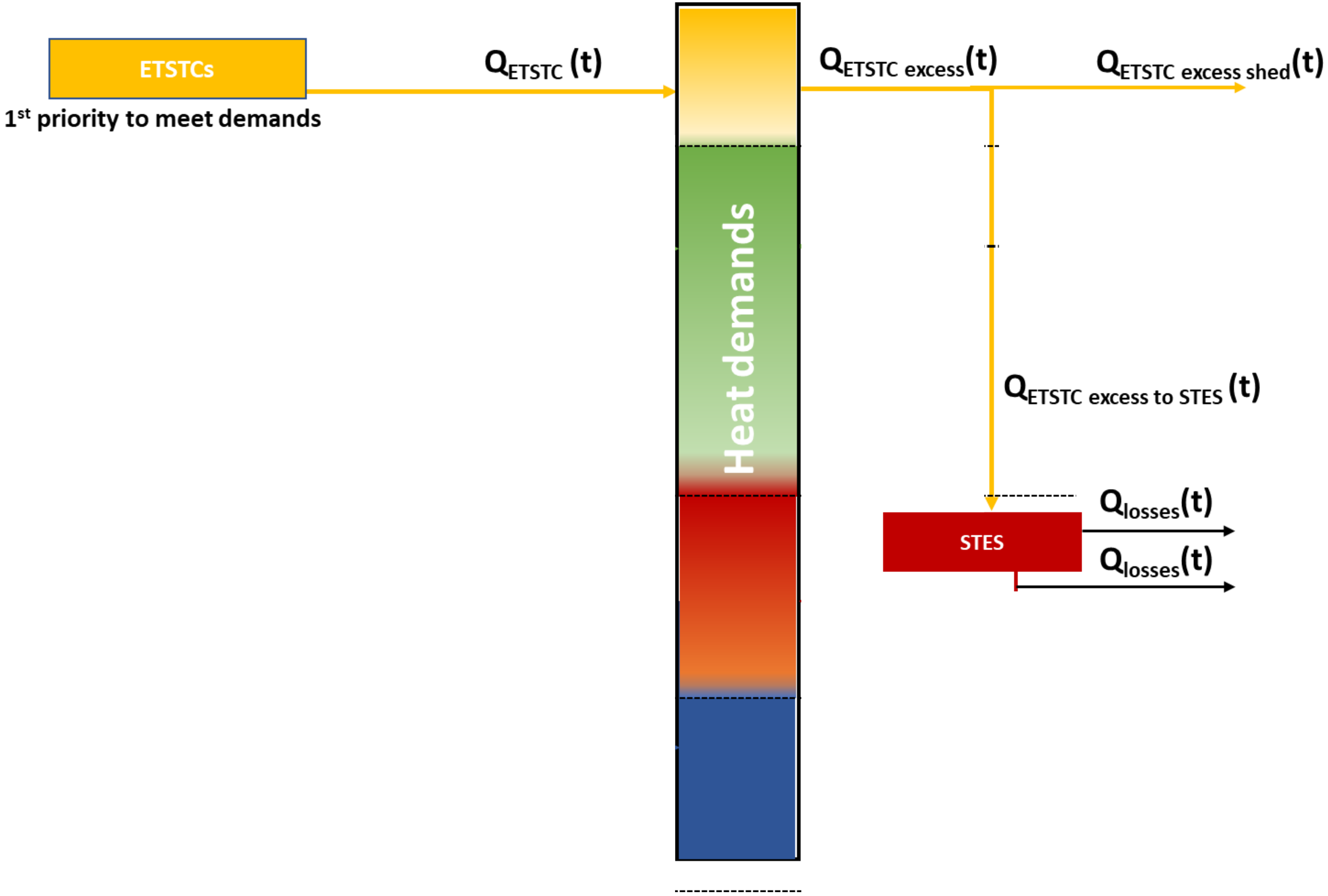
on the share of heating demand met by onsite zero-carbon heat sources and the levelized cost of heat (LCOH) for the period 2000 – 2019 (20 years) was studied.

Methodology: Map of the Holywell Park at Loughborough University (UK) showing the three buildings and the proposed ULC-DHN.

Building	Area
Holywell Building	26,303 m^2
Charnwood Building	1,572 m^2
Holywell Park Conference Centre	2,022 m^2



Methodology: Flow diagram illustrating the order of priority of heat supply approaches for the ULC-DHN configurations.



1. **Pans Castillo, Miguel Angel and Claudio, Gianfranco and Eames, Philip, Transition Pathways for a Gas Supplied District Heating Network to an Ultra Low Carbon District Heating Network: A Case Study for Holywell Park, Loughborough University. Available at SSRN: https://ssrn.com/abstract=4946865 or http://dx.doi.org/10.2139/ssrn.4946865**

2. **M.A. Pans, P.C. Eames, A study of the benefits of including thermal energy stores in district heating networks, Renew. Energy. (2024) 120887. https://doi.org/10.1016/J.RENENE.2024.120887.**

3. **M.A. Pans Castillo, P.C. Eames, Centralised thermal energy stores vs. decentralised thermal energy stores: A comprehensive study of different configurations of a 4th generation district heating system., in: CIBSE Tech. Symp., 2023. https://www.cibse.org/knowledge-research/knowledge-portal/simulation-of-a-district-heating-system.**

4. **M.A. Pans, P.C. Eames, Optimisation of a theoretical 4th generation district heating network located at the town of Loughborough, UK, in: EuroSun2022 Proc., 2022. https://doi.org/doi:10.18086/eurosun.2022.04.08. Available at http://proceedings.ises.org.**

5. **M.A. Pans, G. Claudio, P.C. Eames, Theoretical cost and energy optimisation of a 4th generation net-zero district heating system with different thermal energy storage technologies., Sustain. Cities Soc. 100 (2024) 105064. https://doi.org/10.1016/J.SCS.2023.105064.**

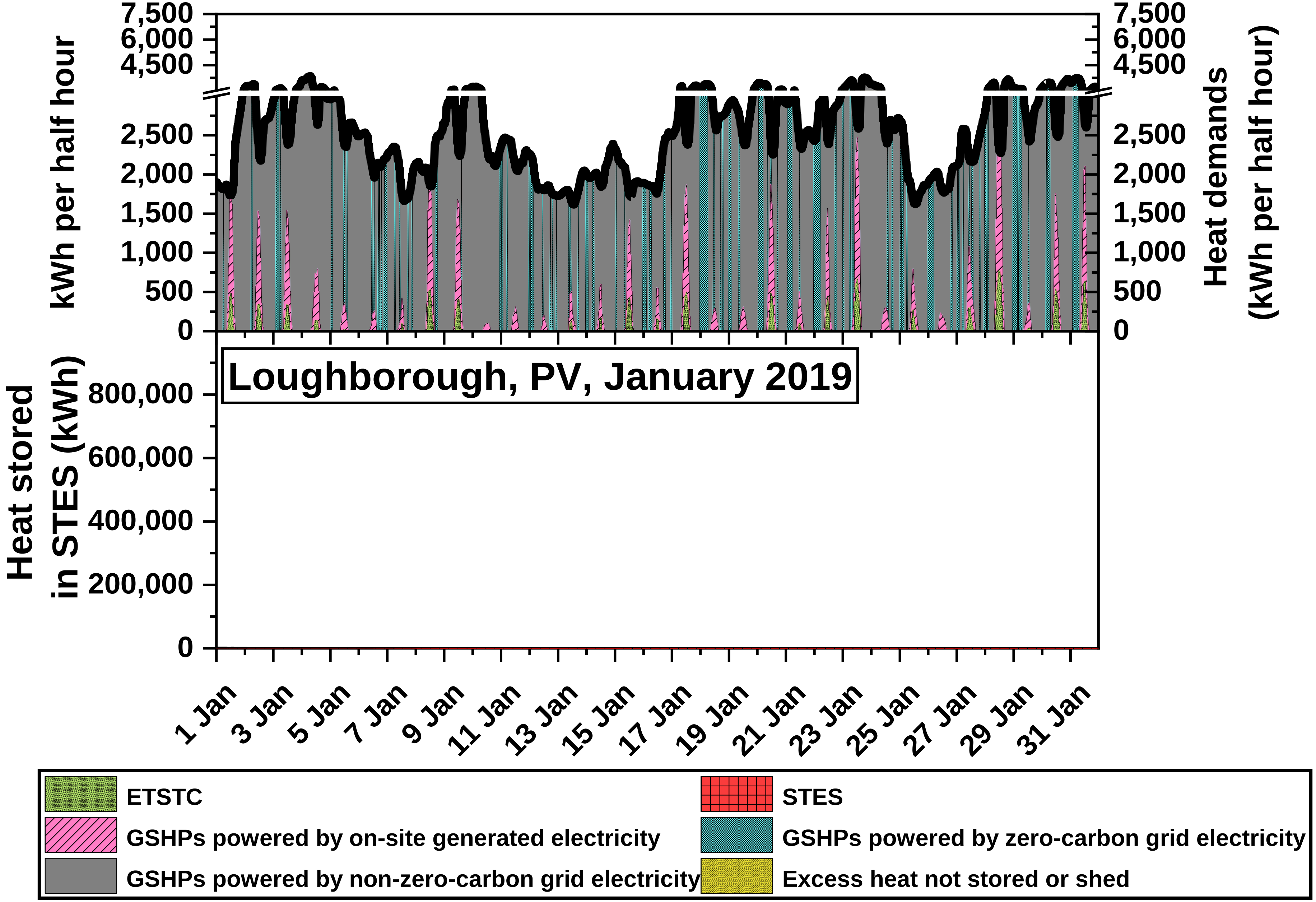
6. **M.A. Pans, G. Claudio, P.C. Eames, Modelling of 4th generation district heating systems integrated with different thermal energy storage technologies – Methodology, Energy Convers. Manag. 276 (2023) 116545. https://doi.org/10.1016/J.ENCONMAN.2022.116545.**

Methodology: Key parameters specified for the simulation.

