Optimisation of a district heating network supplied with only renewable heat sources and different types of thermal energy storage

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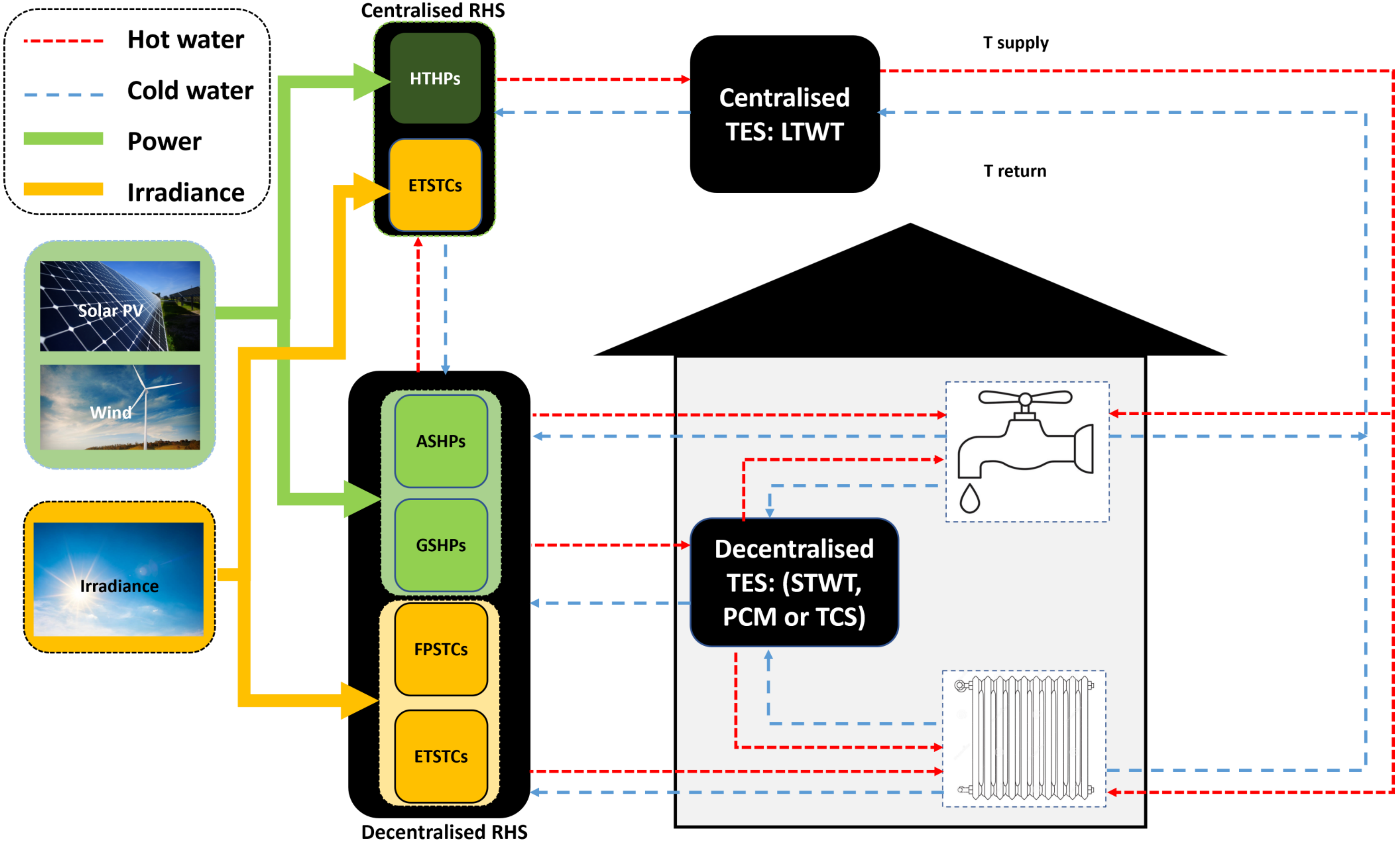
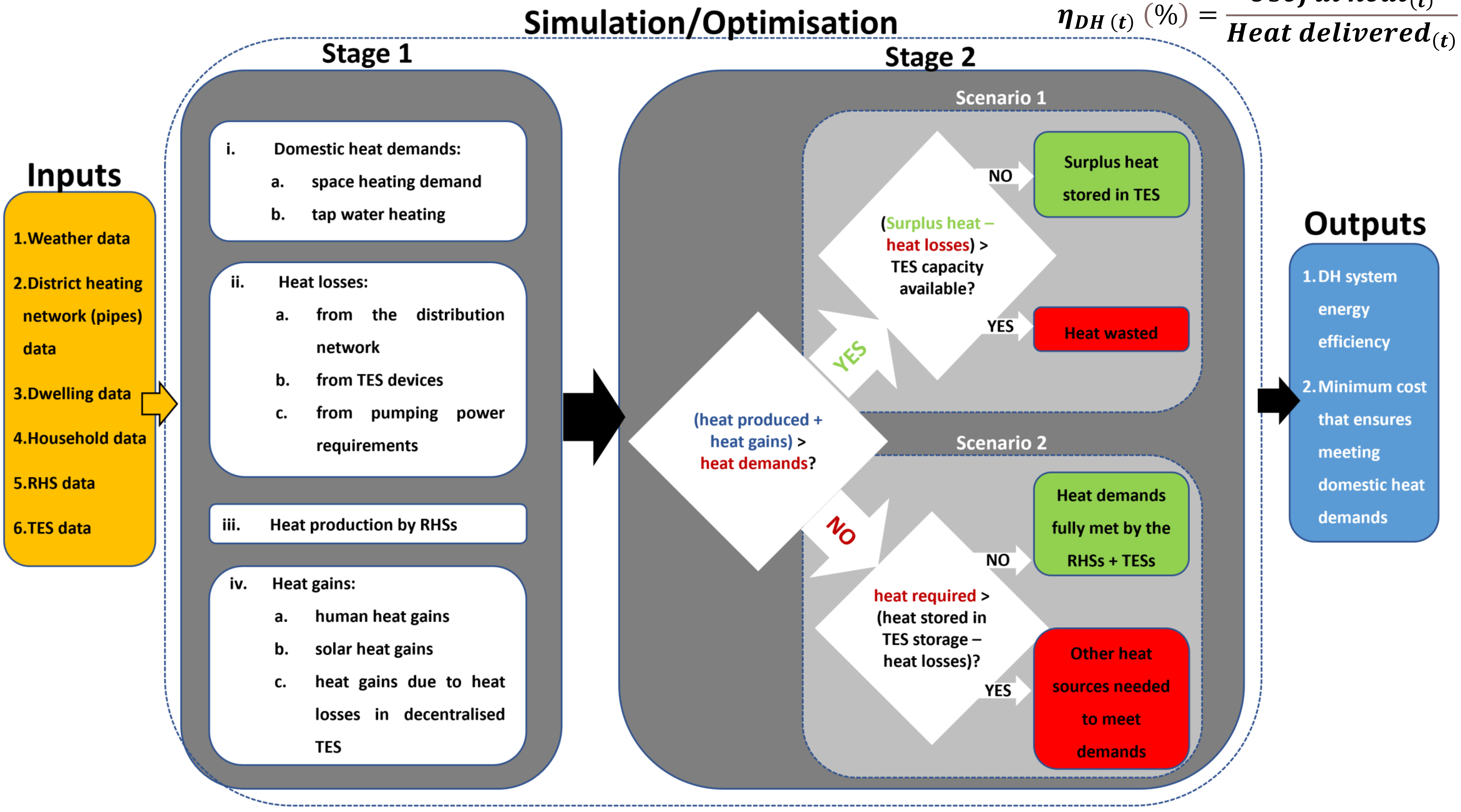
Schematic diagram illustrating the operating mode proposed for the fully renewable DH network.



