Supplementary Information

Forecasting how residential urban form affects the regional carbon savings and costs of retrofitting and decentralized energy supply

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Appendix A. Technology scenarios for decentralised energy supply

Table A1. The selection of decentralised heat and power technologies

These were selected for combinations of development type and area type as shown below.

	Area Type	Heat	Power		Area Type	Heat	Power
Scenario 1		Low-CO_2					
Existing	Central	Micro-CHP & gas	Micro-CHP				
	Urban	Biomass & Gas	PV & Grid				
	Suburban	Biomass & Gas	PV & Grid				
	Rural	Biomass & Gas	PV & Grid				
Intensification	Central	Small Gas CHP &NG DH Boiler	Small gas CHP	New Land	Central	Large Gas CHP & NG DH Boiler	Large gas CHP
	Urban	Biomass DH Boiler	PV & Grid		Urban	NG DH Boiler	PV & Grid
	Suburban	Biomass DH Boiler	PV & Grid		Suburban	Biomass DH Boiler	PV & Grid
	Rural	Biomass DH Boiler	PV & Grid		Rural	Biomass DH Boiler	PV & Grid
Scenario 2		Low-cost					
Existing	Central	Micro-CHP & gas	Micro-CHP				
	Urban	Biomass & Gas	Grid				
	Suburban	Biomass & Gas	Grid				
	Rural	Biomass & Gas	Grid				
Intensification	Central	Small Gas CHP &NG DH Boiler	Small gas CHP	New Land	Central	Large Gas CHP & NG DH Boiler	Large gas CHP
	Urban	NG DH Boiler	Grid		Urban	NG DH Boiler	Grid
	Suburban	Biomass & Gas	Grid		Suburban	Biomass DH Boiler	Grid
	Rural	Biomass & Gas	Grid		Rural	Biomass DH Boiler	Grid
Scenario 3		Highly-electric with district heating (DH)					
Existing	Central	Micro-CHP & gas	Micro-CHP				
	Urban	GSHP	Grid				
	Suburban	GSHP	Grid				
	Rural	GSHP	Grid				
Intensification	Central	Small Gas CHP &NG DH Boiler	Small gas CHP	New Land	Central	Large Gas CHP & NG DH Boiler	Large gas CHP
	Urban	GSHP	Grid		Urban	GSHP	Grid
	Suburban	GSHP	Grid		Suburban	GSHP	Grid
	Rural	GSHP	Grid		Rural	GSHP	Grid
Scenario 4		Highly-electric with resistive heating (for New-build only)					
Intensification	Central	Small Gas CHP & Resistive Heater	Small gas CHP	New Land	Central	Large Gas CHP & Resistive Heater	Large gas CHP
	Urban	Resistive Heater	Grid		Urban	Resistive Heater	Grid
	Suburban	Resistive Heater	Grid		Suburban	Resistive Heater	Grid
	Rural	Resistive Heater	Grid		Rural	Resistive Heater	Grid

Key:

CHP	*Combined heat and power*
DH	*District heating*
GSHP	*Ground source heat pumps*
NG	*Natural gas*
PV	*Photovoltaic*

Table A2. Typical percentages of decentralised supply per area type

The percentages shown are indicative and differed between tile types and area types

Scenario		Low densities				High densities			
		Heat (%)		Electricity (%)		Heat (%)		Electricity (%)	
		Central areas	Other areas	Central areas	Other areas	Central areas	Other areas	Central areas	Other areas
Existing	Low-CO_2	24	23	30	15	50	22	30	11
	Low-cost	24	23	30	0	50	22	30	0
	Highly-electric	24	24	30	0	40	23	30	0
New-build	Low-CO_2	30	30	30	22	30	30	30	10
	Low-cost	30	30	30	0	30	30	30	0
	Highly-electric D.H.	30	100	30	0	30	95	30	0
	Resistive heating	30	0	30	0	30	0	30	0

Table A3. Low carbon technologies tested and their requirements

Technology	Requirements	Comments	Typical cost of one unit	Typical size in kW
Photo-voltaic	Roof or space facing SE/SW	Can export electricity if connected to grid, more cost effective if high on-site demand	£5k to £25k upwards	1 to 4 upwards
Ground source heat pump	Land area for ground collector or a water source	Building with a space heating (and possibly cooling) demand and low temperature heating system (e.g. under-floor)	£5k to £25k upwards	3.5 kW to 15 kW upwards
Micro-CHP	Domestic or communal space	Proportional heat and electricity demand, scope for heat network	£500 to 800 /kWe and £660/kWe	kW to MW [1]
Resistive heater	Open floor space	Building with minimum heating demand, highly-electric future	£30 to 50 /kW	W to kW [1]
CHP & District Heating	Communal space	Higher concentration of heat and electricity demand and their proportionality, scope for networking	£650 to 850 /kWe	kW to MW [1]
Biomass & gas	Domestic space	Fuel supply network	£500/kW	kW [1]

[1] These systems were sized to the on-site requirements by selecting the nearest available manufactured size.