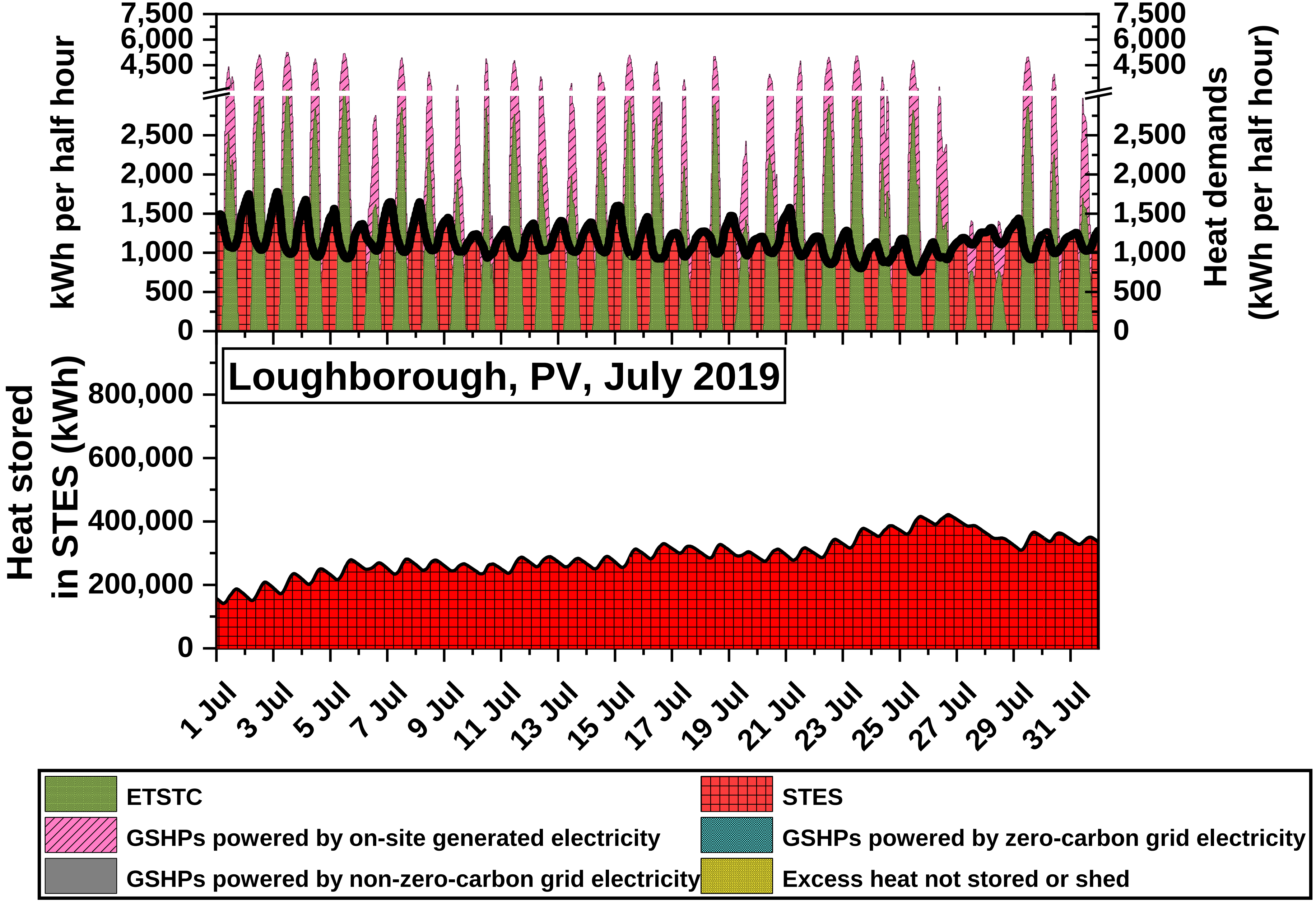
Location and time	
District Heating Network	Holywell Park, Loughborough University, Loughborough, (UK)
Locations studied	Glasgow, Loughborough and Bournemouth (UK)
Time-period simulated	2000 - 2019
STES system main parameters	
Charging temperature for STES (°C)	60
V_{STES} (m^3)	20,000
Initial assumed heat stored in STES (% of the maximum storage capacity)	0%
Heat and electricity main parameters	
Electricity from the grid used by HPs to fully meet demands (kWh per half hour)	Predicted
A_{ETSTC} (m^2)	10,000
On-site PV capacity (MW)	1.5
On-site wind capacity (MW)	1.5
HPs	
Total number	Predicted
Heat Capacity per unit (kW)	500

SHARE OF HEATING DEMAND MET BY ONSITE ZERO-CARBON HEAT SOURCES WHEN USING PV-GENERATED ELECTRICITY TO POWER HPs

RESULTS: share of heating demand met by the different heat sources considered for the ULC-DHN

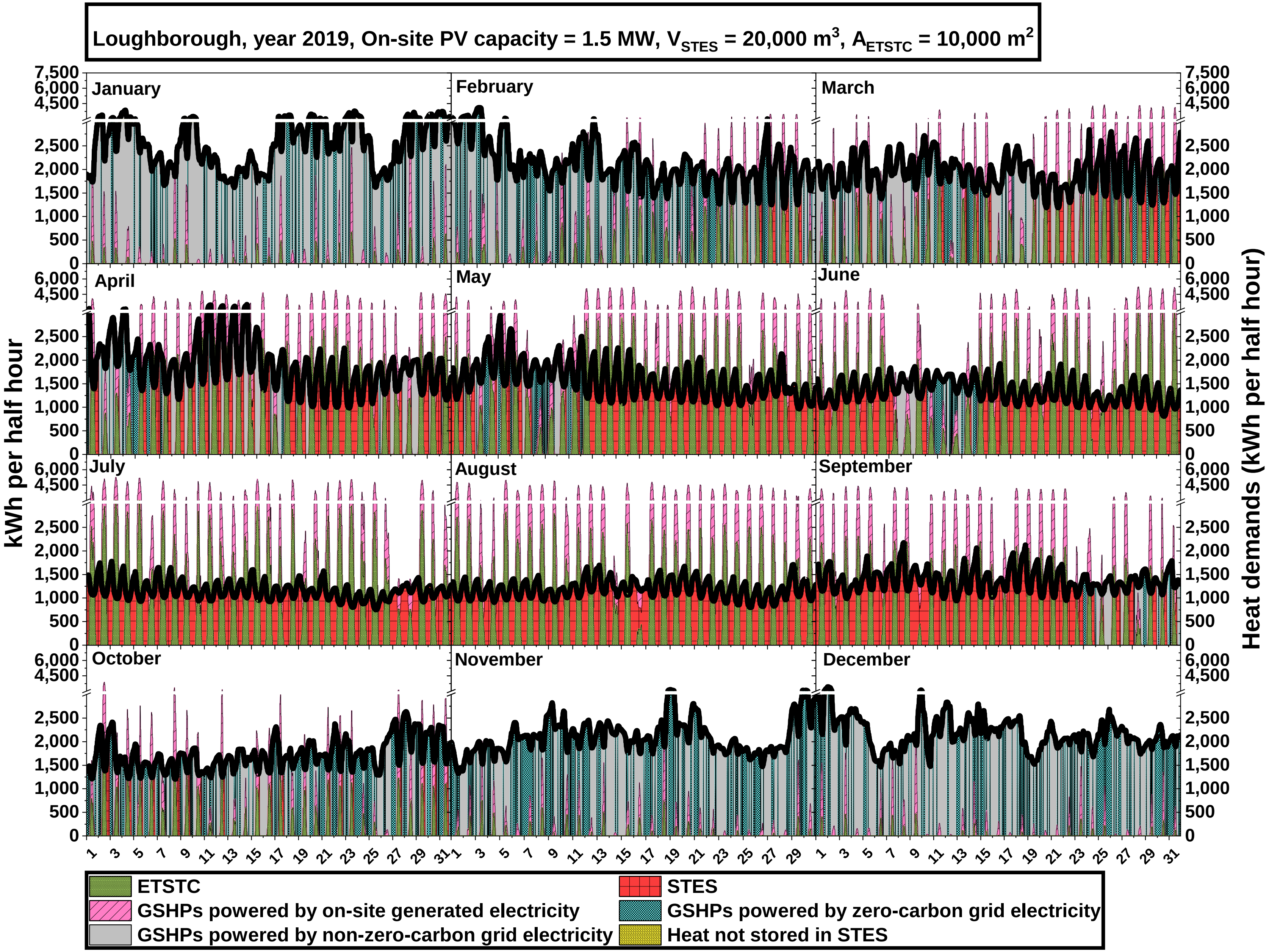


RESULTS: share of heating demand met by the different heat sources considered for the ULC-DHN



RESULTS: share of heating demand met by the different heat sources considered for the ULC-DHN