Two-stage modelling approach adopted to determine heat transferred to/from storage on an hourly basis.

$$\eta_{DH\,(t)}\,(\%) = \frac{Useful\ heat_{(t)}}{Heat\ delivered_{(t)}} \cdot 100$$



Simulation/Optimisation

Inputs

1. Weather data
2. District heating network (pipes) data
3. Dwelling data
4. Household data
5. RHS data
6. TES data

Stage 1

i. Domestic heat demands:
  a. space heating demand
  b. tap water heating

ii. Heat losses:
  a. from the distribution network
  b. from TES devices
  c. from pumping power requirements

iii. Heat production by RHSs

iv. Heat gains:
  a. human heat gains
  b. solar heat gains
  c. heat gains due to heat losses in decentralised TES

Stage 2

(heat produced + heat gains) > heat demands?

YES → Scenario 1

(Surplus heat – heat losses) > TES capacity available?
- NO → Surplus heat stored in TES
- YES → Heat wasted

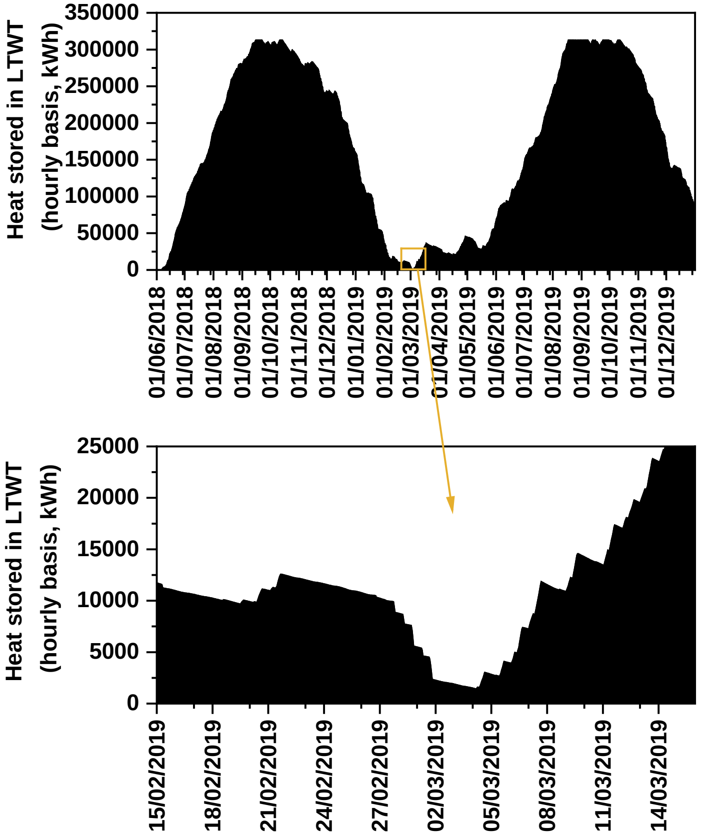
NO → Scenario 2

heat required > (heat stored in TES storage – heat losses)?
- NO → Heat demands fully met by the RHSs + TESs
- YES → Other heat sources needed to meet demands

Outputs

1. DH system energy efficiency
2. Minimum cost that ensures meeting domestic heat demands

WP2: Methodology. DH system optimisation.



The optimisation was done using the Microsoft Excel add-in program Solver. The Solver parameters introduced were:

- **Objective:** Cost per dwelling, to be minimum.
- **Variables:** the optimisation was carried out by modifying the following parameters:
  1. Installed capacity of PV used to power domestic HPs, ($\mathbf{PV_{dwellings}}$).
  2. Installed capacity of Wind used to power domestic HPs, ($\mathbf{WIND_{dwellings}}$).

  The PV and Wind capacity needed to power the HTHPs required to lift the temperature of water prior charging the LTWT (PVLTWT and WINDLTWT) are not included here, as these two are calculated depending on the amount of heat to be charged in the LTWT at every hour.
- **Constrains:** the following constrains were applied:
  1. Domestic heat demands to be met at every hour for the whole time-period considered for the simulation ($\mathbf{\Delta_{dem\text{-}prod}} \leq 0$ kWh).
  2. **0.5 MW ≥ $\mathbf{PV_{dwellings}}$ ≥ 0 MW.**
  3. **0.5 MW ≥ $\mathbf{WIND_{dwellings}}$ ≥ 0 MW.**
  4. **0.05 $\mathbf{LTWT_{max} \geq LTWT_{min} > 0}$**, where $\mathbf{LTWT_{min}}$ is the minimum accumulated heat stored in LTWT between 01/09/2018 00:00:00 and 30/06/2019 23:00:00, and $\mathbf{LTWT_{max}}$ the maximum heat storage capacity of the LTWT. This last constrain was introduced to make the software find the solution faster and avoid local minimums, as it was observed that in all cases the global minimum cost that ensures to meet demands for the whole simulation period is obtained when the minimum heat stored in the LTWT between two summer maximums is the smallest possible (but higher than 0 kWh). In this case, it was assumed that the minimum should be less or equal than the 5% of the maximum heat storage capacity of the LTWT.

WP3: Applications to case-study regions. Case-scenario: 2 urban areas in Loughborough, UK (262 dwellings) for the time period 01/06/2018 00:00 to 31/12/2019 23:00. Inputs.

RHSs main parameters	
USED IN DWELLINGS	
Renewable power sources used to power domestic HPs	
Wind assumed installed capacity (WIND$_{DWELLINGS}$, MW)	0 – 0.5
Solar PV assumed installed capacity (PV$_{DWELLINGS}$, MW)	0 – 0.5
STCs	
%ETSTC$_{DWELLINGS}$	100%
%FPSTC	0%
Area of STC per dwelling (m^2)	2
HPs	
%ASHP	50%
%GSHP	50%
ASHPs capacity per unit (kW)	As required
GSHPs capacity per unit (kW)	As required
USED TO CHARGE LTWT	
Renewable power sources used to power HTHPs needed to lift temperature of water prior charging LTWT	
Wind assumed installed capacity (WIND$_{LTWT}$, MW)	As required
Solar PV assumed installed capacity (PV$_{LTWT}$, MW)	As required
ETSTC$_{LTWT}$ area (m^2)	As required

TES main parameters	
Penetration (% of dwellings with stores)	
STWT	50%
PCM	30%
LTWT	NA
TCS	10%
Charging temperature (°C)	
TCS	120
STWT	50
PCM	50
LTWT	50 - 90
Volume	
STWT volume per dwelling (m^3)	1
PCM volume per dwelling (m^3)	0.2
TCS volume per dwelling (m^3)	1
LTWT (m^3)	Variable

Methodology: Case-scenario: 2 urban areas in Loughborough, UK (262 dwellings). Inputs.

Costs of variable parameters	
Variable parameters	
Installed PV (£/MW)[1]	1000000
Installed Wind (£/MW)[2]	1610000
LTWT (£/m^3)[3]	50
ASHPs (£/unit)	5000
GSHPs (£/unit)	13000
HTHPs (£/kW)[4]	250
STCs (£/m^2)[5]	170
Fixed parameters	
TCS (£/kg)[6]	0.2
PCM (£/kg)[7]	6
STWT (£/200 L)[3]	200
Piping network (£/dwelling), [8,9]	800

[1] S.T.A. (STA), Solar Trade Association (STA), (n.d.). https://solarenergyuk.org/.

[2] Briefings for britain, No Title, (n.d.). https://briefingsforbritain.co.uk/.

[3] E. Guelpa, V. Verda, Thermal energy storage in district heating and cooling systems: A review, Appl. Energy. 252 (2019) 113474. https://doi.org/10.1016/J.APENERGY.2019.113474.

