Loughborough University

LoT-NET

Advisory Board Meeting 5th October 2021

Loughborough Case Study

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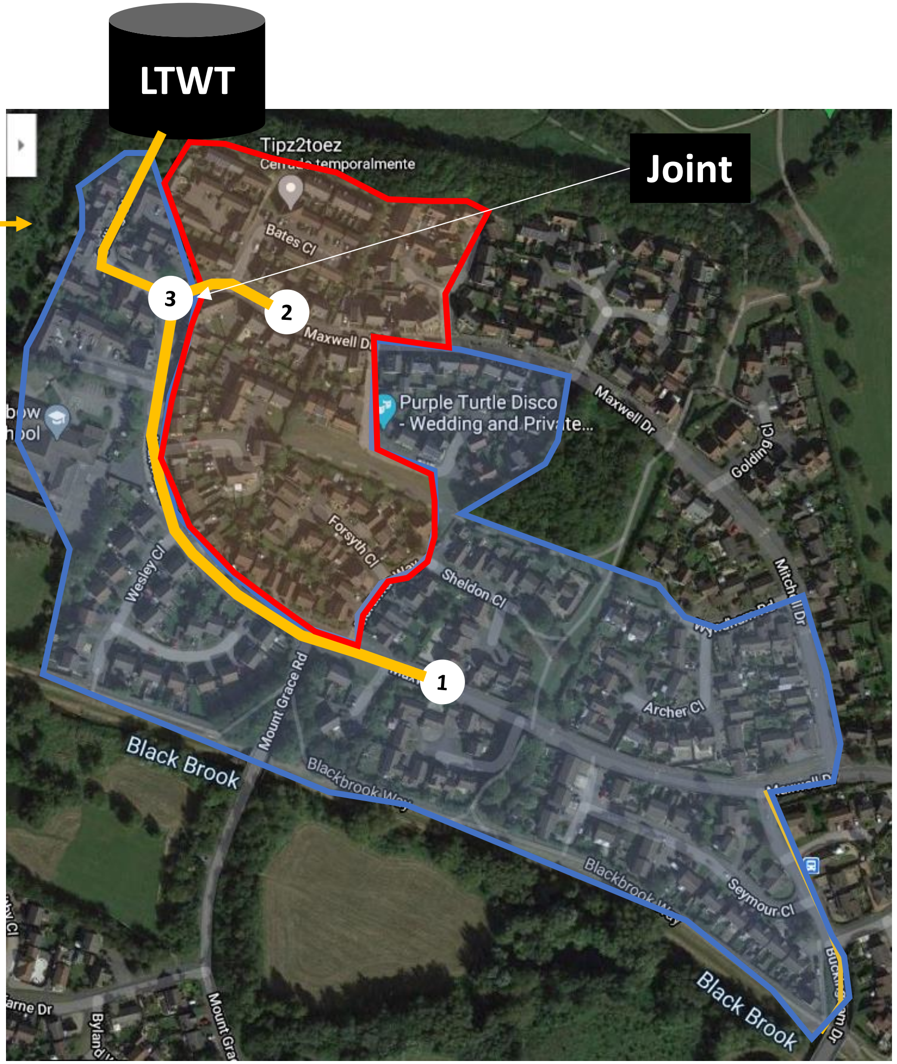
Low Temperature Heat Recovery and Distribution Network Technologies

WP3: Applications to case-study regions. Case-scenario: 2 urban areas in Loughborough, UK (262 dwellings). Inputs.

City/town	Loughborough (UK)
Time-period considered	From 01/06/2018 00:00 to 31/12/2019 23:00



	RED AREA	BLUE AREA
Dwelling type		
detached	44.90%	46.20%
semidetached	29.20%	45.10%
terraced	15.70%	7.50%
flat	10.10%	1.20%
Total number of dwellings	89	173
Household type		
One person household	**25.80%**	**17.90%**
Married couple household	**41.60%**	**49.10%**
With dependent children	24.70%	20.20%
1	6.00%	10.95%
2	14.22%	5.89%
3	4.48%	3.36%
no dependent children	16.90%	28.90%
Same sex couple	**0.00%**	**0.00%**
With dependent children	0.00%	0.00%
1	0.00%	0.00%
2	0.00%	0.00%
3	0.00%	0.00%
no dependent children	0.00%	0.00%
Cohabiting couple	**13.50%**	**14.50%**
With dependent children	3.40%	8.70%
1	0.83%	4.72%
2	1.96%	2.54%
3	0.62%	1.45%
no dependent children	10.10%	5.80%
Lone parent	**10.10%**	**16.70%**
With dependent children	9.00%	12.10%
1	2.19%	6.56%
2	5.18%	3.53%
3	1.63%	2.01%
no dependent children	1.10%	4.60%
Multiperson household	[illegible]	[illegible]

[1] Official labour market statistics, NOMIS, (n.d.). https://www.nomisweb.co.uk/.

WP3: Applications to case-study regions. Case-scenario: 2 urban areas in Loughborough, UK (262 dwellings). Inputs.

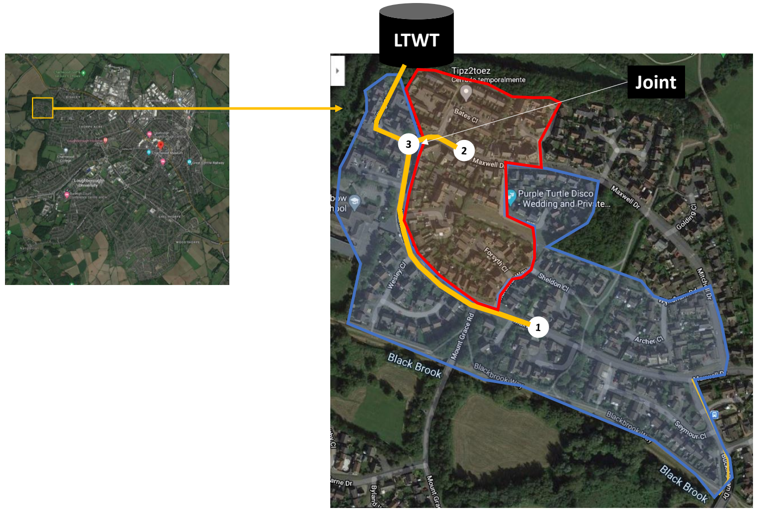
RHSs main parameters	
USED IN DWELLINGS	
Renewable power sources used to power domestic HPs	
Wind assumed installed capacity ($WIND_{DWELLINGS}$, MW)	0 – 0.5
Solar PV assumed installed capacity ($PV_{DWELLINGS}$, MW)	0 – 0.5
STCs	
$\%ETSTC_{DWELLINGS}$	50%
%FPSTC	50%
Area of STC per dwelling (m^2)	0 - 3
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)	1
TCS volume per dwelling (m^3)	1
LTWT (m^3)	Variable

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

Piping network main parameters	
Distance between Point 2 and Point 3 (m)[1]	80.5
Distance between Point 1 and Point 3 (m)[1]	291.5
Distance between Point 3 and LTWT (m)[1]	162.0
Inner diameter of pipes (m)	0.4
Thickness of pipes (m)	0.01
U-value (W/m K)	0.023[2]
Material	AluFlex[2]
Costs of variable parameters	
Variable parameters	
Installed PV (£/MW)[3]	1000000
Installed Wind (£/MW)[4]	1610000
LTWT (£/m³)[5]	50
ASHPs (£/unit)	5000
GSHPs (£/unit)	13000
HTHPs (£/kW)[7]	250
Fixed parameters	
TCS (£/m³)[8,9]	100
PCM (£/kWh)[5]	45
STWT (£/m³)[5]	30
Piping network (£/dwelling), [10,11]	800

[1] Obtain by means of google maps.



[2] M. Brand, J.E. Thorsen, S. Svendsen, Numerical modelling and experimental measurements for a low-temperature district heating substation for instantaneous preparation of DHW with respect to service pipes, Energy. (2012). https://doi.org/10.1016/j.energy.2012.02.061.

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

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

[5] 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.

[6] UK suppliers.

[7] 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.

[8] T. Yang, W. Liu, G.J. Kramer, Q. Sun, Seasonal thermal energy storage: A techno-economic literature review, Renew. Sustain. Energy Rev. 139 (2021) 110732. https://doi.org/10.1016/J.RSER.2021.110732.