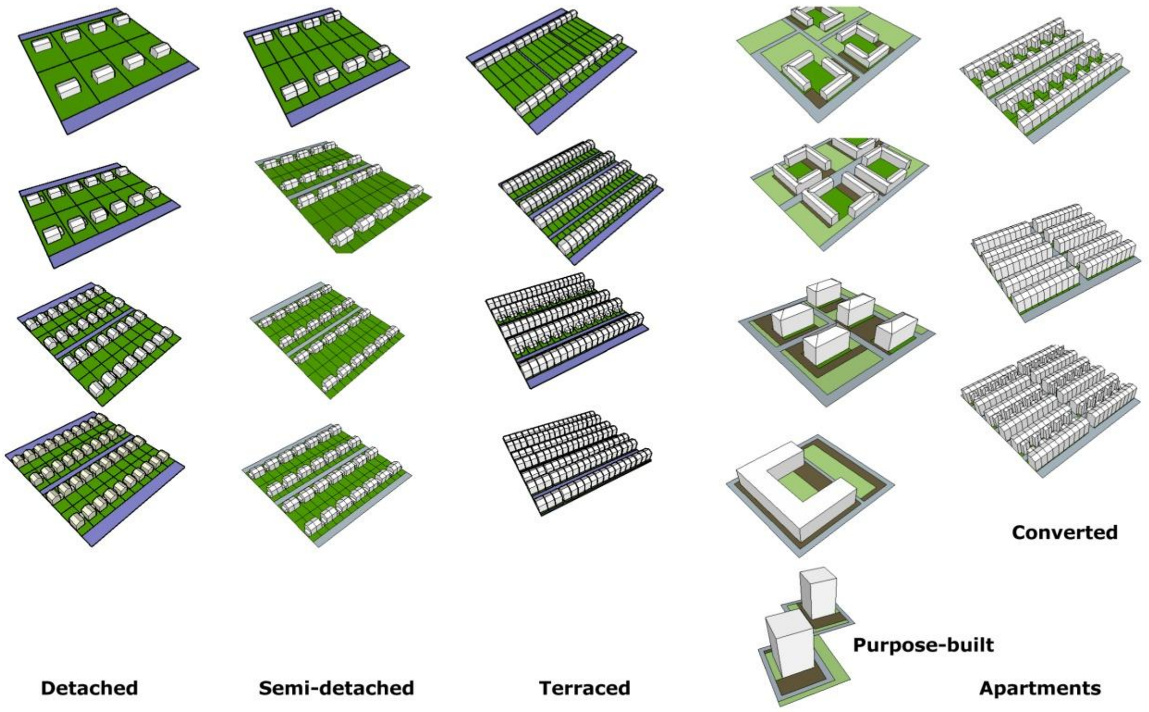

Fig. A1. Schematic illustration of the tiles

Table A4: A subset of the built form data per tile type

Table A4a. Tile data per house (Figure A1 illustrates the tile types)

Dwelling type	Tile Type	Tile Density (dph)	Floor space (sq.m)	Total garden (sq.m.)	Rear garden (sq.m.)	Rear garden soft surface	Top floor roof (sq.m.)	Roads & paths % of tile
Detached	D1	7	234	1131	633	80%	117	14%
	D2	12	191	610	362	80%	87	14%
	D3	23	133	258	140	70%	58	22%
	D4	30	120	184	103	60%	54	24%
Semi-detached	S1	13	126	562	407	75%	63	16%
	S2	23	105	299	198	70%	47	19%
	S3	31	95	196	124	65%	41	22%
	S4	42	85	119	69	60%	37	30%
Terraced	T1	22	106	280	215	65%	53	25%
	T2	68	86	57	42	30%	43	32%
	T3	90	68	25	21	15%	30	43%
	T4	109	62	14	8	5%	31	51%

Table A4b. Tile data for apartments (Figure A1 illustrates the tile types)

Dwelling type	Tile Number	Tile Density (dph)	Floor space per dwelling (sq.m.)	Garden area per block (sq.m.)	Roof area per block (sq.m.)	Pitched roof (%)	Green space (%) of tile	Roads & paths % of tile
Purpose built	F1	77	69	686	549	100%	30%	23%
	F2	101	66	568	662	90%	23%	27%
	F3	164	53	61	259	75%	13%	28%
	F4	216	51	0	2350	55%	27%	21%
	F5	330	62	0	587	0%	29%	26%
Converted	C1	162	70	69	74	100%	0%	23%
	C2	277	57	25	58	100%	0%	38%
	C3	374	59	11	61	100%	0%	35%