[4] C. Arpagaus, F. Bless, M. Uhlmann, J. Schiffmann, S.S. Bertsch, High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials, Energy. 152 (2018) 985–1010. https://doi.org/10.1016/j.energy.2018.03.166.

[5] UK suppliers.

[6] D. Mahon, P. Henshall, G. Claudio, P.C. Eames, Feasibility study of MgSO4 + zeolite based composite thermochemical energy stores charged by vacuum flat plate solar thermal collectors for seasonal thermal energy storage, Renew. Energy. 145 (2020) 1799–1807. https://doi.org/10.1016/J.RENENE.2019.05.135.

[7] M. Fadl, P.C. Eames, An experimental investigation of the heat transfer and energy storage characteristics of a compact latent heat thermal energy storage system for domestic hot water applications, Energy. 188 (2019). https://doi.org/10.1016/j.energy.2019.116083.

[8] Energy technologies institute, DISTRICT HEAT NETWORKS IN THE UK: POTENTIAL, BARRIERS AND OPPORTUNITIES, (2018) 1–17. www.eti.co.uk (accessed August 18, 2021).

[9] Energy research partnership, Potential Role of Hydrogen in the UK Energy System, 2016. https://erpuk.org/wp-content/uploads/2016/10/ERP-Hydrogen-report-Oct-2016.pdf.

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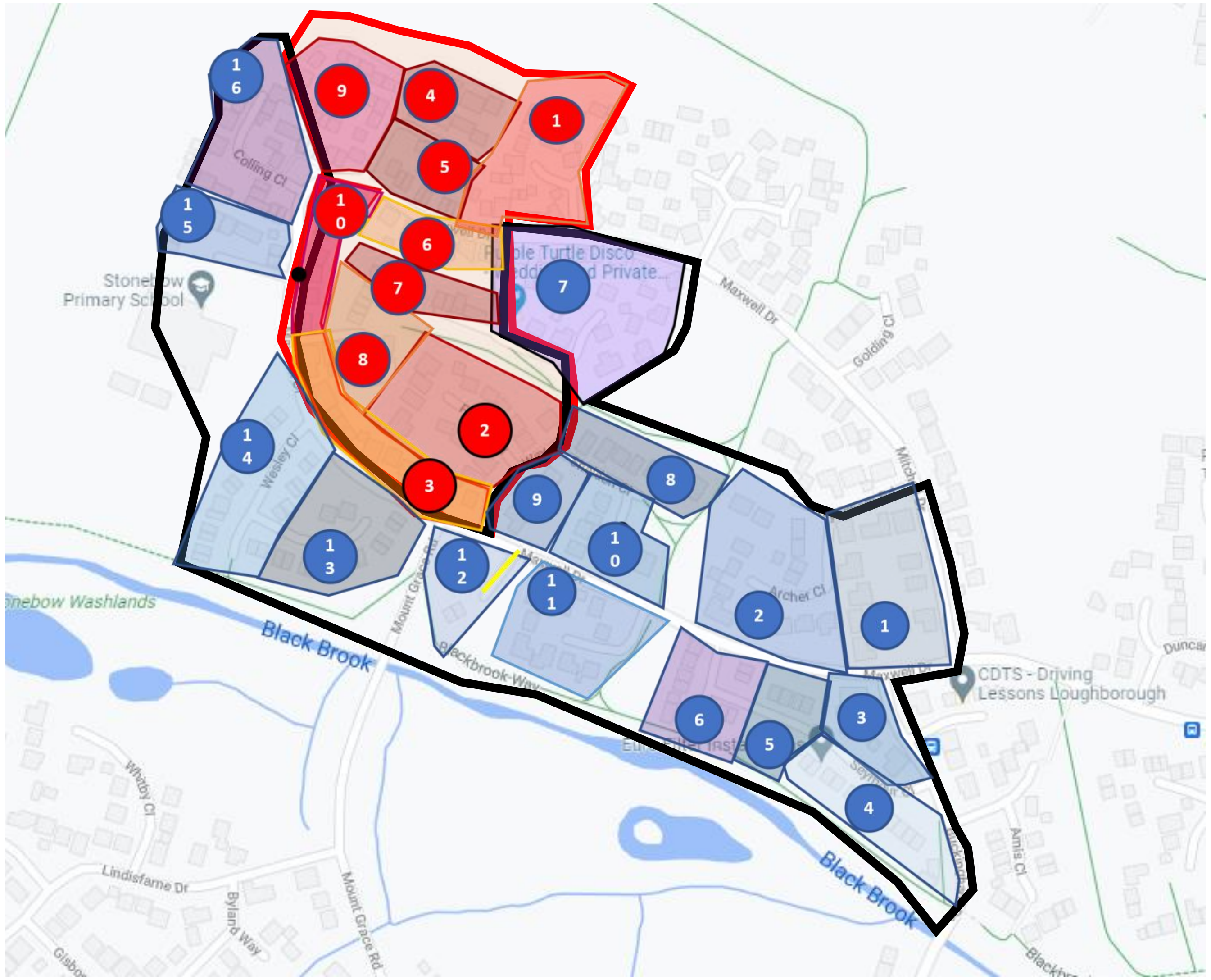
[1] Obtain by means of google maps.

Methodology: Case-scenario: 2 urban areas in Loughborough, UK (262 dwellings).

Methodology: Case-scenario: 2 urban areas in Loughborough, UK (262 dwellings).

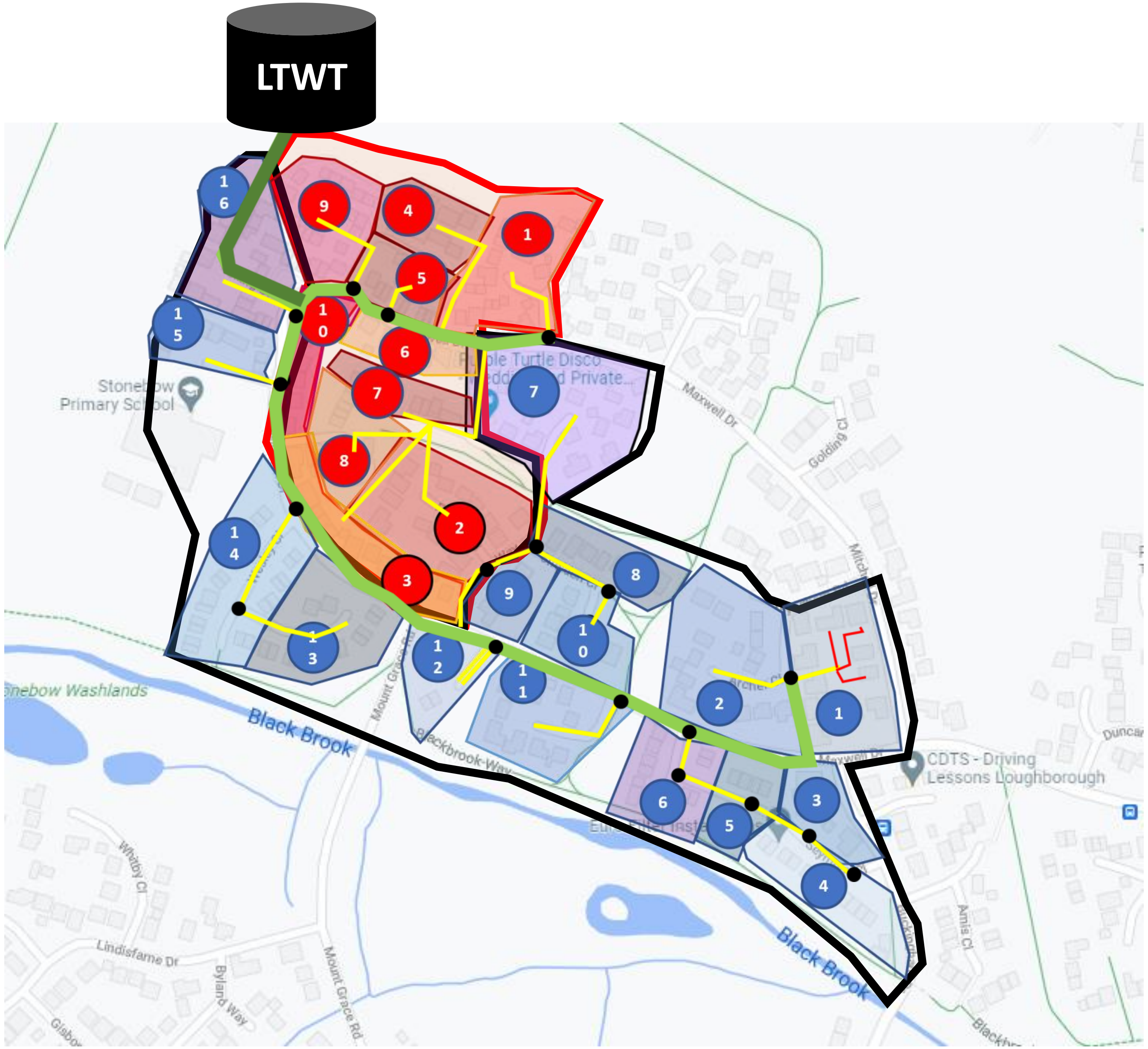
Sub-area number...	number of dwellings
Houses in blue area	
1	10
2	16
3	5
4	14
5	8
6	10
7	12
8	7
9	5
10	6
11	10
12	4
13	14
14	22
15	11
16	19
sum	173
Houses in blue area	
1	9
2	9
3	11
4	6
5	11
6	6
7	8
8	8
9	14
10	7
sum	89