[9] F. Desai, J. Sunku Prasad, P. Muthukumar, M.M. Rahman, Thermochemical energy storage system for cooling and process heating applications: A review, Energy Convers. Manag. 229 (2021) 113617. https://doi.org/10.1016/J.ENCONMAN.2020.113617.

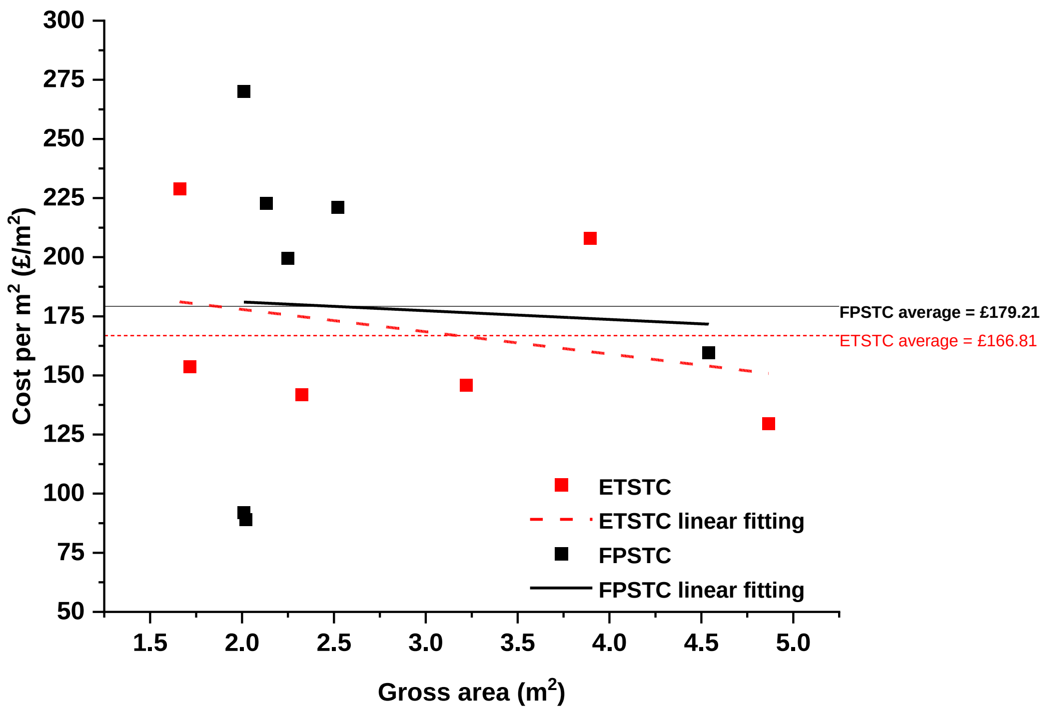
[10] Energy technologies institute, DISTRICT HEAT NETWORKS IN THE UK: POTENTIAL, BARRIERS AND OPPORTUNITIES, (2018) 1–17. www.eti.co.uk (accessed August 18, 2021).

[11] 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.

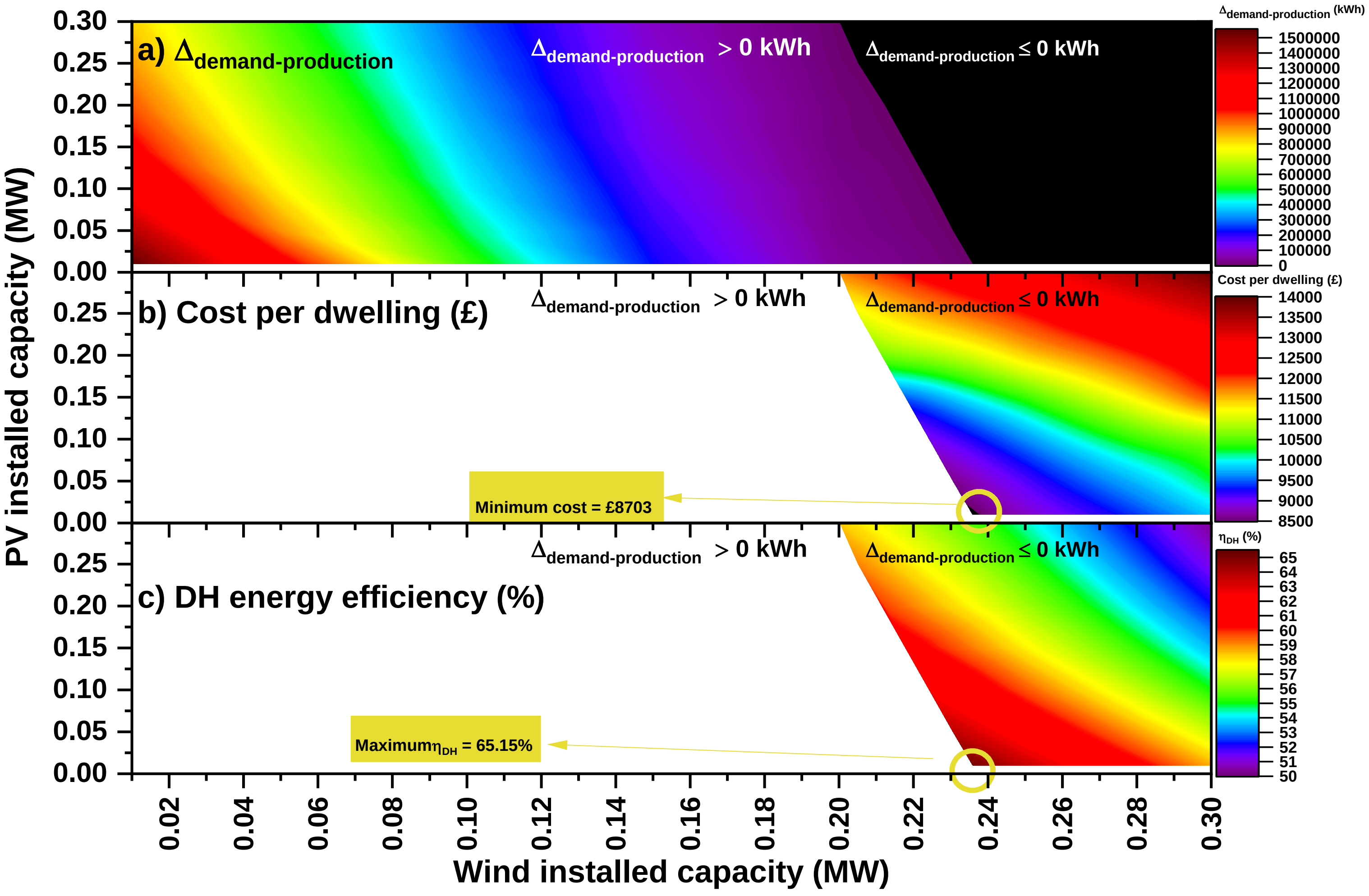
WP3: Applications to case-study regions. Case-scenario: 2 urban areas in Loughborough, UK (262 dwellings). Inputs.

Costs of variable parameters	
Solar thermal collectors	
ETSTC (£/m2)[6]	170
FPSTC (£/m2)[6]	170

Type	Manufacturer	Cost (£)	Area (m^2)	Cost per m2 (£/m2)	website
ETSTC	**Navitron**	725.0	4.54	159.7	ebay
ETSTC	**Slimline**	330.0	2.33	141.8	ebay
ETSTC	**Biasol**	264.0	1.72	153.8	ebay
ETSTC	**Consol UK**	380.0	1.66	228.9	bimblesolar
ETSTC	**Consol UK**	810.0	3.90	208.0	bimblesolar
ETSTC	**Navitron**	470.0	3.22	146.0	stoveandsolar
ETSTC	**Biasol**	630.0	4.86	129.5	ebay
FPSTC	**FPFINO**	241.0	0.89	269.9	ebay
FPSTC	**Biasol**	180.0	2.02	89.1	ebay
FPSTC	**Navitron**	475.2	2.13	222.8	ebay
FPSTC	**Navitron**	557.0	2.52	221.0	ebay
FPSTC	**PL20**	185.0	2.01	92.0	bimblesolar
FPSTC	**Sunex**	543.1	2.01	270.2	heiz24
FPSTC	**NS**	375.0	2.07	181.2	ebay
FPSTC	**Worcester**	449.0	2.25	199.6	ebay