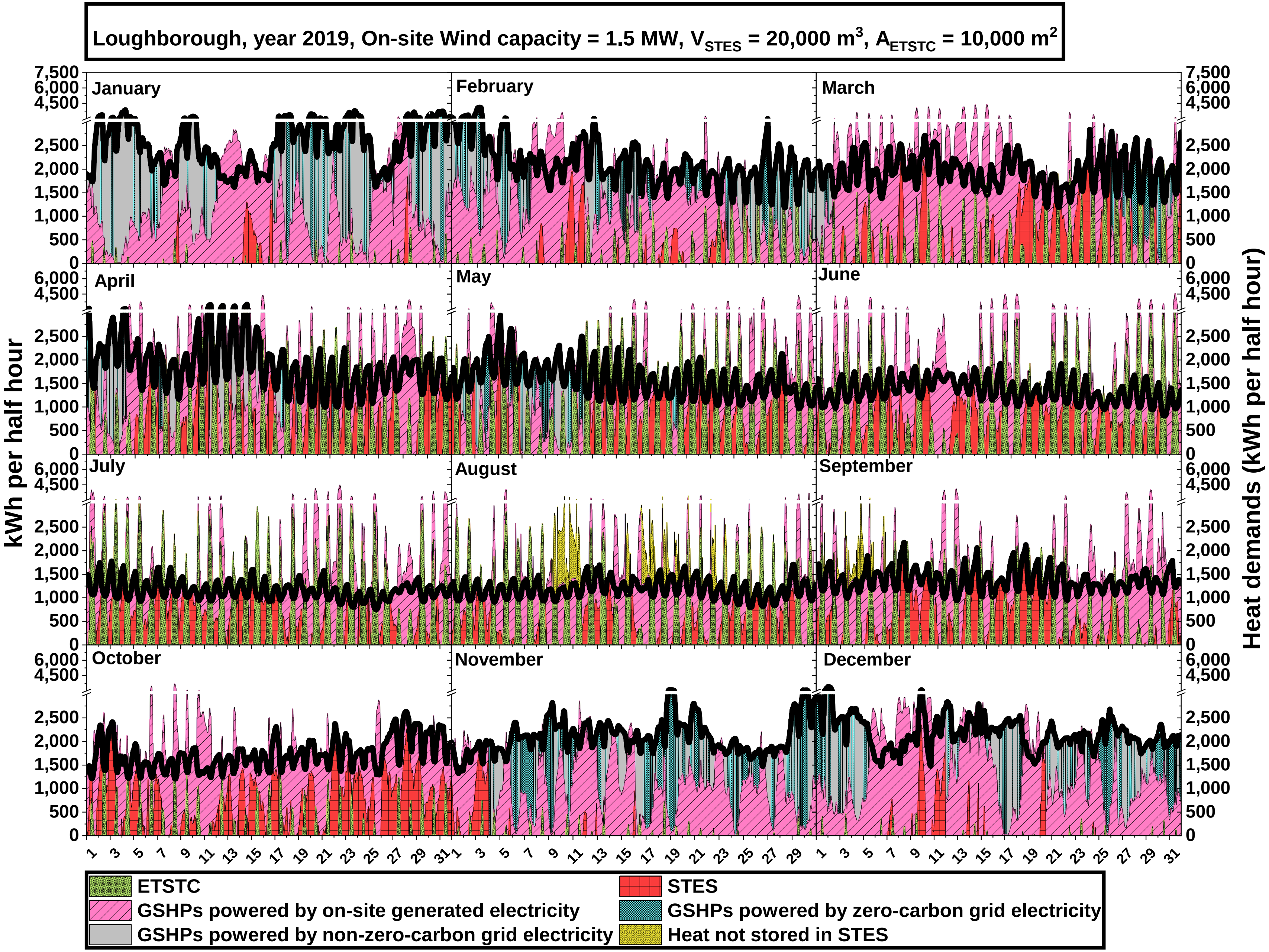
- ✓ In the autumn/winter months heat is supplied mostly by HPs powered by non-zero-carbon grid electricity
- ✓ In spring/summer heat is mostly supplied by onsite zero-carbon heat sources, i.e. HPs powered by onsite PV-generated electricity, ETSTC and STES



PV-GENERATED ELECTRICITY vs. WIND GENERATED ELECTRICITY TO POWER HPs

RESULTS: share of heating demand met by the different heat sources considered for the ULC-DHN

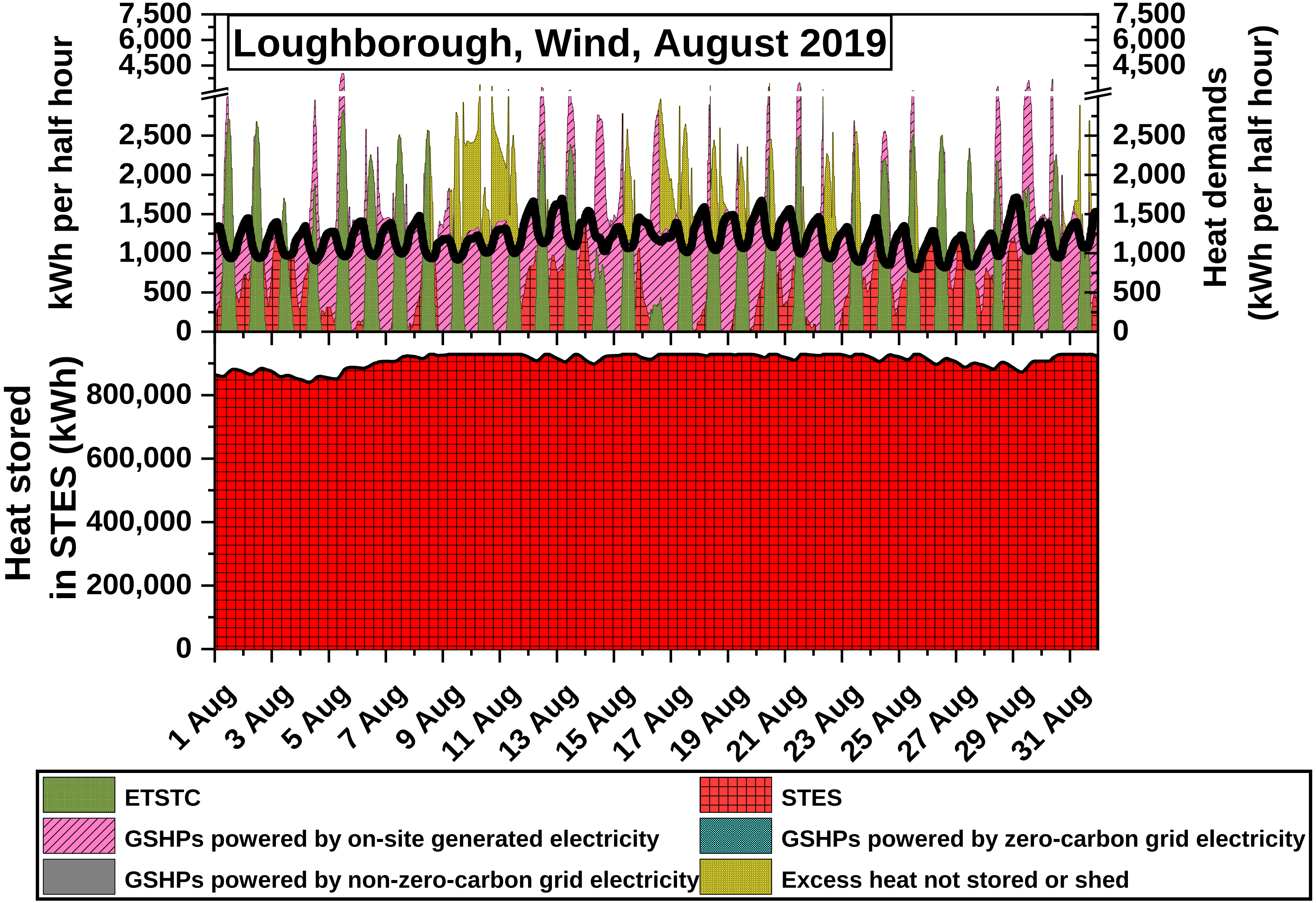
- ✓ When using onsite wind-generated electricity to power HPs, heat demands can be mostly met by zero-carbon onsite heat sources for the whole year 2019



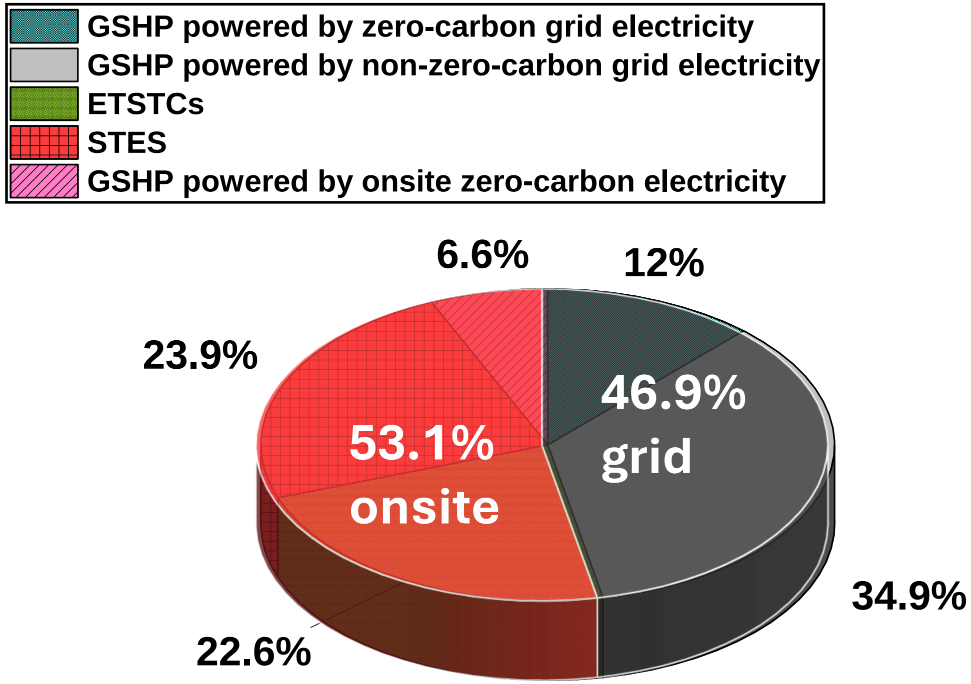
RESULTS: share of heating demand met by the different heat sources considered for the ULC-DHN