Methodology: Case-scenario: 2 urban areas in Loughborough, UK (262 dwellings).

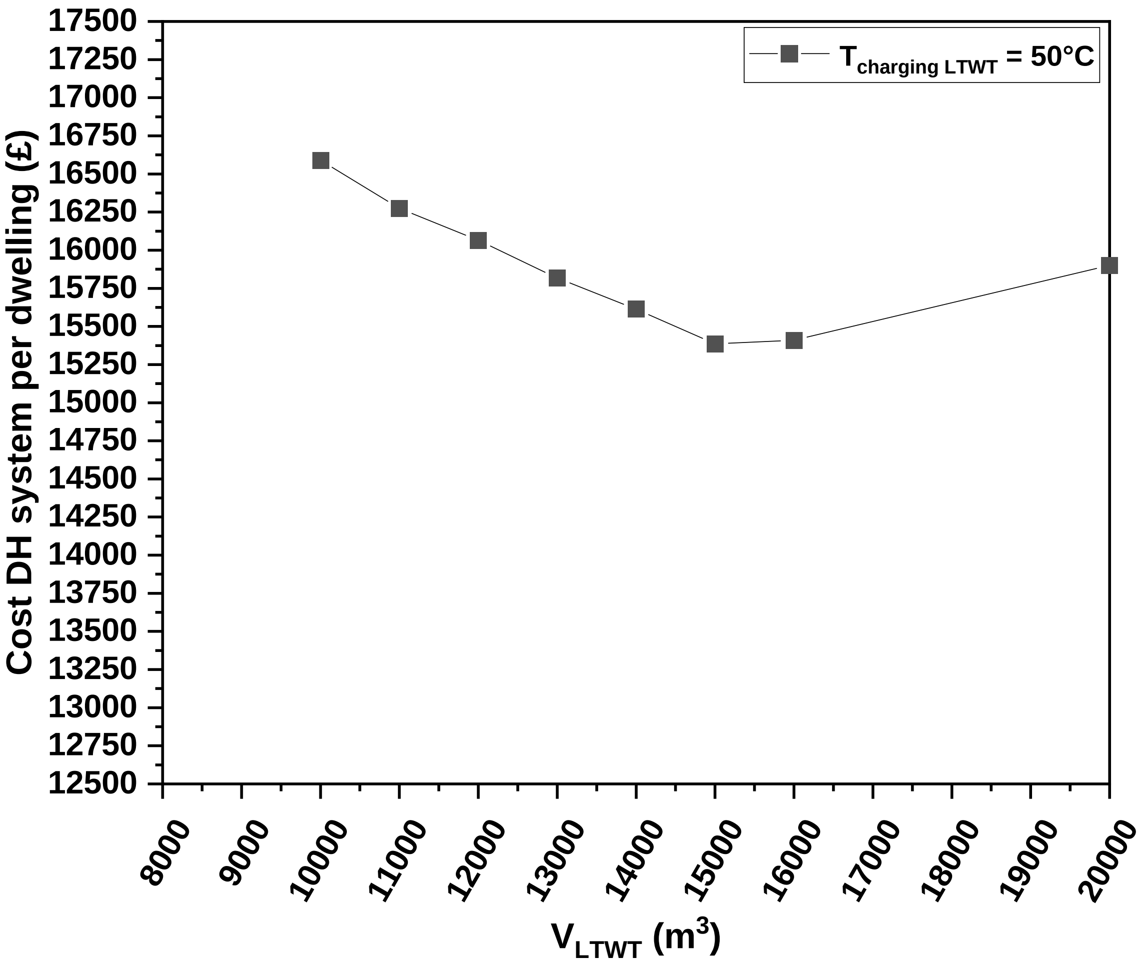
	PIPES inputs				
		main	intermediate	dwellings	LTWT
PIPE	Di (m)	0.102	0.041	0.016	0.128
	De (m)	0.114	0.048	0.021	0.141
	Thickness (m)	0.006	0.004	0.003	0.007
	Material pipe	PVC	PVC	PVC	PVC
	K-value (W/m K)	1.179	1.179	1.179	1.179
INSULATION	Thickness (m)	0.0381	0.0254	0.0254	0.0381
	Material	AluFlex	AluFlex	AluFlex	AluFlex
	K-value (W/m K)	0.023	0.023	0.023	0.023