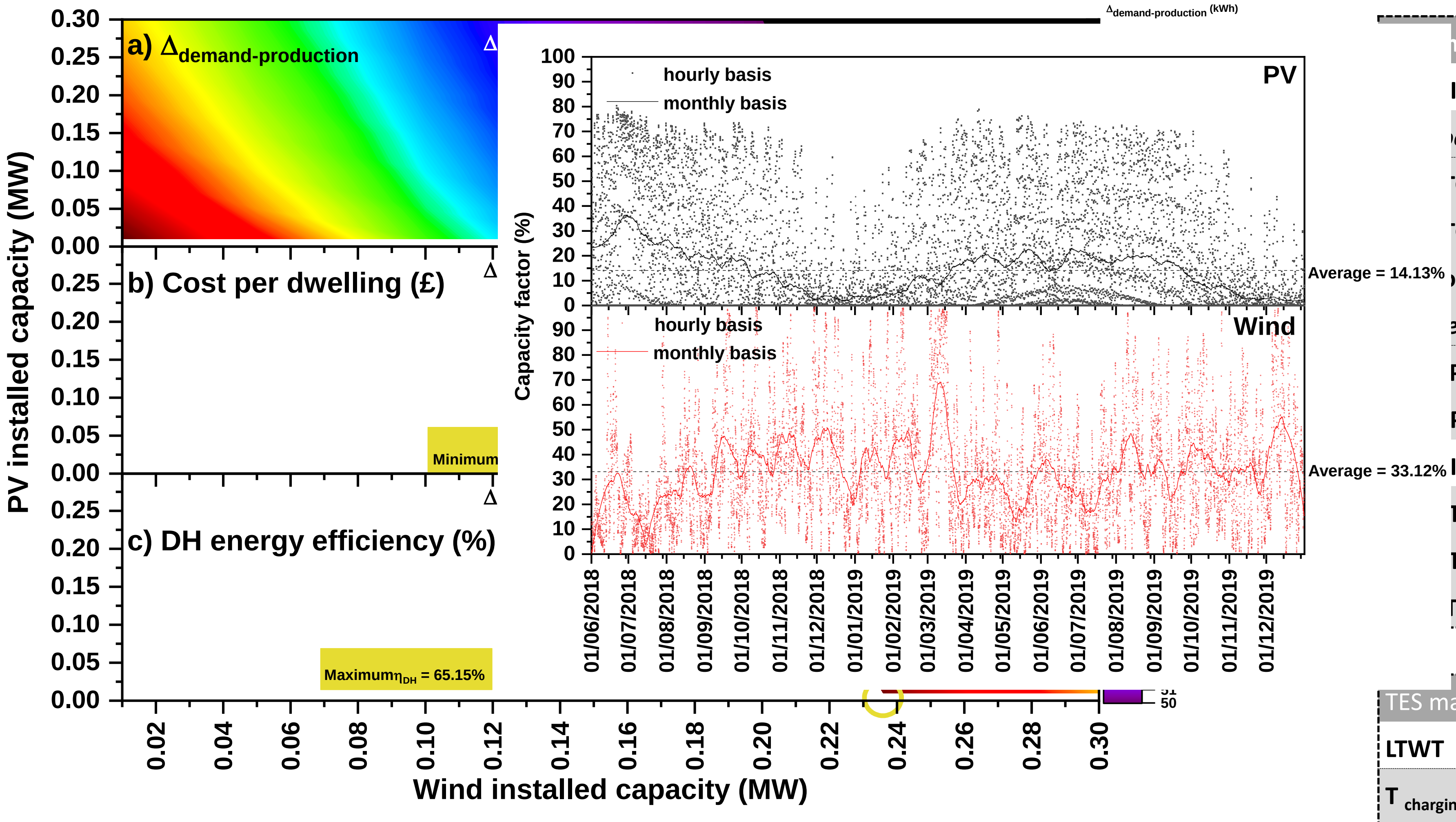
WP3. Results: Effect of PV and Wind installed capacity on i) **$\Delta_{demand-production}$**, ii) cost per dwelling and iii) energy efficiency of the DH network (**η_{DH}**).



RHSs main parameters	
USED IN DWELLINGS	
STCs penetration into dwellings	
%ETSTC$_{DWELLINGS}$	50%
%FPSTC	50%
Area of STC per dwelling (m^2)	2
HPs penetration into dwellings	
%ASHP	50%
%GSHP	50%
USED IN LTWT	
Use HTHPs powered by PV?	YES
Use HTHPs powered by Wind?	YES
Use ETSTCs?	YES

TES main parameters	
LTWT	
T $_{charging\ LTWT}$ (°C)	80
V $_{LTWT}$ (m^3)	2500

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

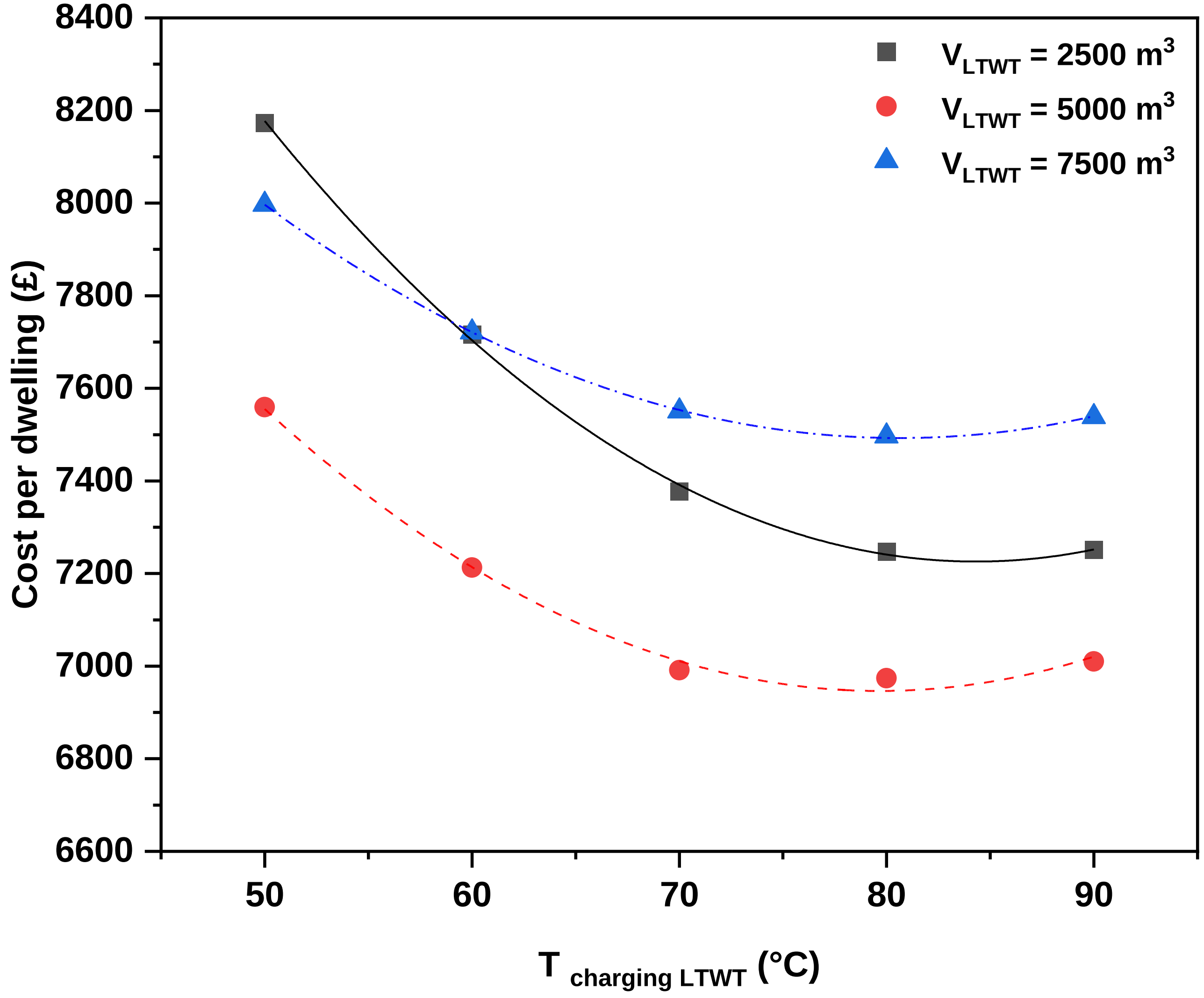


main parameters	
IN DWELLINGS	
enetration into dwellings	
$TC_{DWELLINGS}$	50%
TC	50%
of STC per dwelling (m²)	2
enetration into dwellings	
P	50%
P	50%
IN LTWT	
THPs powered by PV?	YES
THPs powered by Wind?	YES
TSTCs?	YES

TES main parameters	
LTWT	
$T_{charging\ LTWT}$ (°C)	80

- ✓ 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.