Table A5. Suitability of the technologies tested for the tile types

Table A5a. Suitability Table for Existing houses

Area Type	Technology	Tile Types											
		D1	D2	D3	D4	S1	S2	S3	S4	T1	T2	T3	T4
Central	Micro-CHP & gas	√	√	√	√	√	√	√	√	√	√	x	x
	Micro-CHP & biomass	√	√	√	√	√	√	√	√	√	√	x	x
Urban, Sub-urban & Rural	Biomass & gas	√	√	√	√	√	√	√	√	√	√	x	x
	GSHP	√(H)	√(H)	√(H)	√(H)	√(H)	√(H)	√(H)	x(V)	√(H)	x(V)	x(V)	x(V)
	PV	√	√	√	√	√	√	√	√	√	√	√	√

Table A5b. Suitability Table for Existing apartments

Area Type	Technology	Tile Types							
		F1	F2	F3	F4	F5	C1	C2	C3
Central	Micro-CHP & gas	√	x	x	x	x	√	x	x
	Micro-CHP & biomass	√	x	x	x	x	√	x	x
Urban, Sub-urban & Rural	Biomass & gas	√	x	x	x	x	√	x	x
	GSHP	√(H)	√(H)	x(V)	x(V)	x(V)	x(V)	x(V)	x(V)
	PV	√	√	√	√	√	√	√	√

Key:

√	The technology outputs are suitable for this tile type
x	The technology outputs are unsuitable for this tile type
√(H)	Suitable for the horizontal GSHP systems tested
x(V)	Unsuitable because only vertical GSHP would be feasible (not tested for this case study)

Table A5c. Suitability Table for New-build houses

Area Type	Technology	Tile types											
		D1	D2	D3	D4	S1	S2	S3	S4	T1	T2	T3	T4
Central	Gas CHP & NG DH boiler	x	x	x	x	x	x	x	x	x	√	√	√
	Gas CHP & resistive heating	x	x	x	x	x	x	x	x	x	√	√	√
Urban	NG DH boiler	x	x	x	x	x	x	x	x	x	√	√	√
Urban, Sub-urban & Rural	Biomass DH boiler	x	x	x	x	x	x	x	x	x	√	√	√
	GSHP DH	√(H)	√(H)	√(H)	√(H)	√(H)	√(H)	√(H)	x(V)	√(H)	x(V)	x(V)	x(V)
	Resistive heating	√	√	√	√	√	√	√	√	√	√	√	√
	PV	√	√	√	√	√	√	√	√	√	√	√	√

Table A5d. Suitability Table for New-build apartments

Area Type	Technology	Tile types							
		F1	F2	F3	F4	F5	C1	C2	C3
Central	Gas CHP & NG DH Boiler	√	√	√	√	√	√	√	√
	Gas CHP & resistive heating	√	√	√	√	√	√	√	√
Urban	NG DH Boiler	√	√	√	√	√	√	√	√
Urban, Sub-urban & Rural	Biomass DH boiler	√	√	√	√	√	√	√	√
	GSHP DH	√(H)	√(H)	x(V)	x(V)	x(V)	x(V)	x(V)	x(V)
	Resistive heating	√	√	√	√	√	√	√	√
	PV	√	√	√	√	√	√	√	√

Key:
√ The technology outputs are suitable for this tile type
x The technology outputs are unsuitable for this tile type
√(H) Suitable for the horizontal GSHP systems tested
x(V) Unsuitable because only vertical GSHP would be feasible (not tested for this case study)

Appendix B. Further details of the tiles method

B1. Regional spatial planning forecasts

There were planning projections available from TEMPro [1] which was based on the land use transport interaction modelling for the National Transport Model of the UK Department for Transport. These projections included households, jobs and population that were spatially disaggregated into TEMPro zones and produced in consultation with the local authorities (each local authority district consists of several TEMPro zones). The local planning authorities produce local development frameworks with policies on densities for future development in different parts of their District. This information was combined with the planning projections to deduce the local authority expectations of housing capacity and densities per electoral ward to thereby derive an estimate of the future residential land available within urban areas. (Estimating future land and housing capacities outside urban areas is less problematic due to fewer constraints.)

The total future residential land a_i per ward i included the Existing-areas a_{ei} and the estimates of New-land a_{hi}. The increase in households h_i over the forecast period to year 2031 was allocated to this New-land based on density targets of local authority planning policies. Surplus households were accommodated by the intensification of Existing-areas, so that:

$$a_i = a_{fi} + a_{gi} + a_{hi} \tag{1}$$

Where:
a_{fi} = Estimate of Existing residential land remaining in year 2031
a_{gi} = The Existing residential land that would be redeveloped by Intensification
$a_{fi} + a_{gi} \equiv a_{ei}$

Hence there were three development types *j* that consisted of Existing, Intensification and New-land.