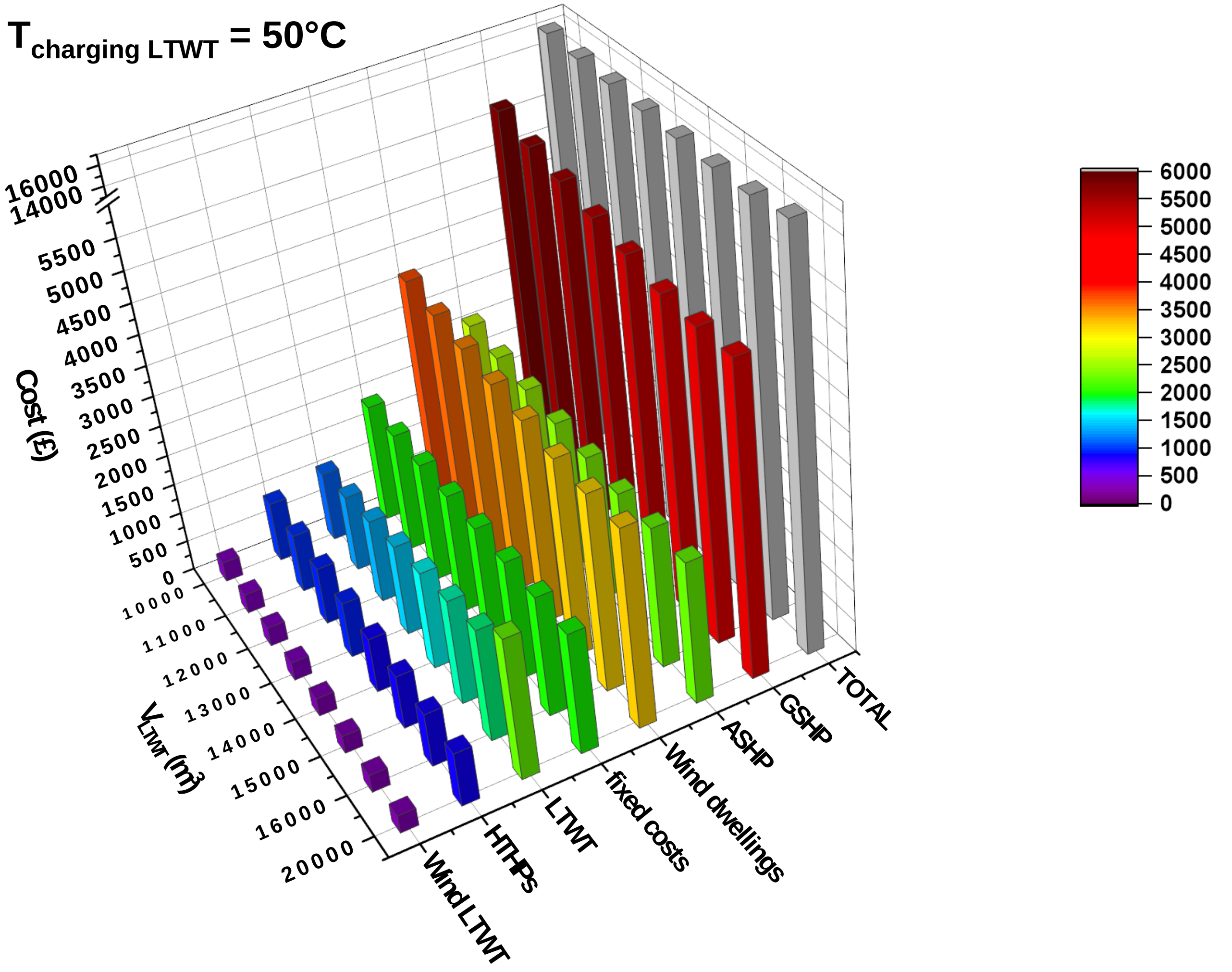
The size of the different sections of the piping network were chosen in order to avoid velocities of the fluid inside the pipes > 1.5 m/s [1]



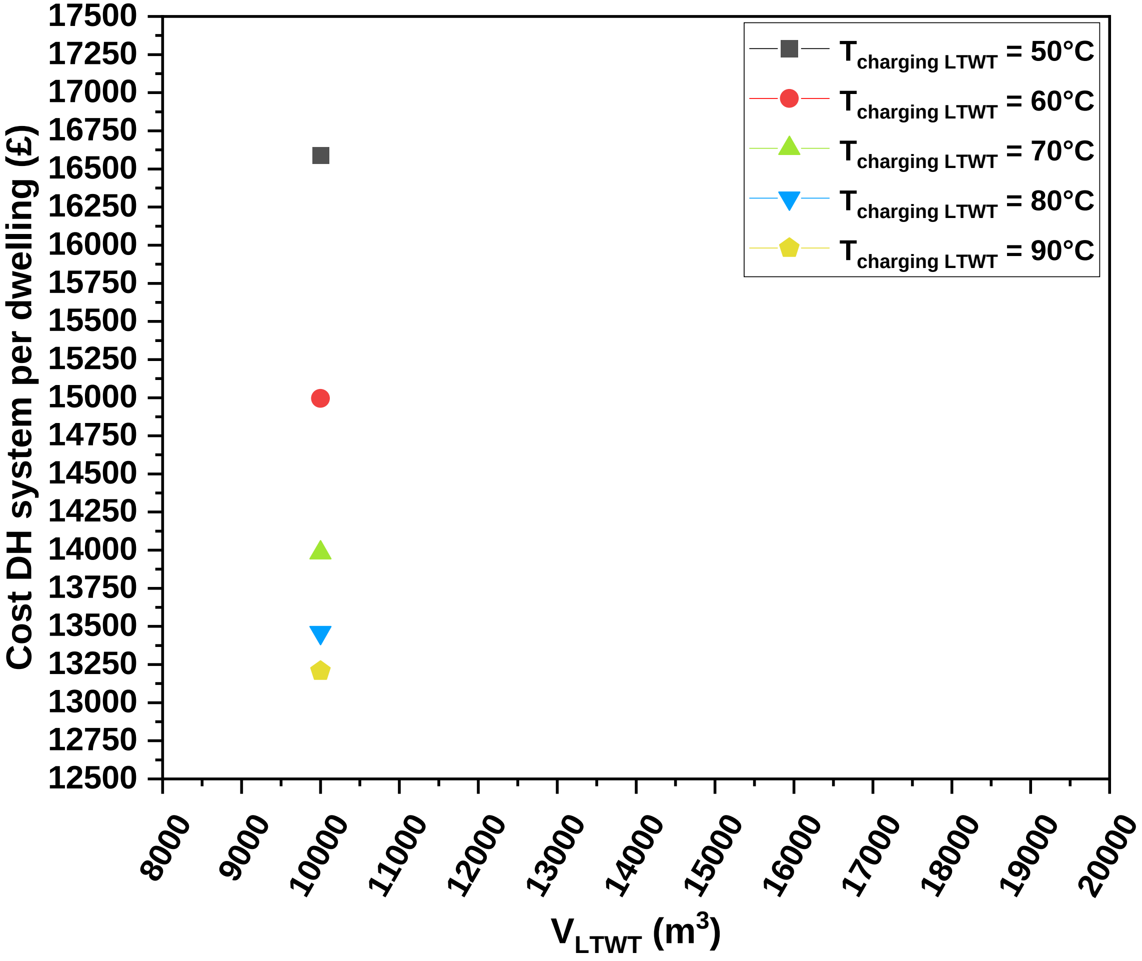
[1] Handbook of PVC Pipe Design and Construction, n.d.

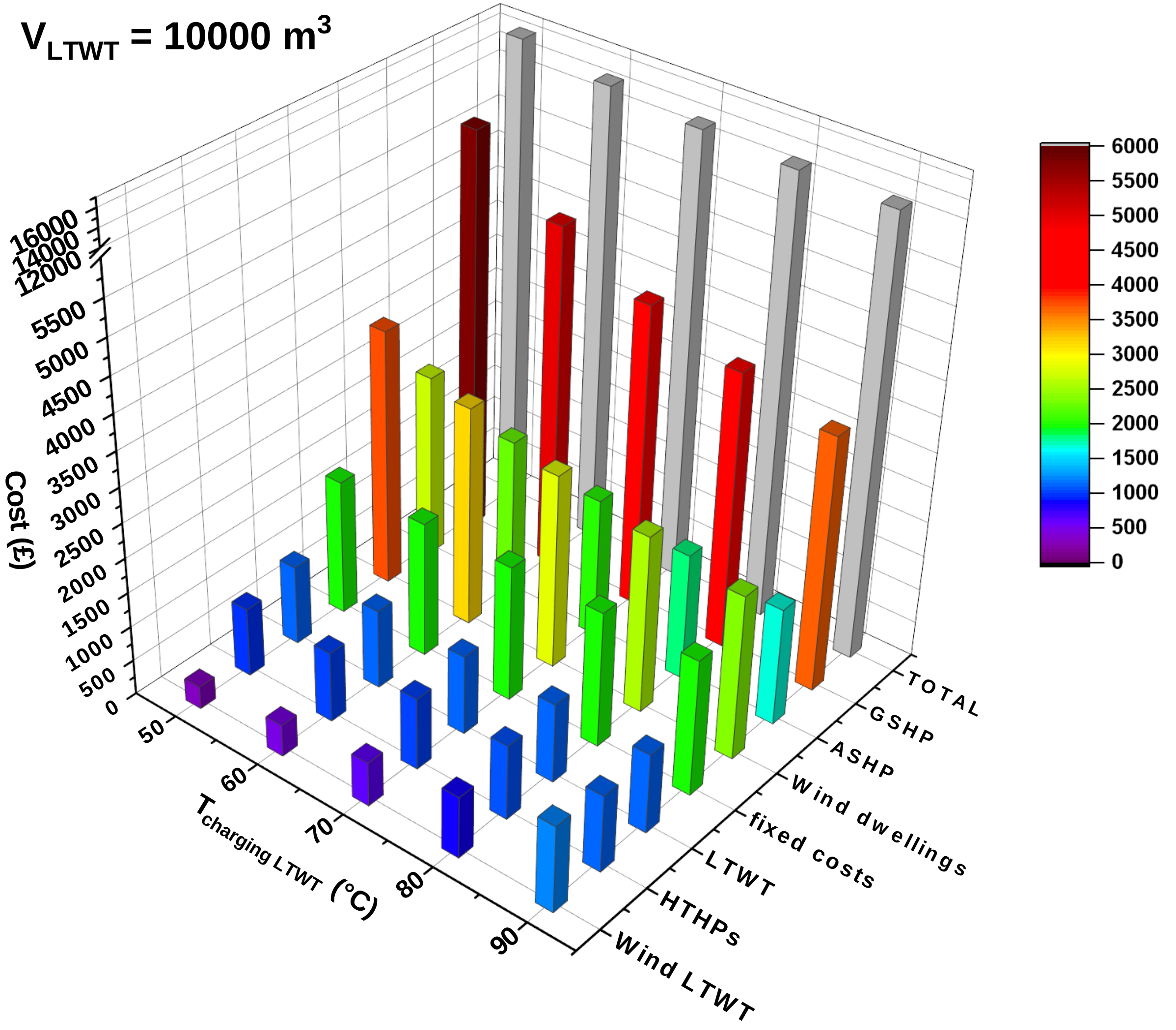
WP3. Results: Effect of i) **V_{LTWT}** and ii) **$T_{charging\ LTWT}$** on the **cost per dwelling**.