WP3. Results: Effect of i) heat sources used to charge LTWT, ii) V_{LTWT} and iii) $T_{charging\ LTWT}$ on the cost per dwelling.

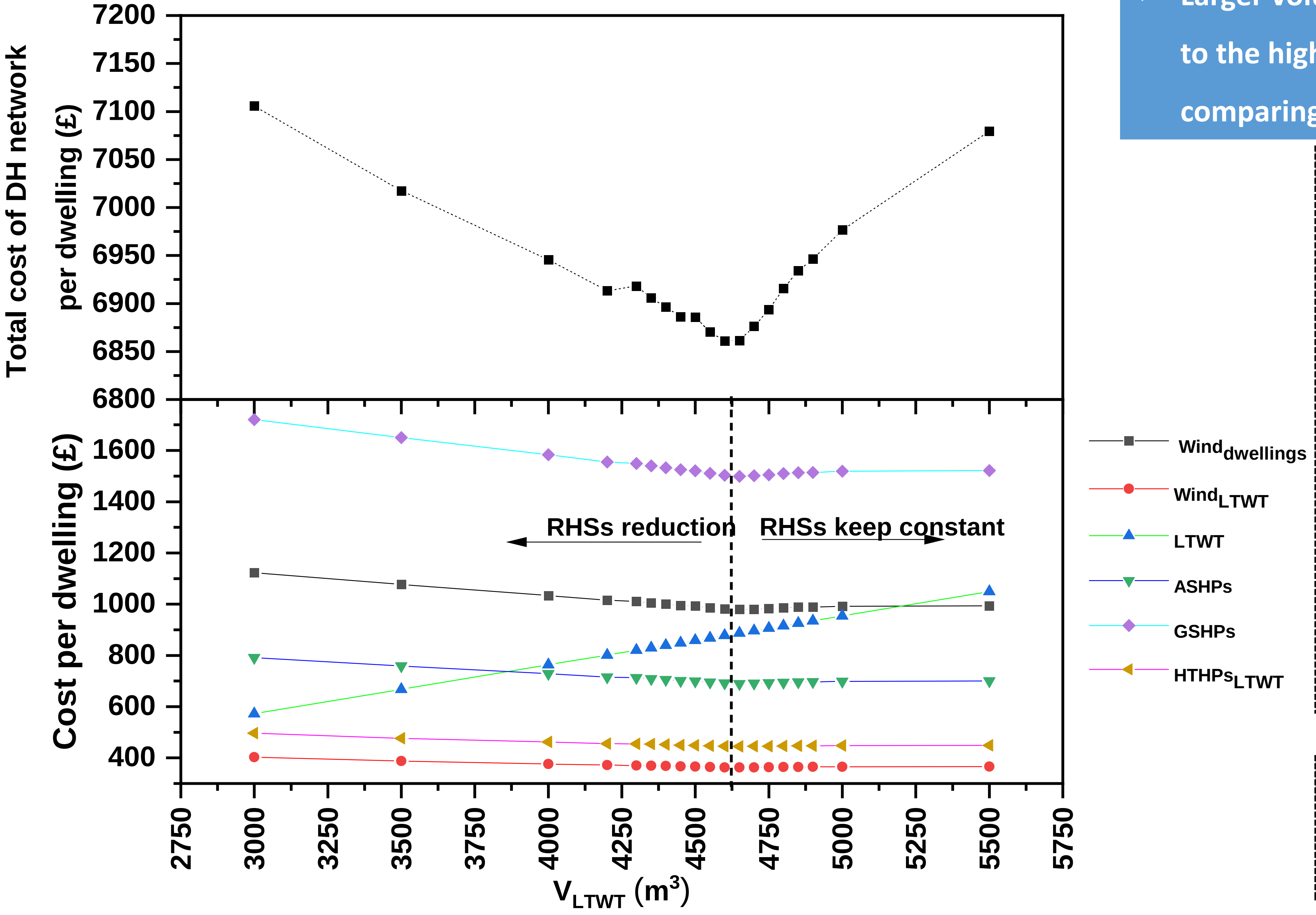


RHSs main parameters	
USED IN DWELLINGS	
STCs penetration into dwellings	
%ETSTC$_{DWELLINGS}$	50%
%FPSTC	50%
Area of STC per dwelling (m^2)	2
HPs penetration into dwellings	
%ASHP	50%
%GSHP	50%
USED IN LTWT	
Use HTHPs powered by PV?	NO
Use HTHPs powered by Wind?	YES
Use ETSTCs?	NO

✓ The cost decreases with $T_{charging\ LTWT}$ and V_{LTWT} up to ca. 5000 m^3, due to a larger storage capacity available which leads to a less heat sources capacity needed to fully meet demands.

WP3. Results: Effect V_{LTWT} on the cost per dwelling.

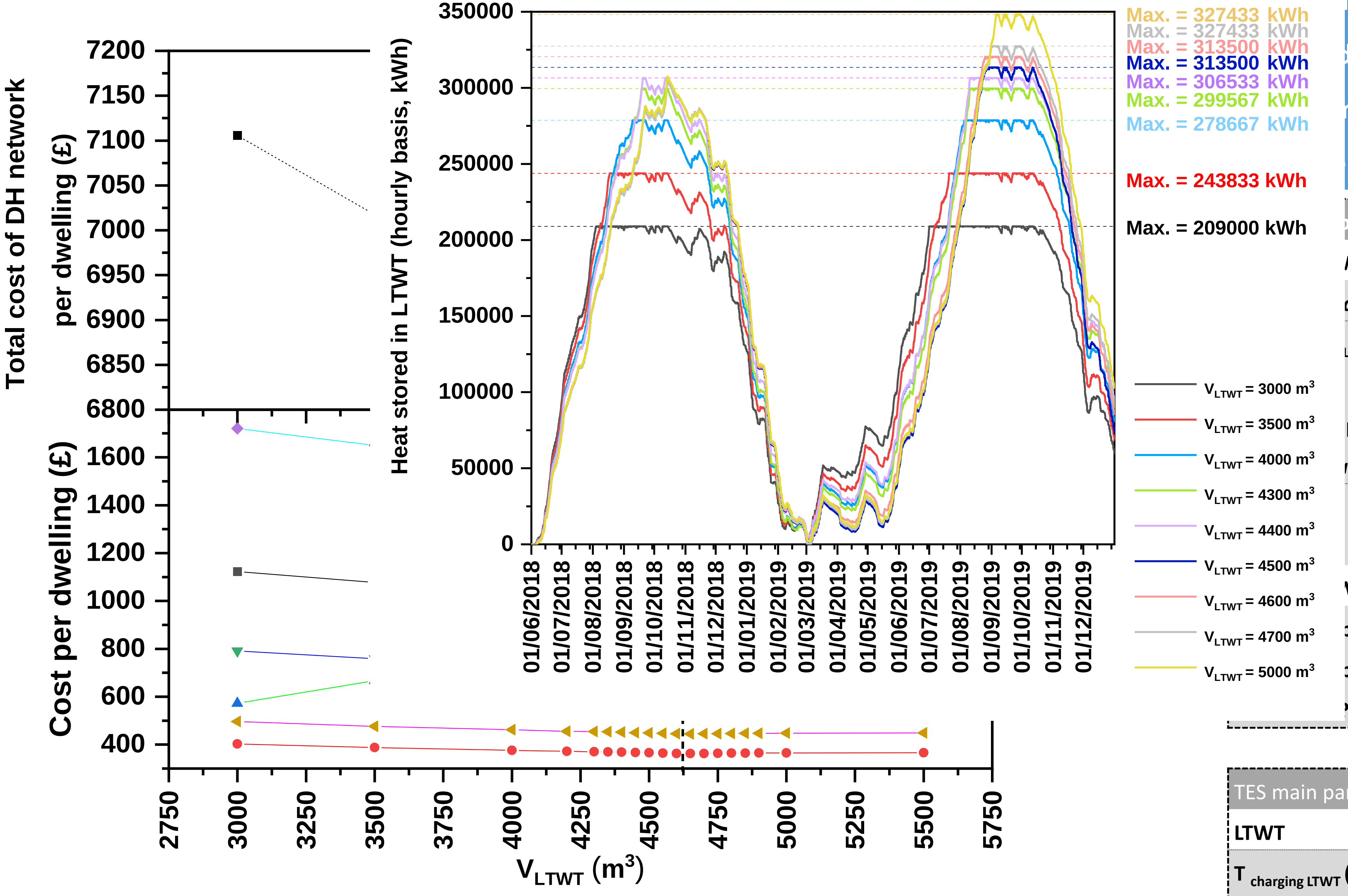
- ✓ A minimum cost was obtained for $V_{LTWT} = 4600\ m^3$.
- ✓ Larger volumes leads to an increase of the cost due to the higher increment of cost of the LTWT comparing with the reduction of the cost of RHSs.