When reaching the maximum STES storage capacity:

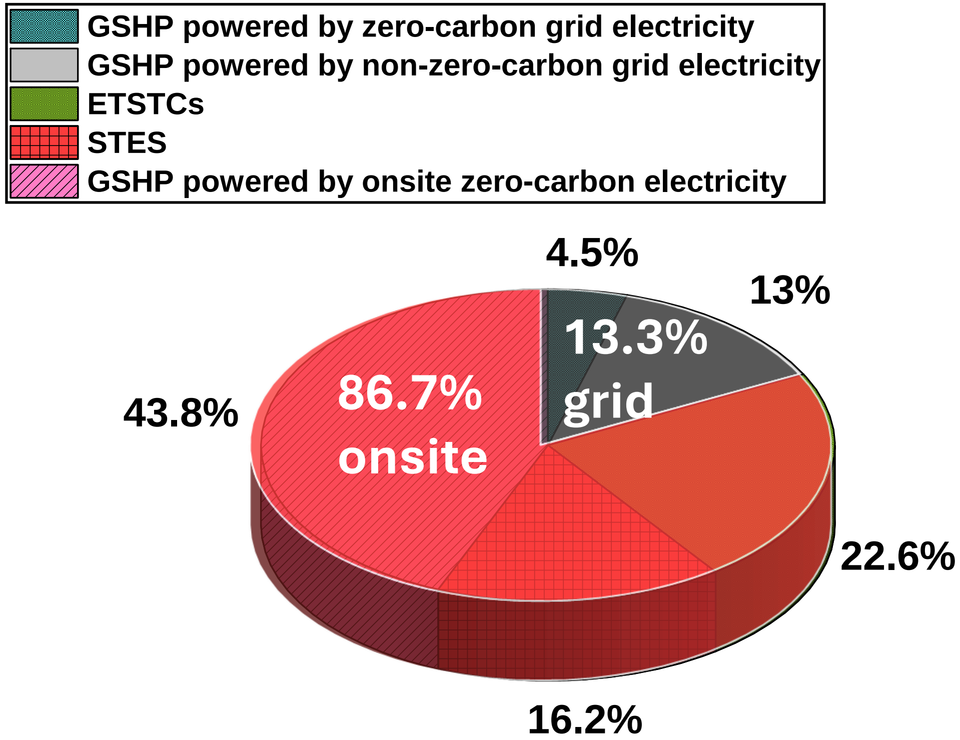
1) Any extra electricity produced by onsite wind-generated is sold to the grid.
2) Any extra heat produced by ETSTC is shed or used in other applications



RESULTS: share of heating demand met by the different heat sources considered for the ULC-DHN, totals for Loughborough, year 2019. Comparison between PV and Wind

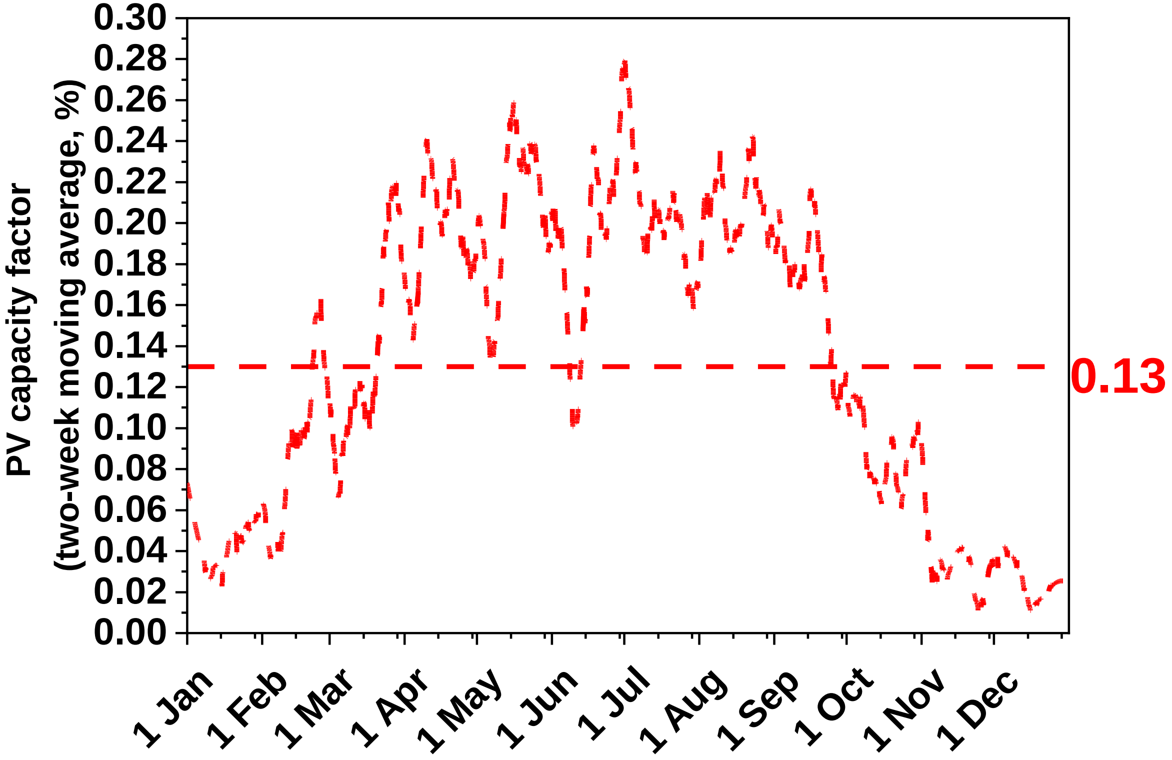


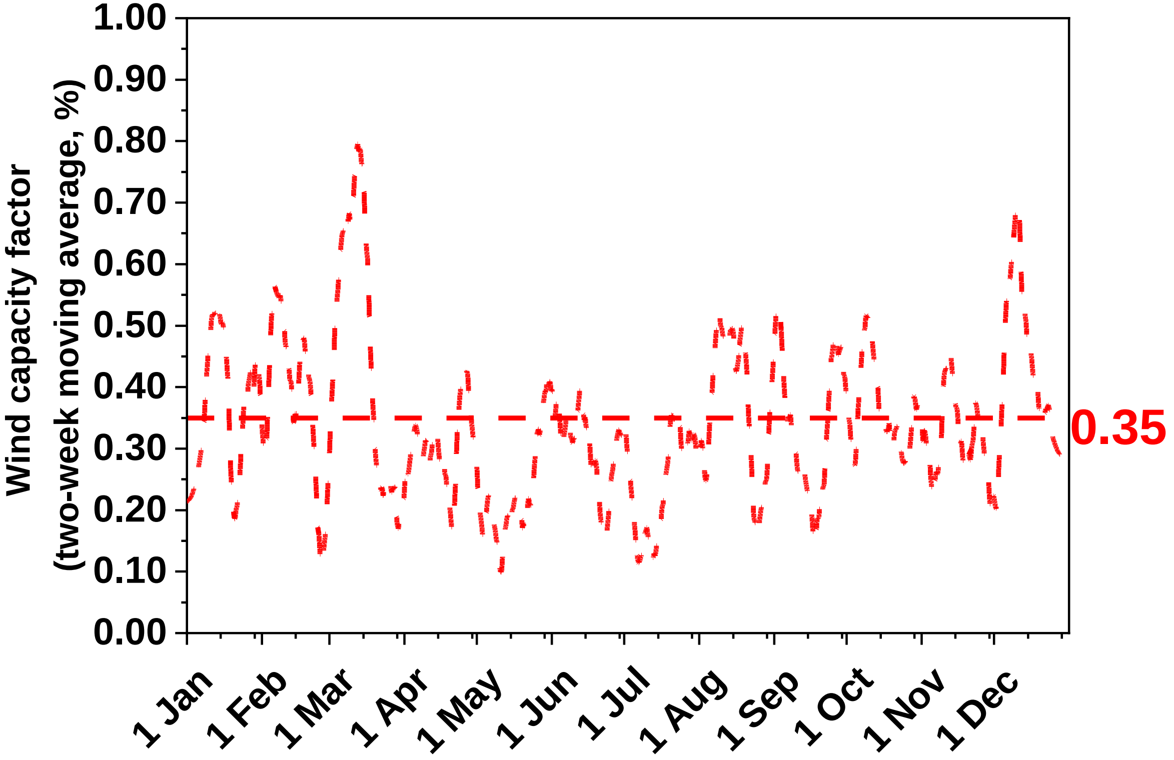
Contribution of different heat sources to meet heat demands Loughborough, onsite PV, year 2019



Contribution of different heat sources to meet heat demands Loughborough, onsite Wind, year 2019