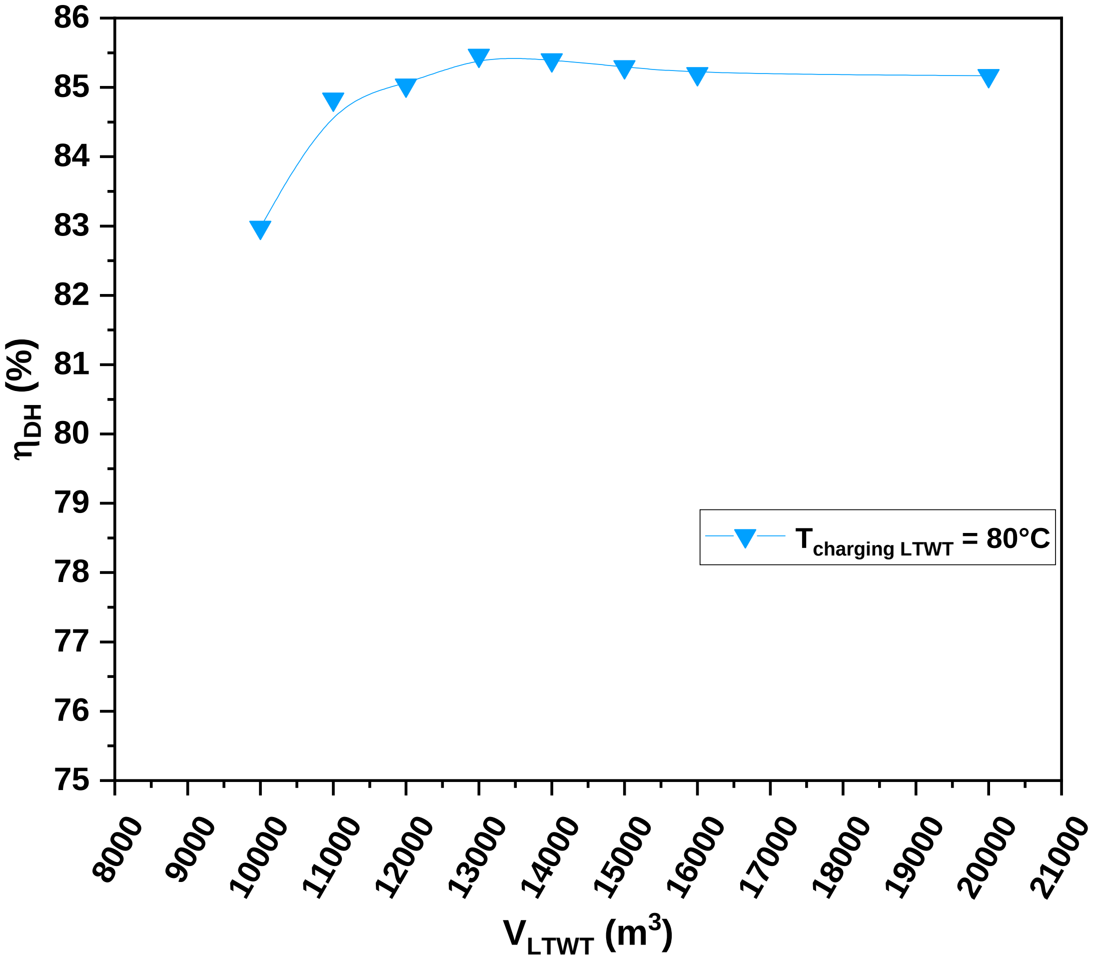


WP3. Results: Effect of i) $\mathbf{V_{LTWT}}$ and ii) $\mathbf{T_{charging\ LTWT}}$ on the **cost per dwelling**.