RHSs main parameters	
USED IN DWELLINGS	
STCs penetration into dwellings	
%ETSTC$_{DWELLINGS}$	50%
%FPSTC	50%
Area of STC per dwelling (m^2)	2
HPs penetration into dwellings	
%ASHP	50%
%GSHP	50%
USED IN LTWT	
Use HTHPs powered by PV?	NO
Use HTHPs powered by Wind?	YES
Use ETSTCs?	NO

TES main parameters	
LTWT	
$T_{charging\ LTWT}$ (°C)	80

WP3. Results: Effect V_{LTWT} on the cost per dwelling.



…s obtained for V_{LTWT} = 4600 m^3.

…ds to an increase of the cost due

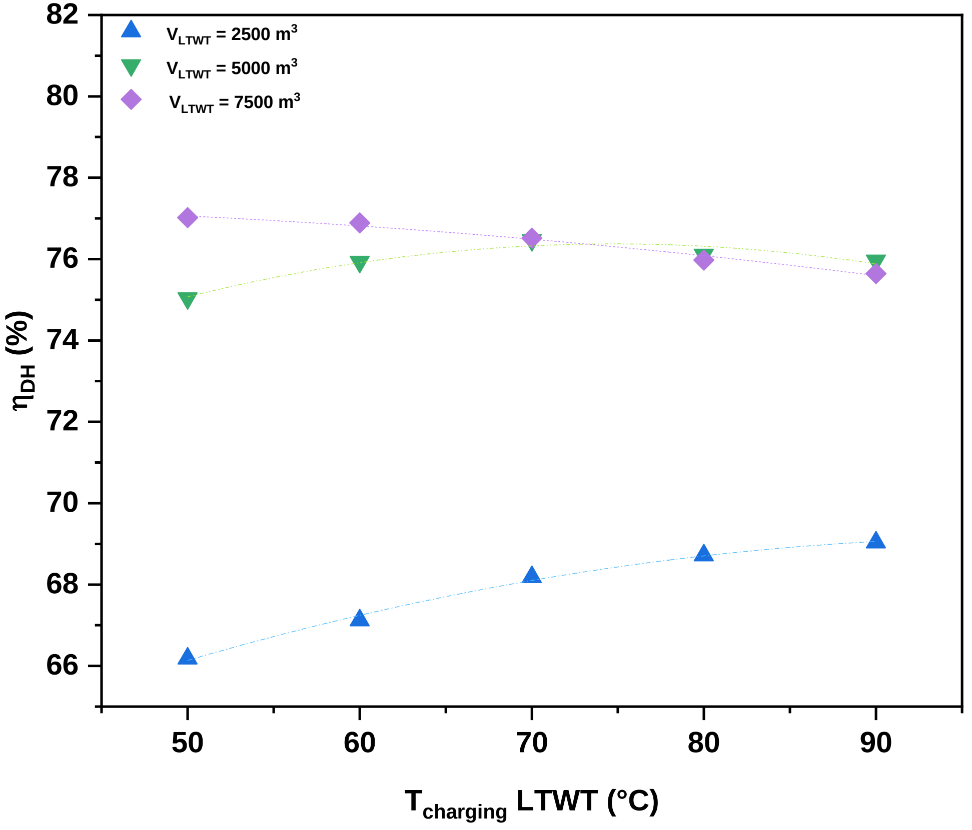
…nent of cost of the LTWT

… reduction of the cost of RHSs.

…parameters	
…ELLINGS	
…ation into dwellings	
…LINGS	50%
	50%
…per dwelling (m²)	2
…tion into dwellings	
	50%
	50%
…VT	
…powered by PV?	NO
…powered by Wind?	YES
…?	NO

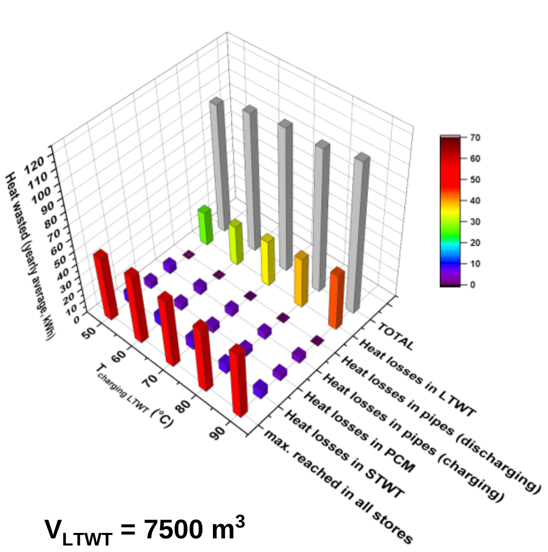
TES main parameters	
LTWT	
$T_{charging\ LTWT}$ (°C)	80

WP3. Results: Effect of i) heat sources used to charge LTWT, ii) **V_{LTWT}** and iii) **$T_{charging\ LTWT}$** on the energy efficiency of the DH network (**η_{DH}**).

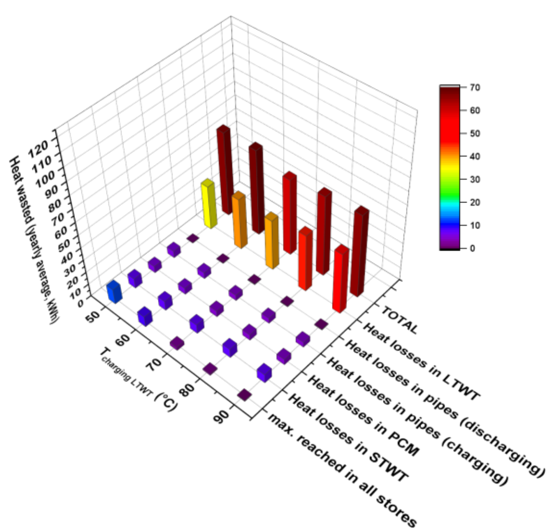


- ✓ For a V_{LTWT} = 2500 m^3, η_{DH} increases with $_{T\ charging\ LTWT}$ due to more storage room available at the tank and therefore less heat wasted due to maximum capacity reached at the store.
- ✓ For larger V $_{LTWT}$ (>5000 m^3) η_{DH} decreases with T $_{charging\ LTWT}$ due to more heat losses at the tank as a result of both i) tank not fully filled with hot water and ii) higher exposed surface of the tank.