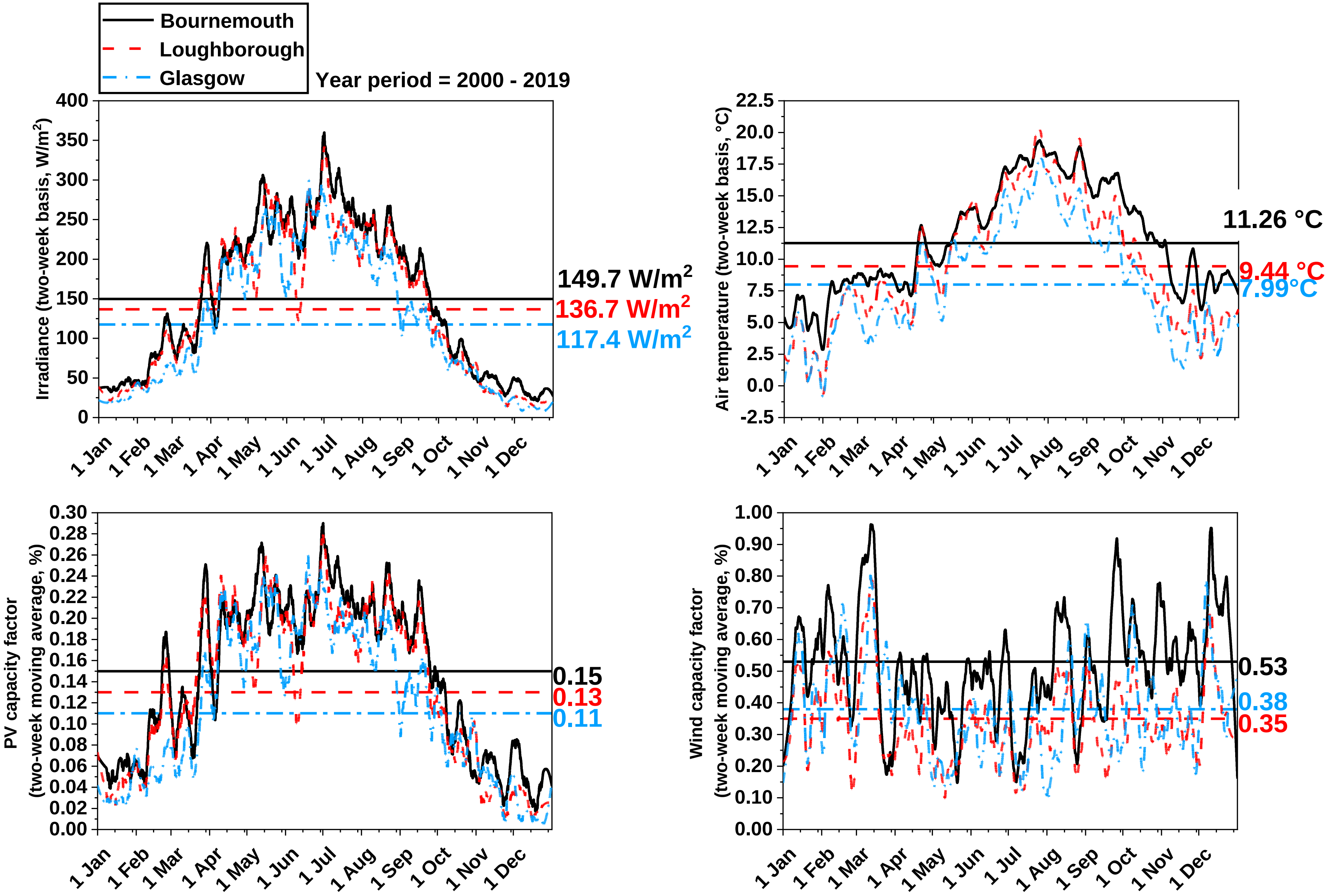
RESULTS: PV capacity and Wind capacity for Loughborough, years 2000 - 2019

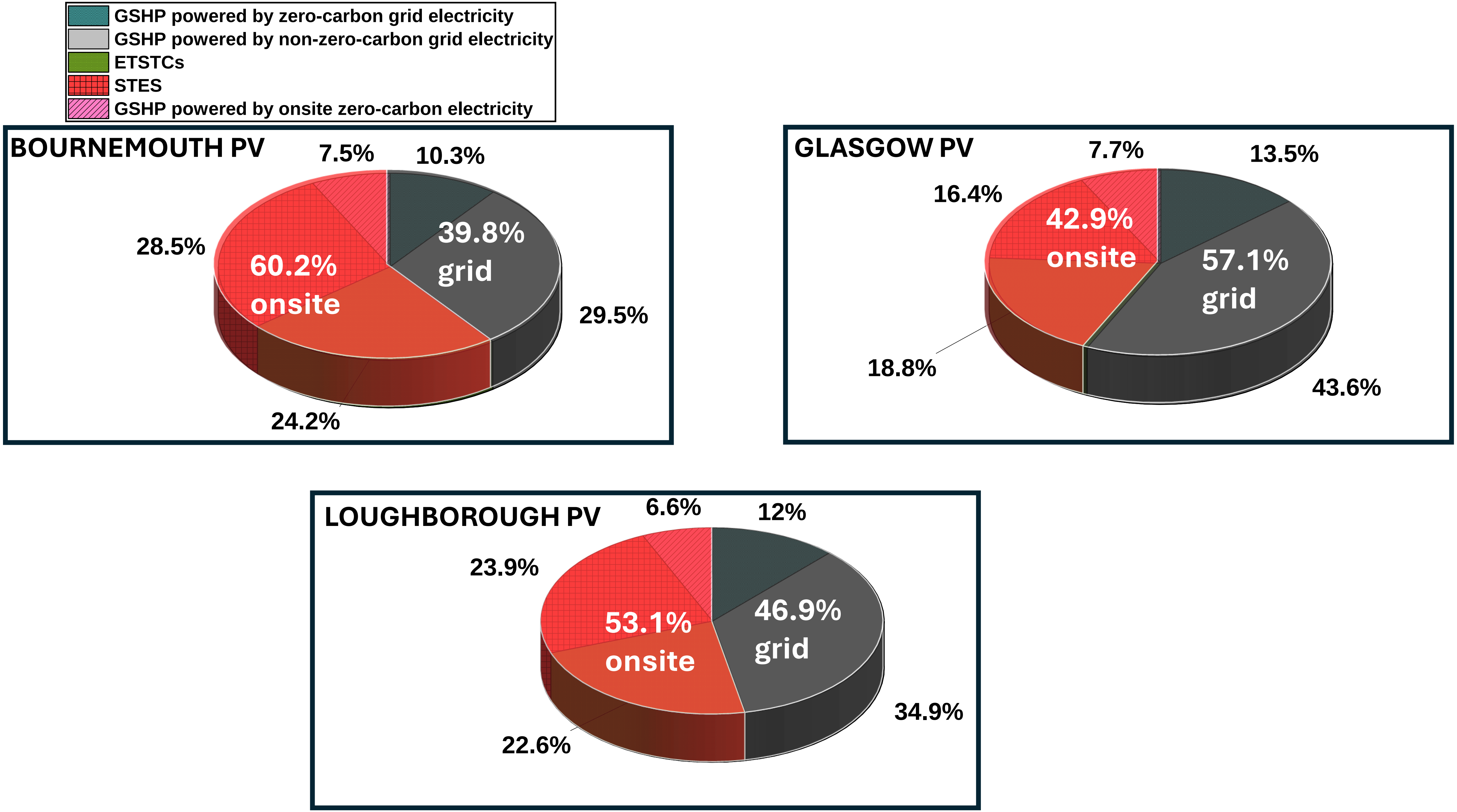




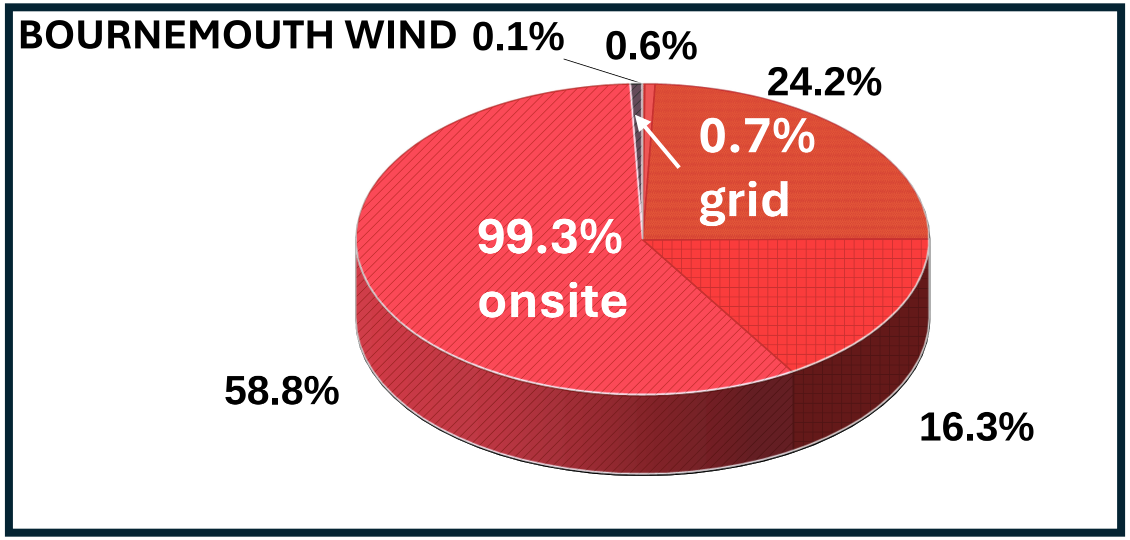
EFFECT OF LOCATION ON THE SHARE OF HEATING DEMAND MET BY ONSITE ZERO-CARBON HEAT SOURCES