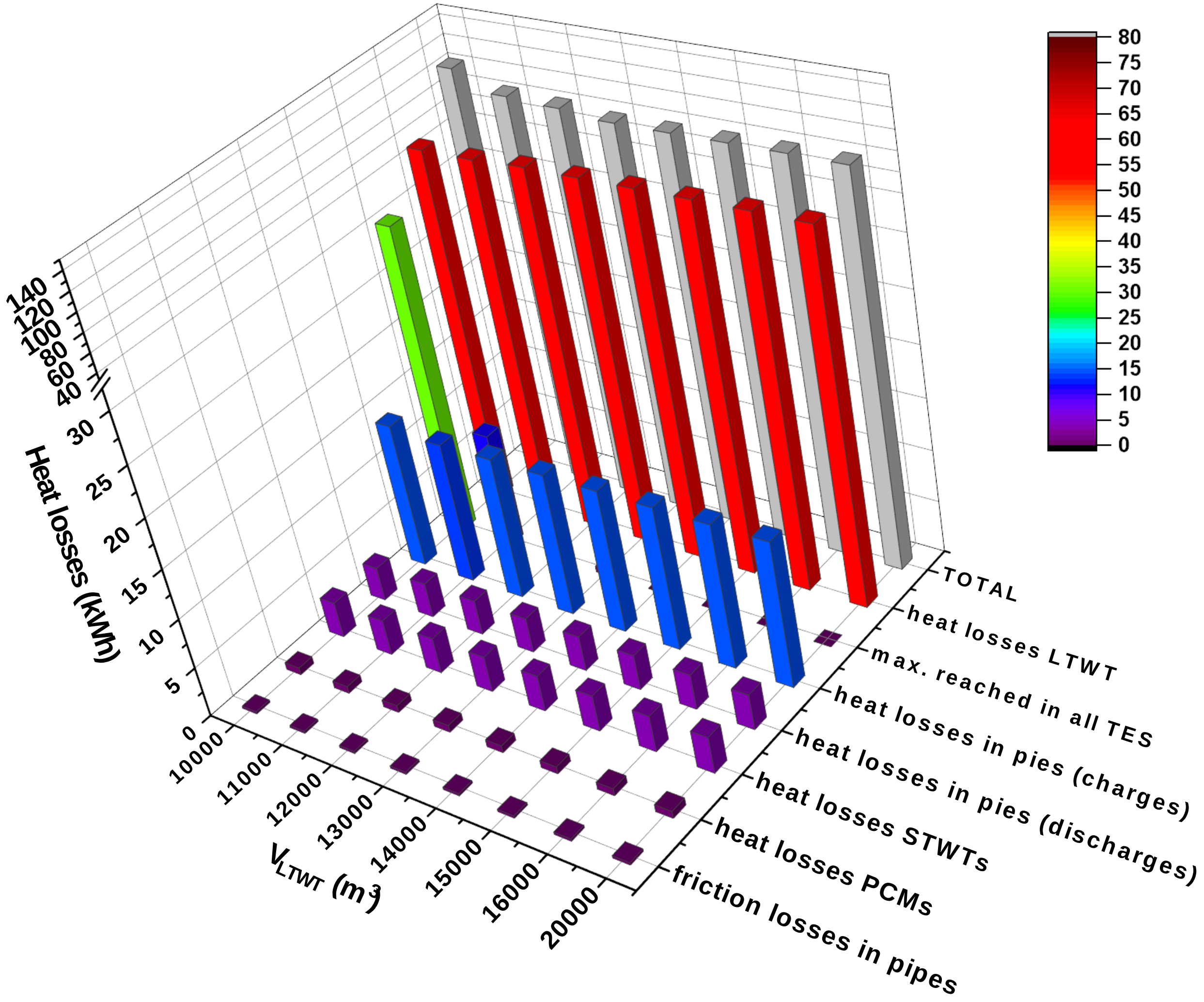




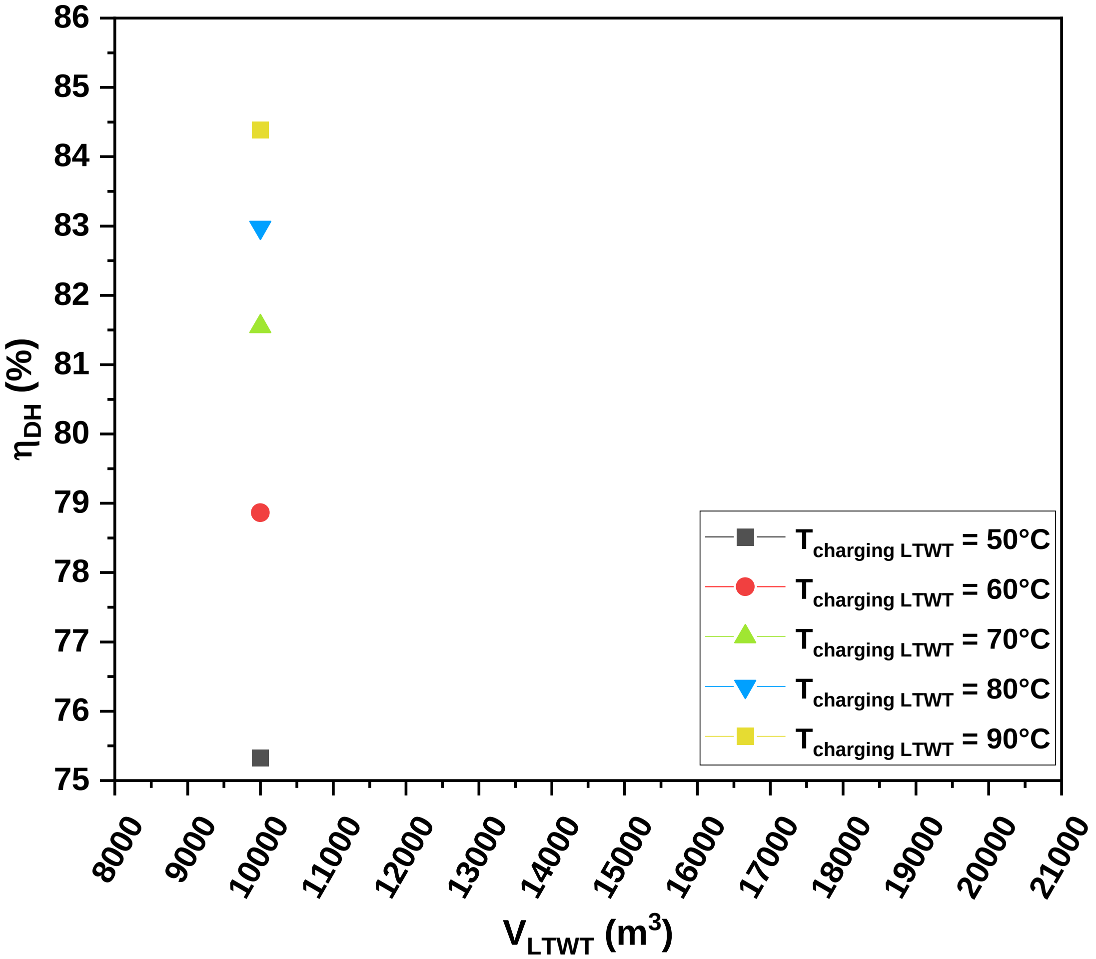
WP3. Results: Effect of i) $\mathbf{V_{LTWT}}$ and ii) $\mathbf{T_{charging\ LTWT}}$ on $\boldsymbol{\eta_{DH}}$.