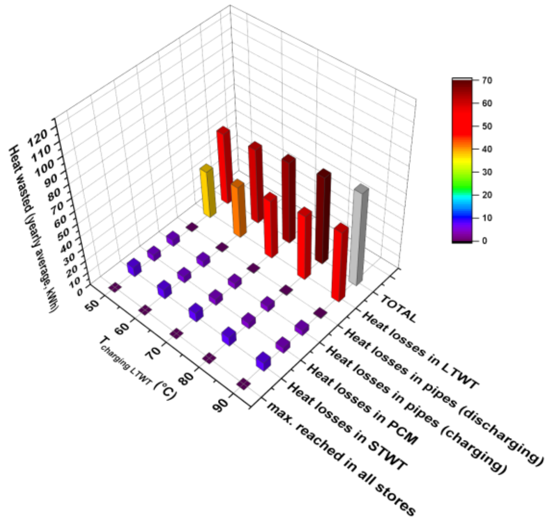
V_{LTWT} = 2500 m^3



V_{LTWT} = 5000 m^3

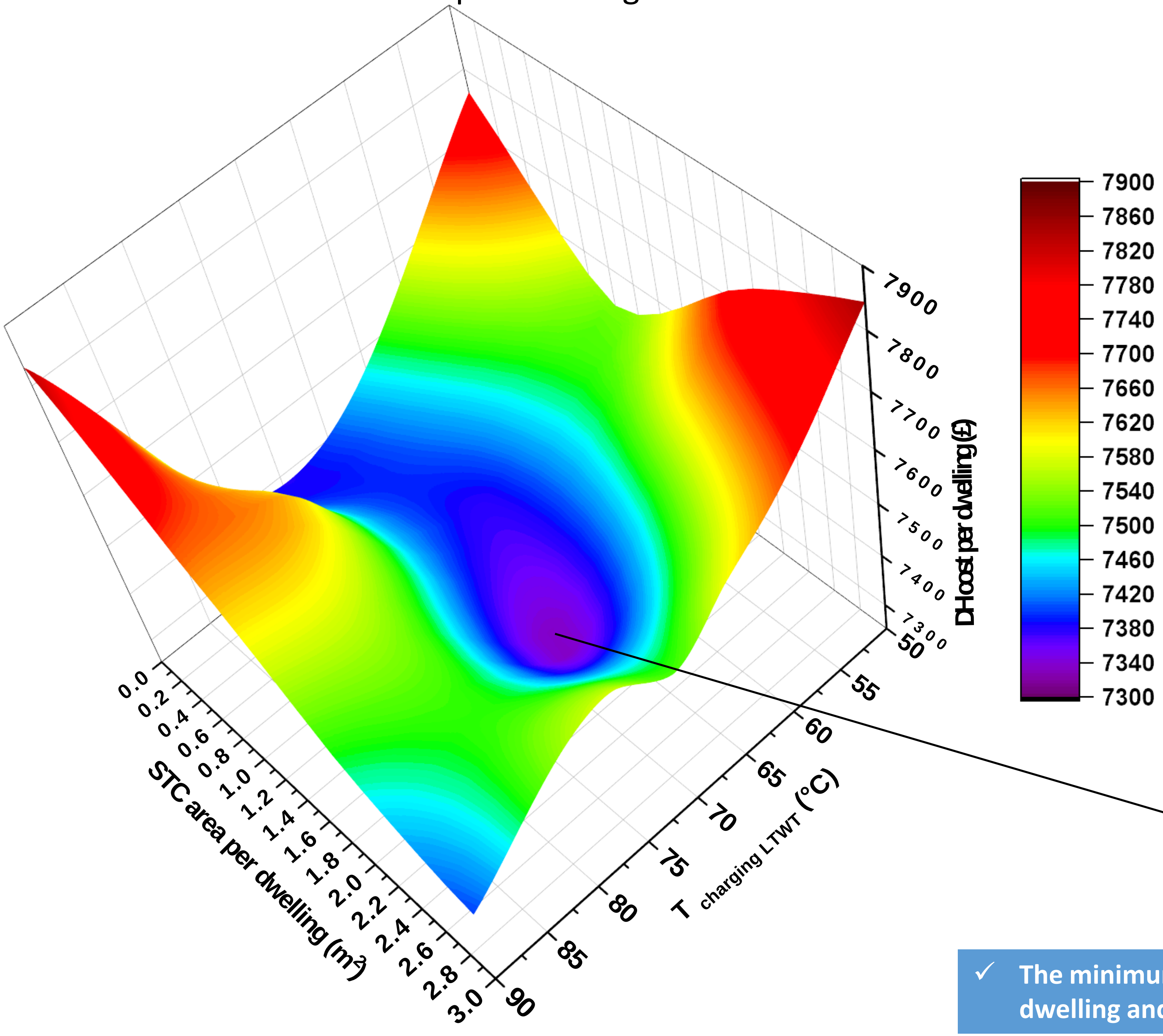


V_{LTWT} = 7500 m^3



RHSs main parameters	
USED IN DWELLINGS	
STCs penetration into dwellings	
%ETSTC$_{DWELLINGS}$	50%
%FPSTC	50%
Area of STC per dwelling (m^2)	2
HPs penetration into dwellings	
%ASHP	50%
%GSHP	50%
USED IN LTWT	
Use HTHPs powered by PV?	NO
Use HTHPs powered by Wind?	YES
Use ETSTCs?	NO

WP3. Results: Effect of STC's area per dwelling on the cost.



RHSs main parameters	
USED IN DWELLINGS	
STCs penetration into dwellings	
%ETSTC$_{DWELLINGS}$	50%
%FPSTC	50%
HPs penetration into dwellings	
%ASHP	50%
%GSHP	50%
USED IN LTWT	
Use HTHPs powered by PV?	NO
Use HTHPs powered by Wind?	YES
Use ETSTCs?	YES

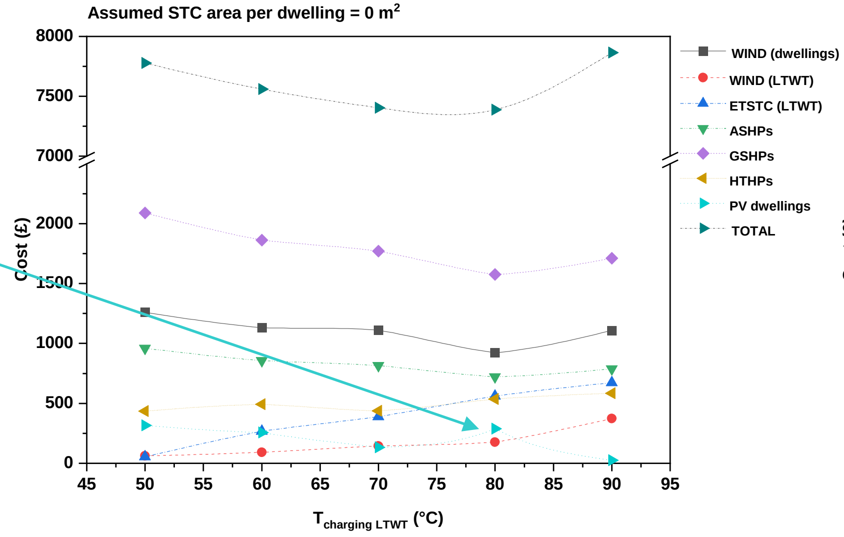
TES main parameters	
LTWT	
V $_{LTWT}$ (m^3)	5000

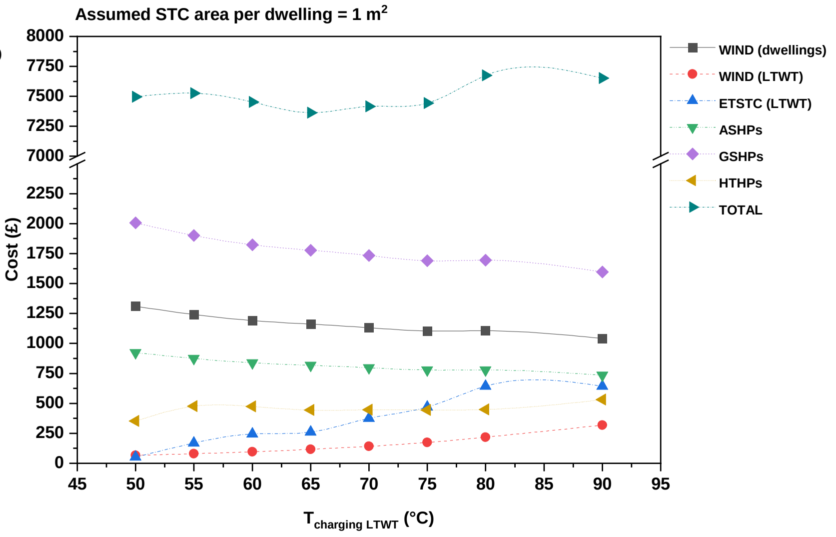
Minimum cost operating conditions	
T charging LTWT (°C)	70
STC area per dwelling (m^2)	2
Cost DH per dwelling (£)	7299