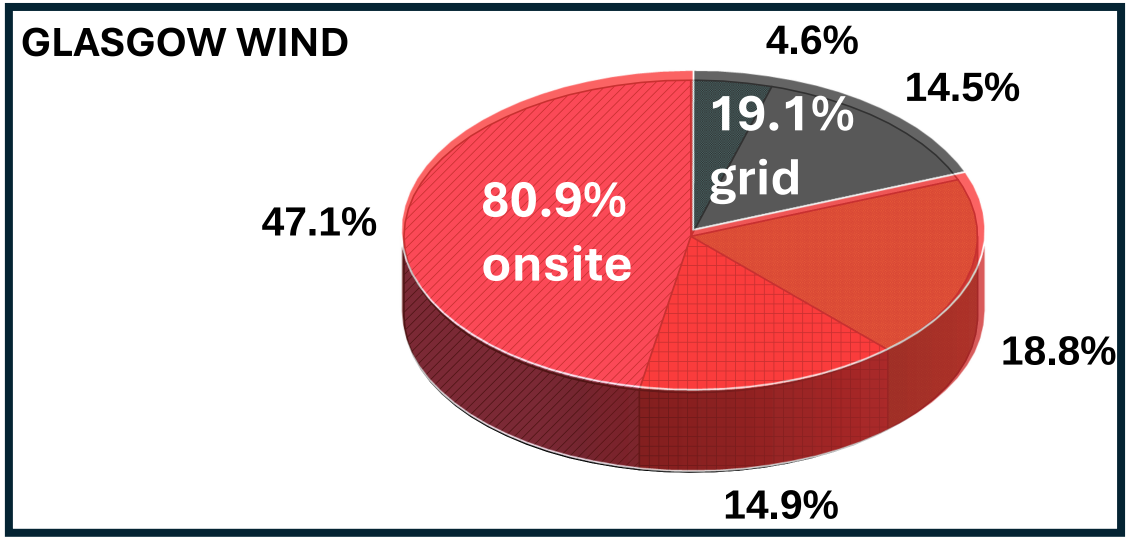
RESULTS: Average irradiance, air temperature, PV capacity and Wind capacity for Loughborough, years 2000 - 2019



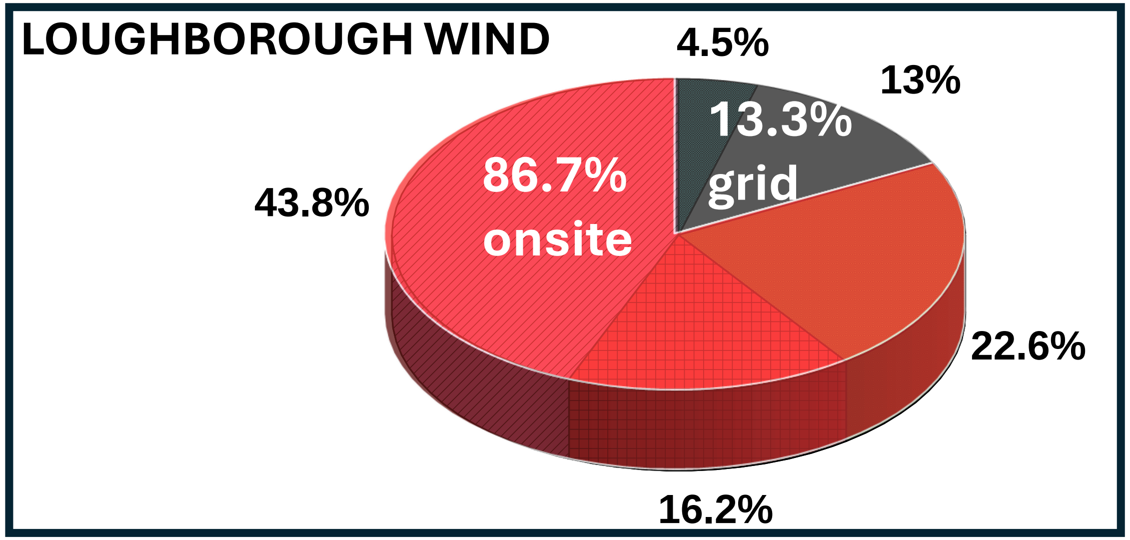

GSHP powered by zero-carbon grid electricity
GSHP powered by non-zero-carbon grid electricity
ETSTCs
STES
GSHP powered by onsite zero-carbon electricity
BOURNEMOUTH PV
7.5%
10.3%
28.5%
39.8% grid
60.2% onsite
29.5%
24.2%
GLASGOW PV
7.7%
13.5%
16.4%
42.9% onsite
57.1% grid
18.8%
43.6%
LOUGHBOROUGH PV
6.6%
12%
23.9%
53.1% onsite
46.9% grid
34.9%
22.6%

- ▨ GSHP powered by zero-carbon grid electricity
- ☐ GSHP powered by non-zero-carbon grid electricity
- 🟩 ETSTCs
- ▦ STES
- ▨ GSHP powered by onsite zero-carbon electricity





✓ When using Wind-generated electricity to power HPs in Bournemouth the heat demands can be met almost entirely by onsite zero-carbon heat sources



CONCLUSIONS

- ✓ When comparing with onsite PV, the simulations show that using on-site wind generated electricity to power heat pumps leads to a higher share of heating demand met by onsite zero-carbon heat sources, meaning a higher reduction in operational cost and thus a lower levelized cost of heat calculated for 20 years.
- ✓ Among all three cases studied (corresponding to three different locations of the ULC-DHN), Bournemouth has the better conditions for the usage of HPs powered by wind-generated electricity, reaching an almost 100% of share by the year 2019 (with a calculated levelized cost of heat for the period 2000 – 2019 of 1.5 p/kWh).
- ✓ Loughborough and Glasgow would need a both higher capacity of onsite wind and greater volume of STES to reach a 100% of share of heating demand met by onsite zero-carbon heat sources for the year 2019. However, with the capacity of onsite wind and the volume of STES assumed, the calculated share was an acceptable ca. 80% with a LCOH of ca. 3 p/kWh.

FUTURE WORK

Study of the behaviour of the ULC-DHN for the period 2020 – 2039, including predictions in the air temperature variations due to the global warming effects provided by UK Climate Projections (UKCP) [17] and projections for the CO_2 emissions per kWh of electricity produced in the UK.

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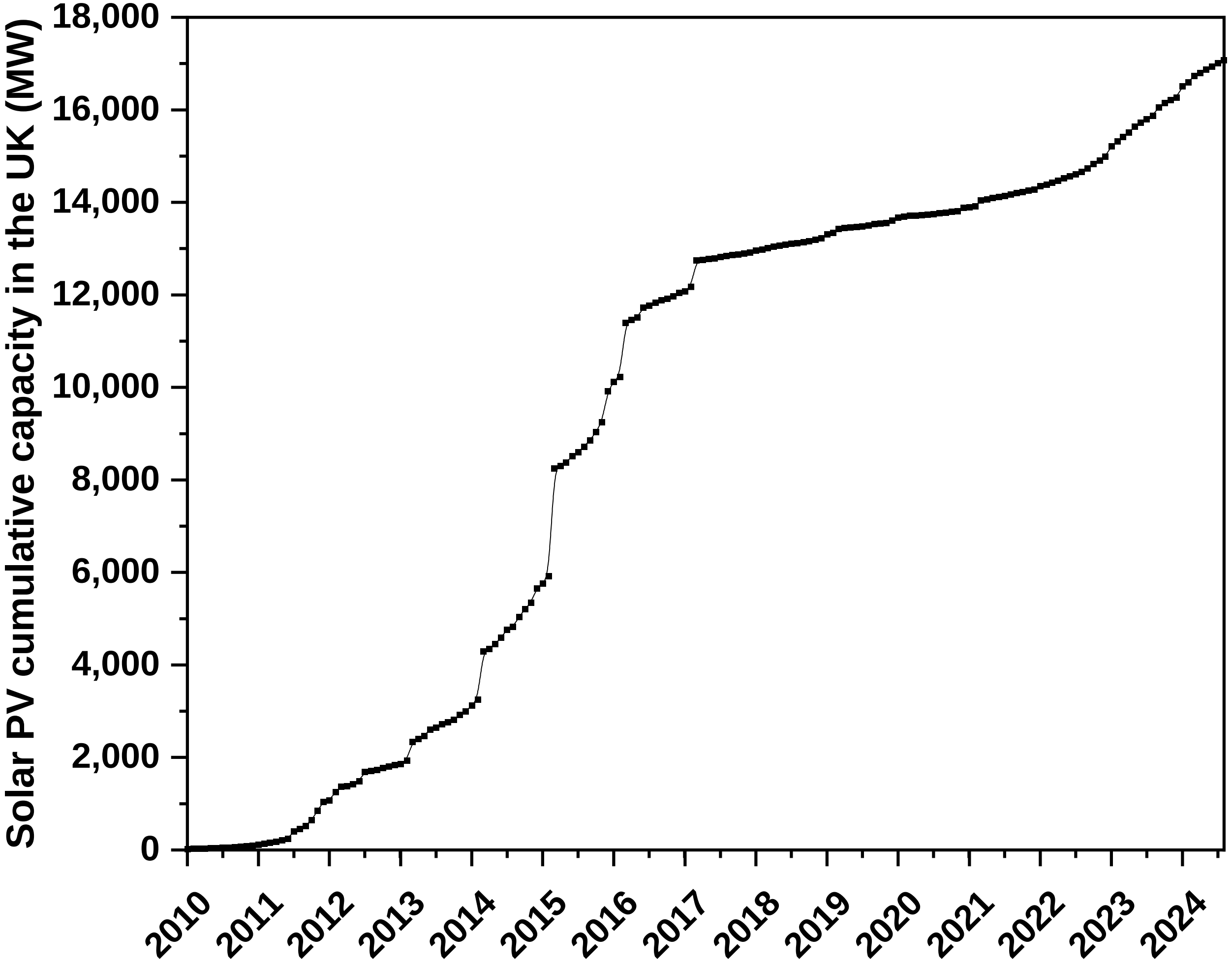

Source: Department for Energy Security and Net Zero
(https://www.gov.uk/government/statistics/solar-photovoltaics-deployment)