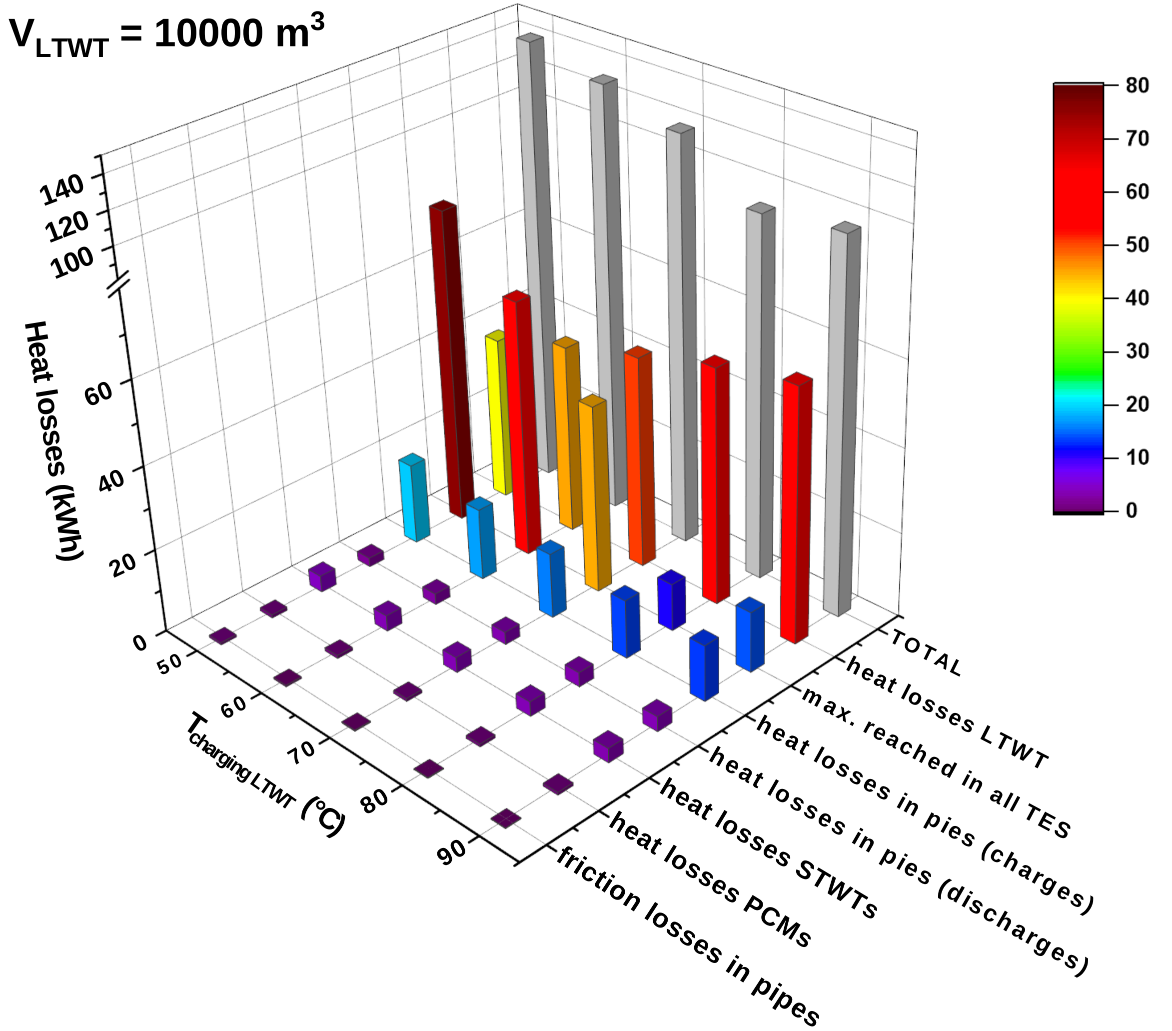


$T_{charging\ LTWT}$ = 80°C



WP3. Results: Effect of i) $\mathbf{V_{LTWT}}$ and ii) $\mathbf{T_{charging\ LTWT}}$ on $\boldsymbol{\eta_{DH}}$.





Main conclusions:

The results showed that:

1. **HPs powered by Wind** energy are the **best option** to provide heat to dwellings in the Loughborough area for the time-period considered.

2. A minimum cost of **£12723** per dwelling and a $\boldsymbol{\eta_{DH} = 74.32\%}$ was obtained so far for $\mathbf{T_{charging\ LTWT} = 90°C}$ and $\mathbf{V_{LTWT} = 10000\ m^3}$ obtained at the optimum conditions.

3. In general terms, an increase of both $\mathbf{V_{LTWT}}$ and $\mathbf{T_{charging\ LTWT}}$ reduces the cost per dwelling and increases the overall efficiency of the system, due to a larger storage capacity of the LTWT, which leads to a less heat sources capacity needed to fully meet demands and less heat wasted.

4. Volumes larger than **certain values** lead to an increase of the total cost due to the higher increment of cost of the LTWT comparing with the reduction of the cost of RHSs.

Future work:

Developing a “digital twin” of the actual model in order to obtain the dynamics/response of each individual dwelling.

Further parametric analysis of other variables of the district heating system, using the actual method.

Application of the model to existing district heating networks in order to i) validate the results and ii) improve the existing network.

Preparation of 2 peer-reviewed scientific publications.

Optimisation of a district heating network supplied with only renewable heat sources and different types of thermal energy storage

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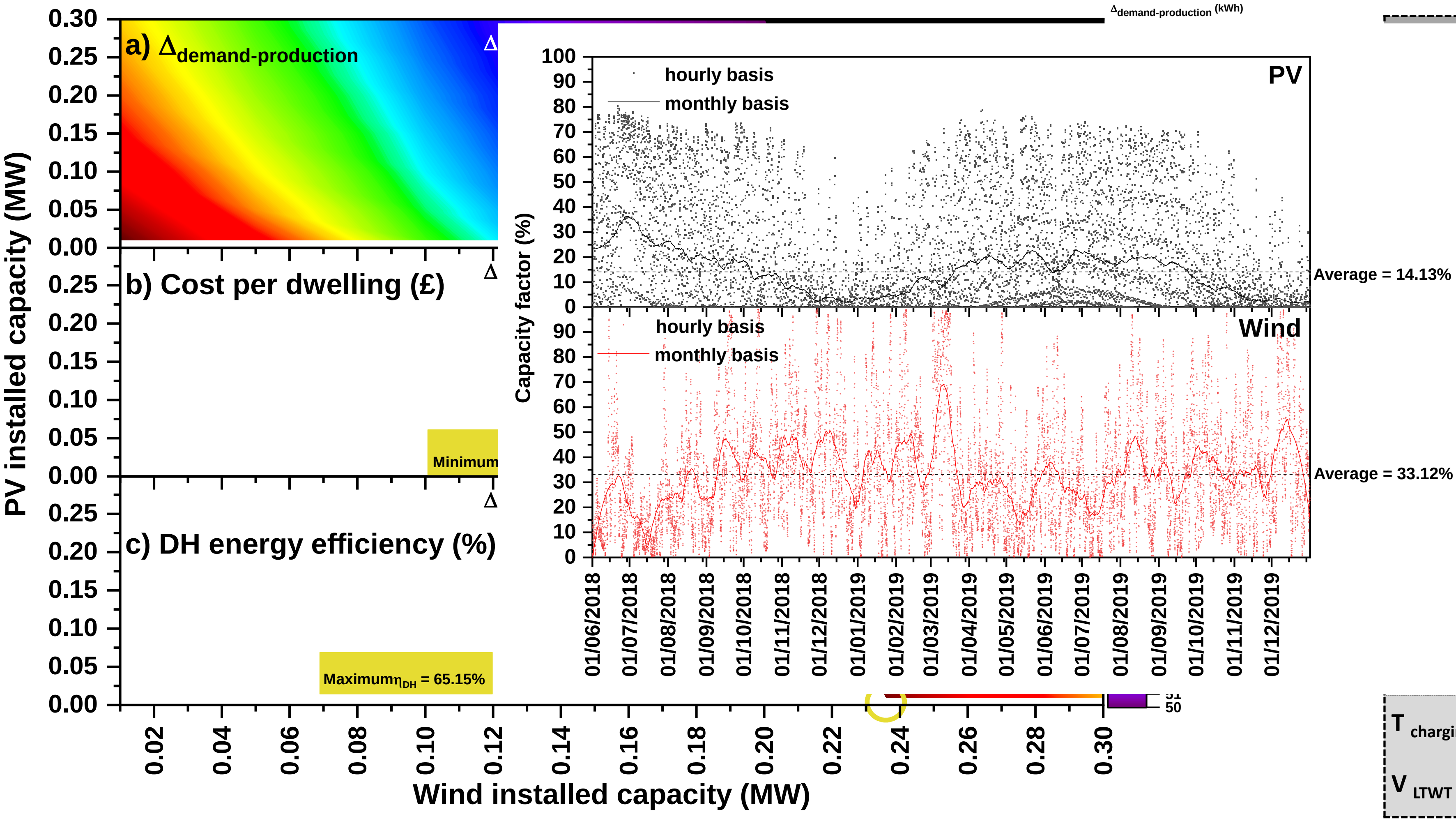
WP3. Results: Effect of PV and Wind installed capacity on i) $\boldsymbol{\Delta_{demand\text{-}production}}$, ii) cost per dwelling and iii) energy efficiency of the DH network ($\boldsymbol{\eta_{DH}}$).



main parameters	
IN DWELLINGS	
enetration into dwellings	
$C_{DWELLINGS}$	50%
C	50%
of STC per dwelling (m²)	2
enetration into dwellings	
P	50%
P	50%
IN LTWT	
THPs powered by PV?	YES
THPs powered by Wind?	YES
TSTCs?	YES

ain parameters	
$T_{charging\ LTWT}$ (°C)	80
V_{LTWT} (m³)	2500

- ✓ Minimum **cost per dwelling** and maximum **energy efficiency** obtained in $\Delta_{demand\text{-}production} \leq 0$ zone when using just Wind and **not using PV** (BUT using the other solar-based source considered in this study: **STCs**)
- ✓ This is due to the **much higher capacity factor** of Wind compared with that of PV in Loughborough for the time-period considered.