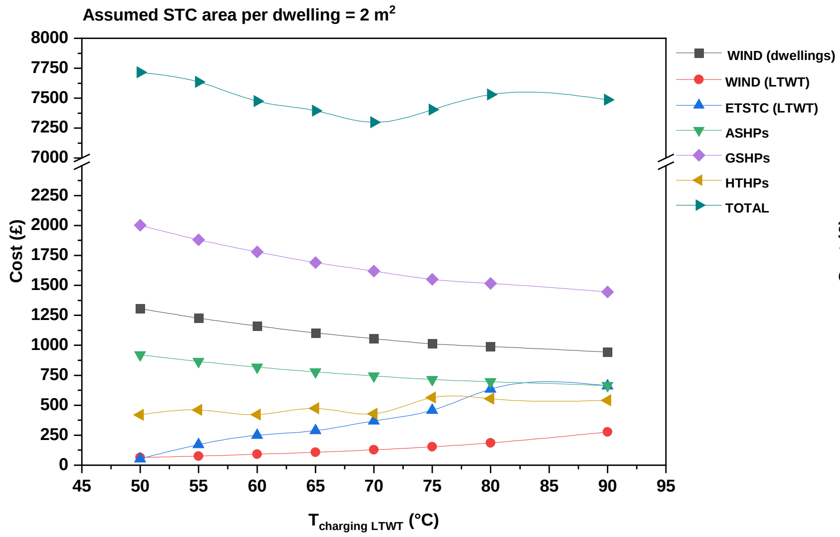
✓ **The minimum cost is obtained when using an area of STC = 2 m^2 per dwelling and a charging temperature for LTWT of ca. 70°C.**

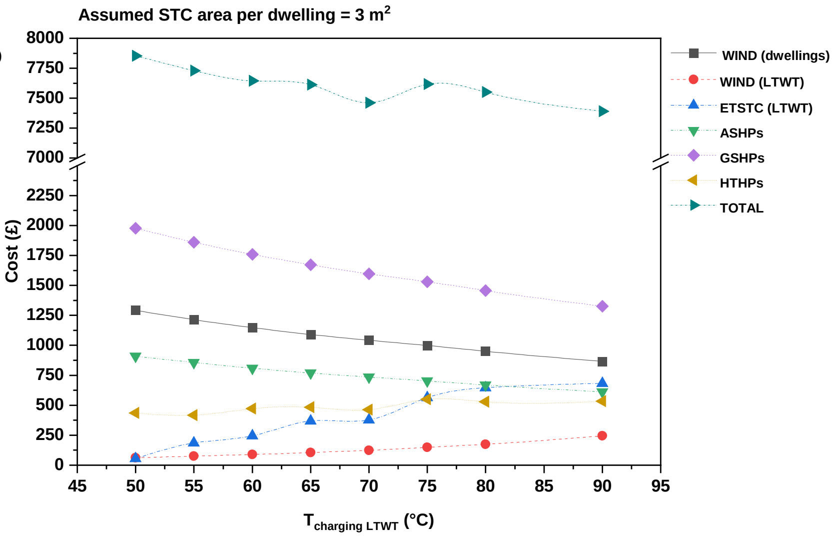
WP3. Results: Effect of STC's area per dwelling on the cost.

- ✓ When not using STCs in dwellings, a small installed capacity of PV (compared with that of Wind) is required to fully meet domestic heat loads at the beginning of the time-period considered for the simulation (June 2018), due to both low Wind-based power production efficiency in this period of the year and none heat stored at TES at the beginning of the simulation.



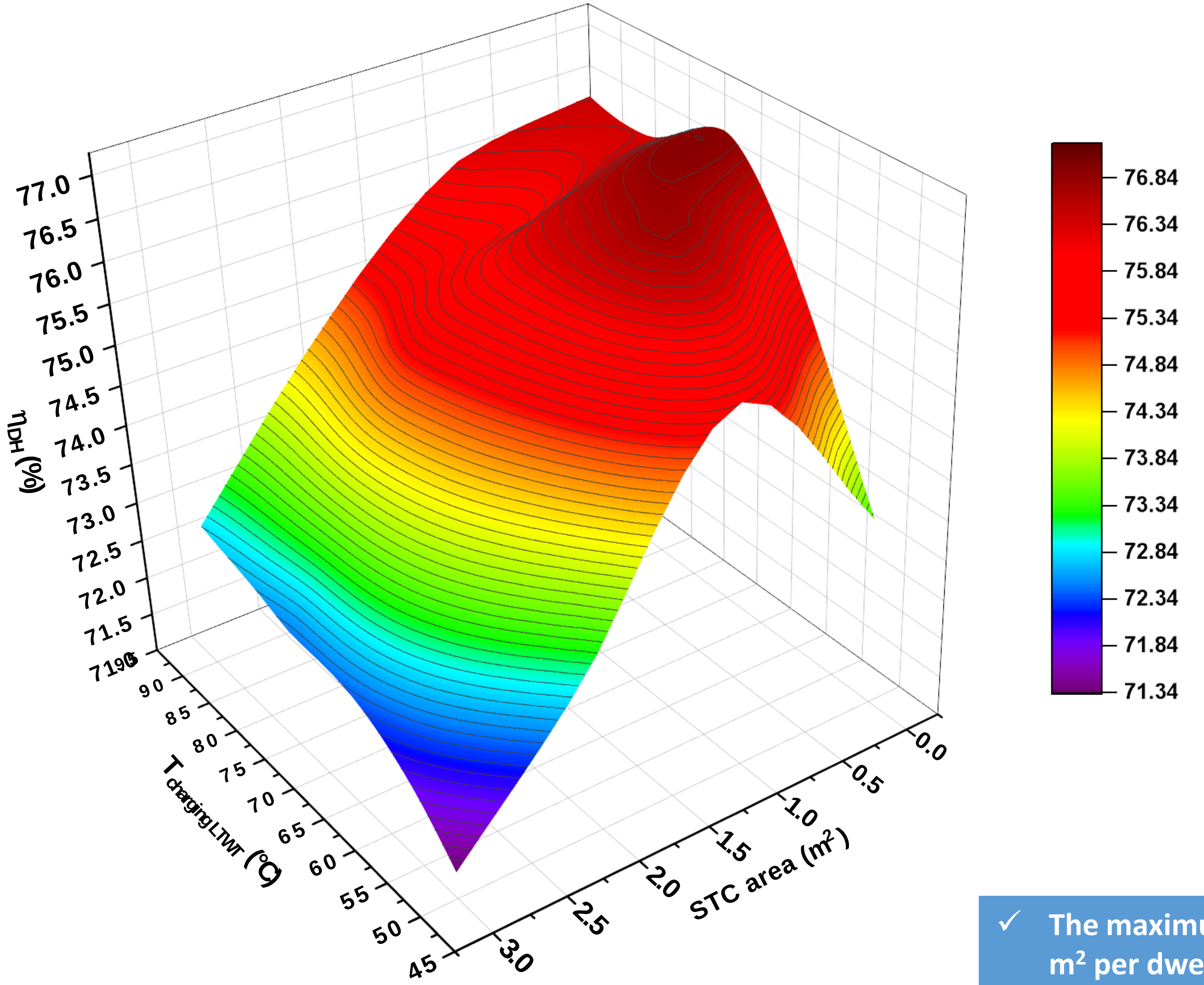






- ✓ Within the range 50-70°C, the increase of the $T_{charging\ LTWT}$ implies a decrease of the cost due to the higher storage capacity available in LTWT which leads to less RHSs needed to meet demands.
- ✓ $T_{charging\ LTWT}$ > 70°C results in a increase of the total cost due to the higher increase of the cost of the RHSs needed to lift the temperature of water before charging the LTWT than the decrease of the cost of RHSs needed to meet domestic demands.

WP3. Results: Effect of STC's area per dwelling on η_{DH}.