Department for Energy Security and Net Zero, Solar photovoltaics deployment, (2024).
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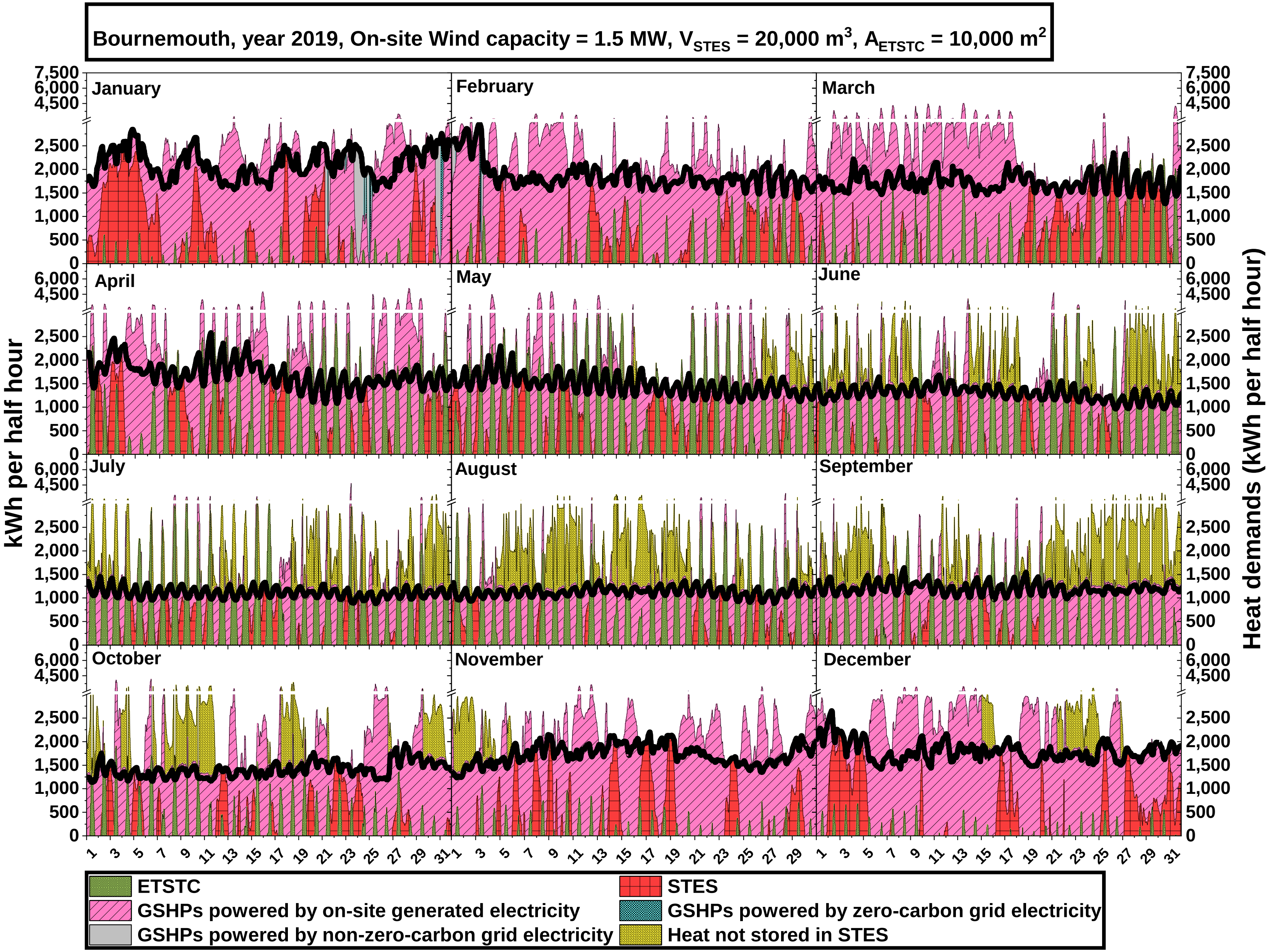
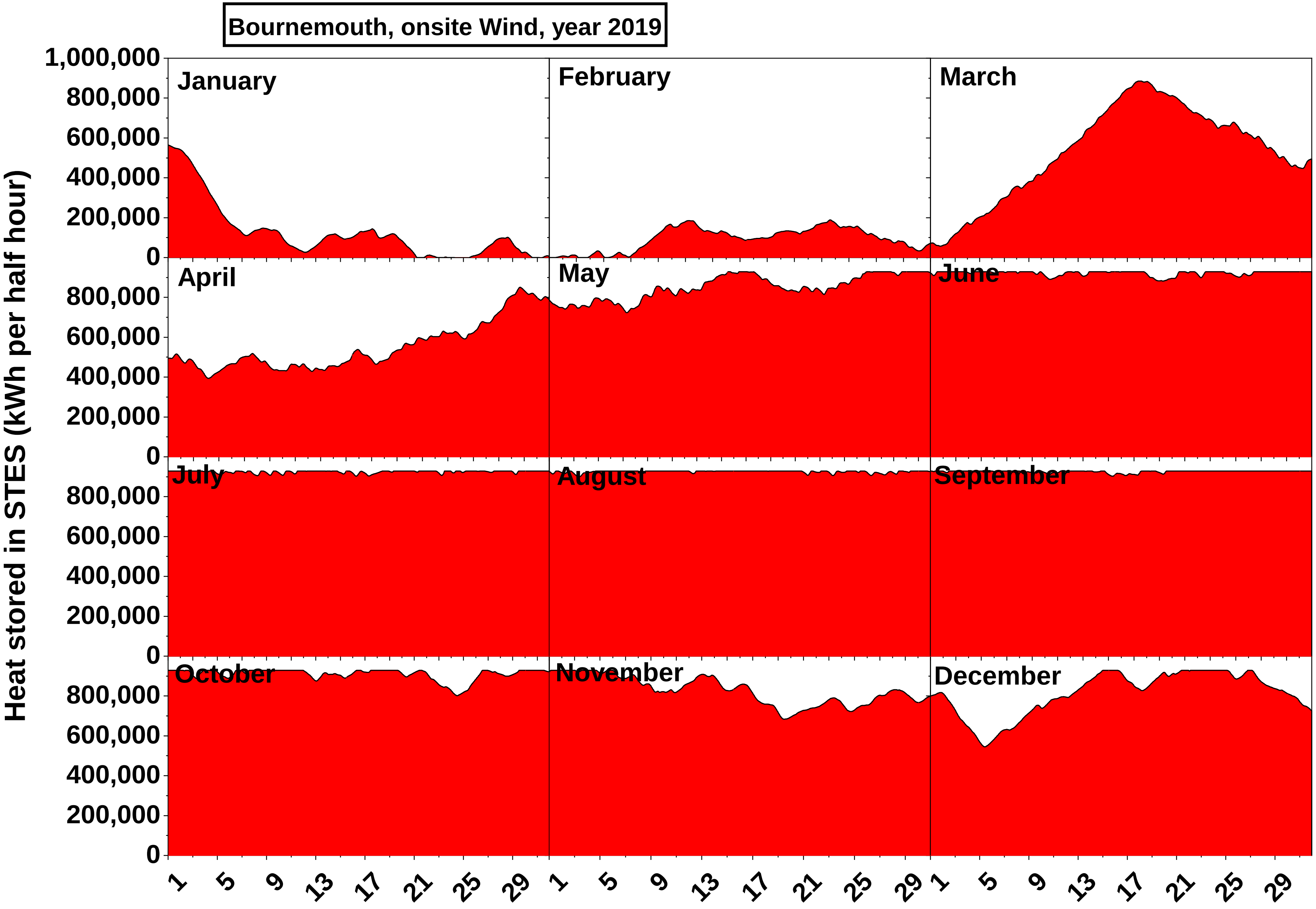
RESULTS: share of heating demand met by the different heat sources considered for the ULC-DHN



RESULTS: Total heat stored in STES



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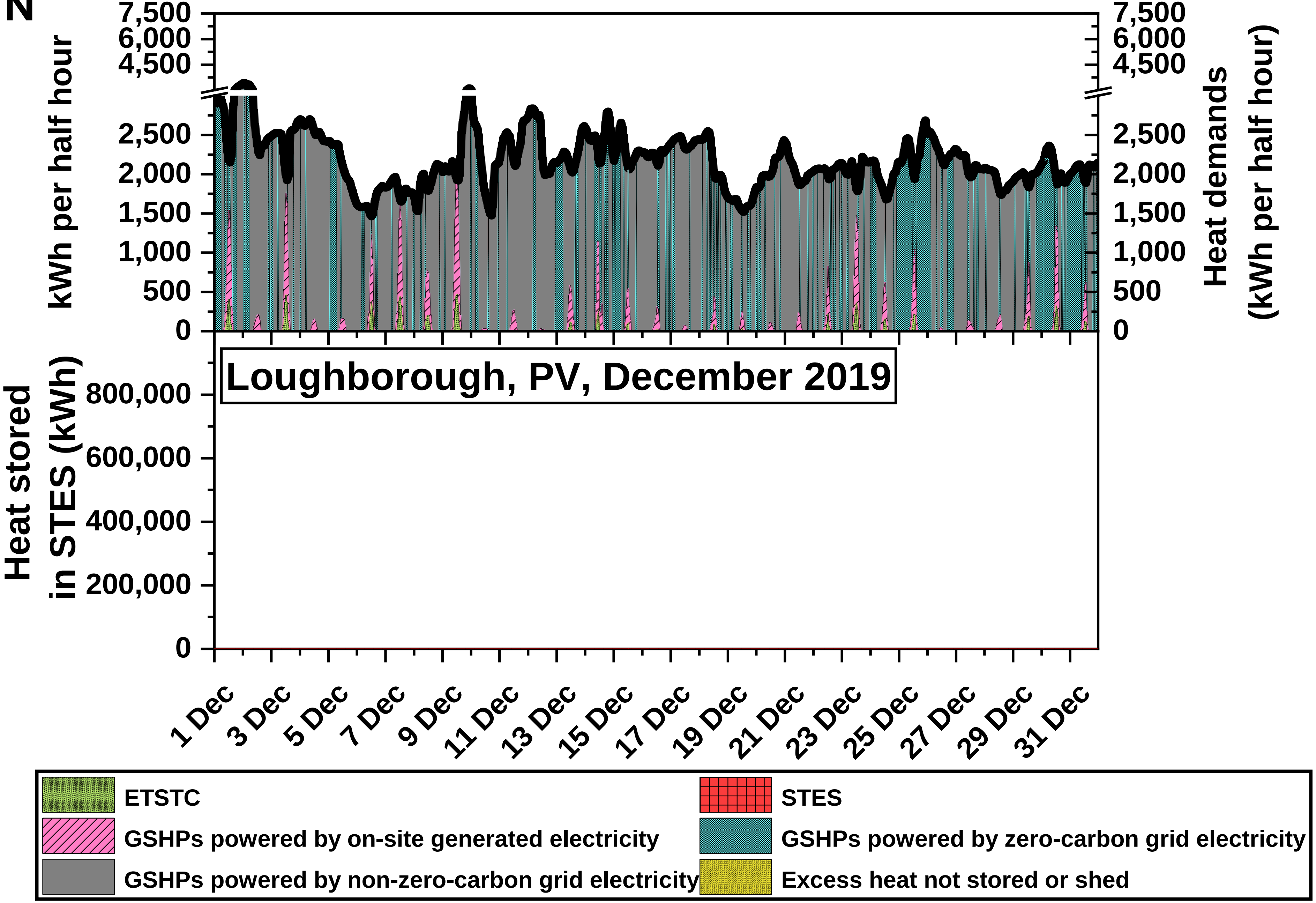