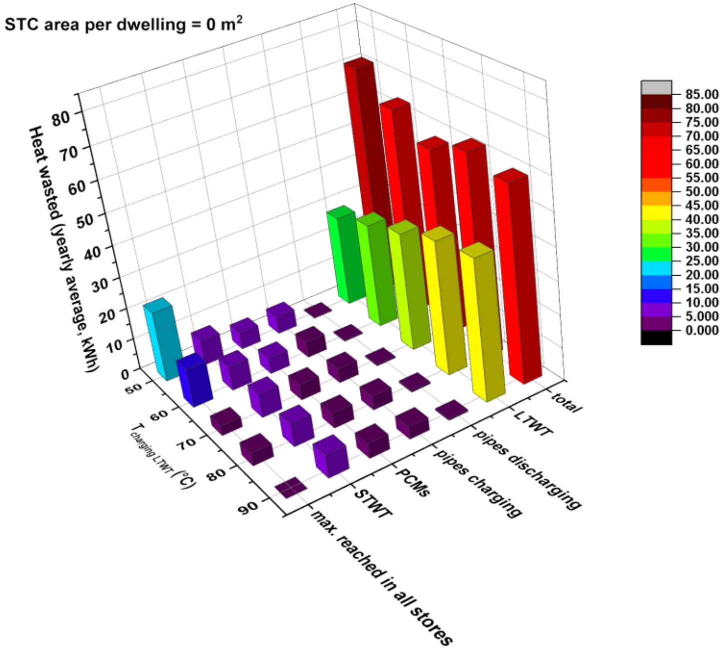


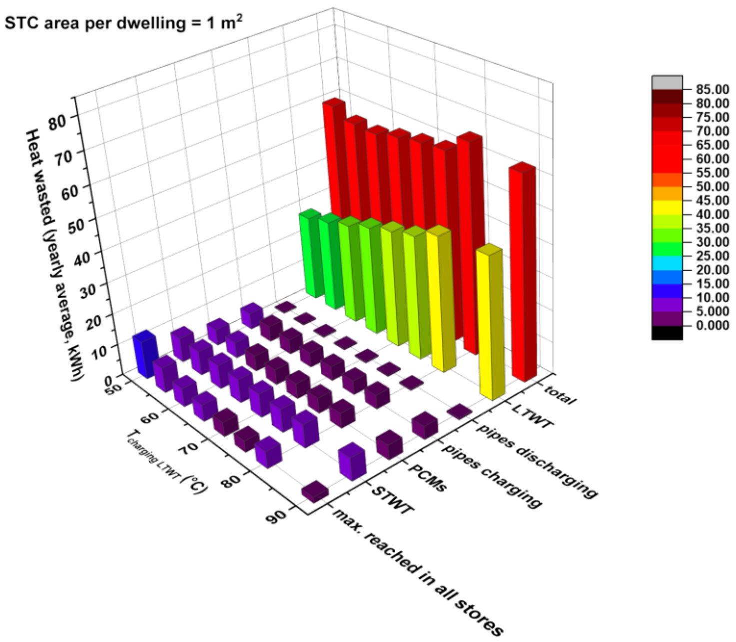
RHSs main parameters	
USED IN DWELLINGS	
STCs penetration into dwellings	
%ETSTC$_{DWELLINGS}$	50%
%FPSTC	50%
HPs penetration into dwellings	
%ASHP	50%
%GSHP	50%
USED IN LTWT	
Use HTHPs powered by PV?	NO
Use HTHPs powered by Wind?	YES
Use ETSTCs?	YES

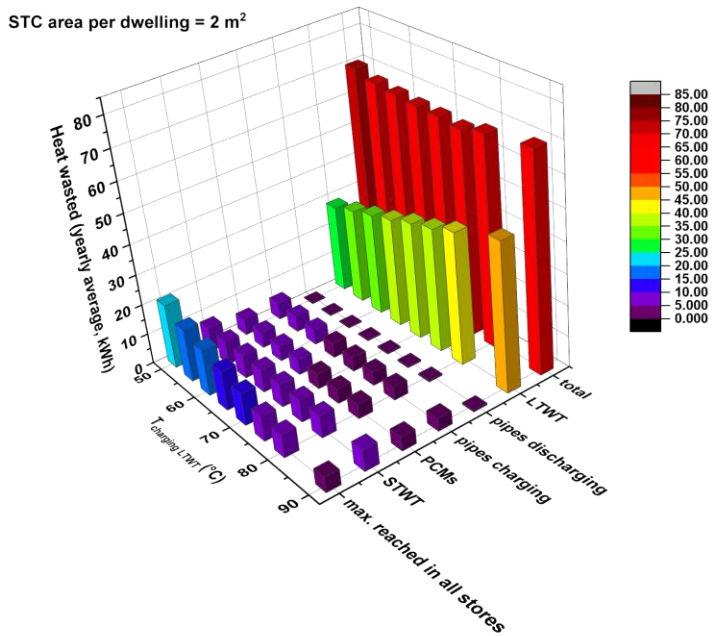
TES main parameters	
LTWT	
V $_{LTWT}$ (m³)	5000

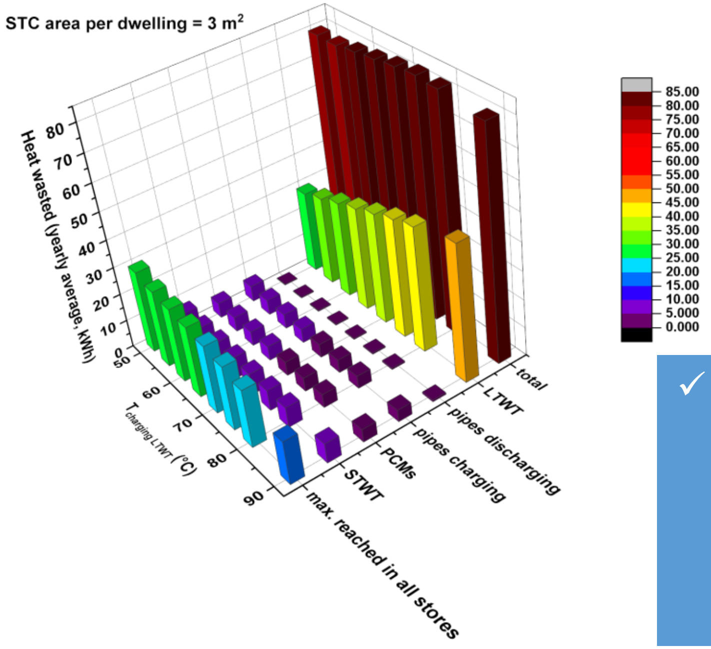
✓ **The maximum efficiency is obtained when using an area of STC = 0 m² per dwelling and a charging temperature for LTWT of ca. 70°C.**

WP3. Results: Effect of STC's area per dwelling on η_{DH}.









RHSs main parameters	
USED IN DWELLINGS	
STCs penetration into dwellings	
%ETSTC$_{DWELLINGS}$	50%
%FPSTC	50%
HPs penetration into dwellings	
%ASHP	50%
%GSHP	50%
USED IN LTWT	
Use HTHPs powered by PV?	NO
Use HTHPs powered by Wind?	YES
Use ETSTCs?	YES

TES main parameters	
LTWT	
V $_{LTWT}$ (m^3)	5000

- ✓ **The maximum efficiency obtained when using an area of STC = 0 m² per dwelling and a T $_{charging\ LTWT}$ = 70°C is due to the lower heat wasted due to maximum storage capacity reached in all TES, as a result of the low heat production by RHSs at these conditions.**

WP3. Results: Optimum results.

Simulation operating conditions						Results									
		System used to lift T before LTWT							RHSss used in dwellings		RHSss used in LTWT				
$T_{charging\ LTWT}$	V_{LTWT}	ETSTC	HTHP powered by:		Domestic STCs	η_{DH}		$\Delta_{dem-prod}$	PV	WIND	PV	WIND	HTHP	ETSTC	Cost
(°C)	(m^3)		PV	Wind	(m^2 per dwelling)	(yearly average, %)		(yearly average, kWh)	(MW)	(MW)	(MW)	(MW)	(MW)	(m^2)	(£)
70	5000	YES	NO	YES	2	75.2	TOTAL	- 190.8	0	0.1720	0	0.0209	0.449	569	£1912433
							Per dwelling	-0.7	0	6.56E-04	0	7.98E-05	1.71E-03	2.17	£7299

Main conclusions:

Methodology:

i. A cost-optimisation study of a simulated DH network at the town of **Loughborough**, **UK**, for the time period comprised between **01/06/2018 00:00** to **31/12/2019 23:00**, was undertaken.

ii. A parametrical analysis of the effect of different operating parameters of the DH network such as i) V_{LTWT} and ii) $T_{charging\ LTWT}$ on the **cost per dwelling** and η_{DH} was carried out.

iii. For each case-scenario the results were obtained by modifying both $WIND_{dwellings}$ and $PV_{dwellings}$ installed capacity in order to ensure domestic heat loads to be met for the whole time-period considered at the minimum cost.

The results showed that:

1. **HPs powered by Wind** energy and an average of **STC's area = 2 m^2 per dwelling** are the **best option** to provide heat to dwellings in the Loughborough area for the time-period considered.

2. A minimum cost of **£7023** per dwelling and a η_{DH} **= 74.39%** were obtained at the optimum conditions.

3. In general terms, an increase of the $T_{charging\ LTWT}$ 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. The increase of the V_{LTWT}, up to **4600 m^3** reduces the cost per dwelling, again due to increase of the heat storage capacity available in the LTWT which leads to less RHSs installed capacity needed to fully meet demands. Volumes larger than **4600 m^3** 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.