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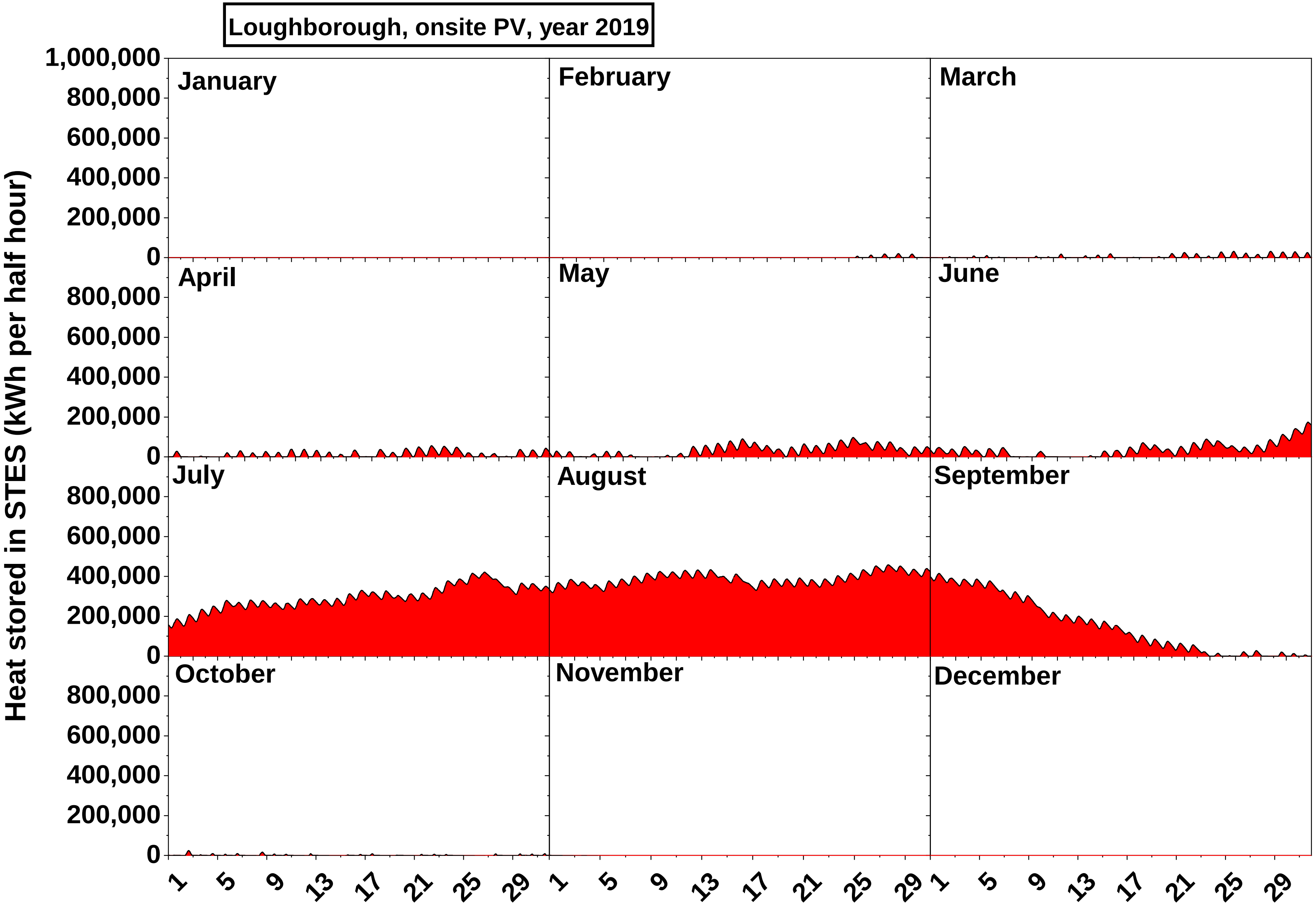
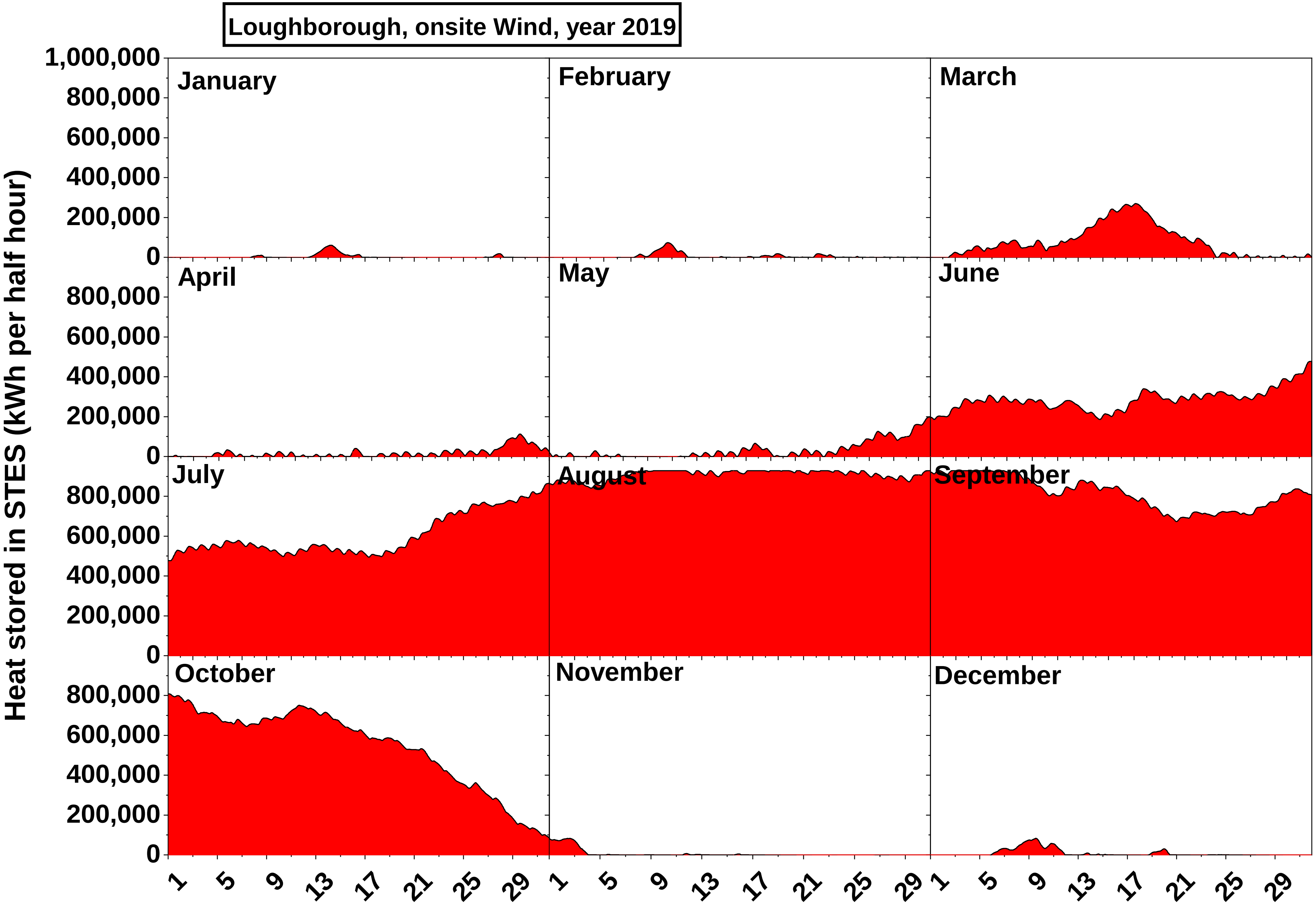


RESULTS: Total heat stored in STES

- ✓ When using onsite wind-generated electricity to power HPs, the STES reaches its maximum heat capacity by August, allowing to use the stored heat in the autumn months of September and October



Methodology: Correlation between the outdoor temperature and the heat demands for Holywell Park, Loughborough University, UK, for the year 2021 (left) and historic CO_2 emissions per kWh of grid electricity for the North West region of the UK, 2021 (7% transmission and distribution loss included) (right).