A LUTI model could be used to test alternative spatial planning policies by changing the inputs of the constraints on land available per area. The rate of intensification per ward was constrained within the LUTI model so that this did not exceed the empirically evidence of what would be achievable and acceptable in practice. This depended on the planning policy and area type. Any remaining surplus was allocated within the model to other nearby areas.

B2. Generating the tiles to represent the future dwelling stock

The forecast of average density d_{ij} was converted into a representation of the future dwelling stock h_{ij} by systematically selecting from a set of one-hectare tiles (Section 2.2) using the tiles method [2], where:

$$h_{ij} = d_{ij}.a_{ij} \tag{1}$$

We considered that having just 20 tile types was sufficient to demonstrate the method with our limited time and resources. More tile types could be added to increase the accuracy of approximating the distribution of dwelling plot densities. However, this would have increased the amount of time needed for the building-scale modelling of energy consumption and supply for the various combinations of technology scenario, area type and development type per tile type.

The number of tiles n_t selected of each tile type t can be any rational positive number (e.g. fractions of one-hectare). The tiles were systematically selected to represent the dwellings forecast and land constraints:

$$h_{ij} = \sum_{t=1}^{t=20} z_{t.} n_{tij} \tag{2}$$

$$a_{ij} \cong \sum_{t=1}^{t=20} n_{tij} \tag{3}$$

Where:
$z_t = tile\ density\ of\ tile\ type\ t$

B3. Modelling the energy demands and consumption per tile

The application of the building energy model [3] is described in Section 2.3. There were four energy demand scenarios *e* per tile type for year 2031; one for New-build and three for Existing dwellings i.e., without retrofitting, 'low CO_2' retrofitting and 'low cost' retrofitting. Outputs included the fuel mix of gas, oil, solid fuel, biomass and electric for space heating, water heating, cooking and electrical power per tile type. The monthly heat and electricity demands were aggregated to annual Kw/hr per dwelling and the demands per tile calculated based on the tile density z_t. The energy demands for Existing dwellings were converted into energy consumption per fuel type using the heating efficiency factors in SAP 2005 [4]. It was assumed that there would be on average a 10% improvement in the efficiency of conventional boiler heating systems over the forecast period.

B4. Energy supply outputs per tile

The method of modelling the energy supply per tile is outlined in Section 2.4 and Appendix C. There were four energy supply scenarios for Existing dwellings i.e.: conventional supply only; or with the three technology scenarios shown in Table A1. There were five energy supply scenarios for New-build dwellings i.e.: conventional supply only, or the four technology scenarios shown in Table A1. These technologies for New-build differed depended on the development type *j* (Intensification or New-land). The energy scenarios per development type were modelled as a combination of the energy demand scenarios *e* and the energy supply scenarios *s* (there were therefore 3x4= 12 combinations for Existing dwellings, and 5 for Intensification and 5 for New-land). The selection of the energy supply technologies differed depending on the 'area type' *k* (4 types) and development type *j* (3 types). The outputs per tile included CO_2 emissions, capital & operating costs, overall supply cost, (and land take – not presented). Therefore, each was produced as 'lookup' tables of outputs x for the forecast year as an array: x_{tesjk}.

B5. Taking into account the uptake assumptions

For energy supply, the technology uptake assumptions were taken into account when designing the system sizes per tile type as explained in Section 2.4. Examples of the percentages of decentralised supply are shown in Table A2. However, energy demands were modelled per dwelling either with, or without the retrofitting for energy efficiency.

The uptakes per tile for the demand and supply were therefore combined as follows:

$$x = (1-u)x_1 + u.x_2 \tag{5}$$

Where:
$x_1 = energy\ supply\ outputs\ for\ unretrofitted\ dwellings$
$x_2 = energy\ supply\ outputs\ for\ retrofitted\ dwellings$
$u = proportion\ of\ retrofitted\ dwellings$

For this case study, u=0.4 for Existing dwellings and u=zero for New-build

B6. Outputs per area

The outputs per tile *t* for the required scenario were aggregated per electoral ward *i*. The tile outputs could easily be aggregated to a larger spatial area and, or by development type j or area type *k*.

$$x_{iesj} = \sum_{t=1}^{t=20} n_{tj} . x_{tesjk} \qquad (6)$$

The output per capita $= {}^{x_{iesj}}/_{p_{ij}}$

Where: $p_{ij} = population\ forecast\ for\ development\ type\ j\ in\ ward\ i$

B7. Assessment of cost effectiveness

The reference case for the assessment was the tiles with conventional supply only, and the alternative case was the tiles with the decentralised technologies included. The cost effectiveness was calculated as the cost of a one tonne reduction of CO_2 emissions, as follows:

$$\text{Cost effectiveness} = \frac{(Cost_{alt} - Cost_{ref})}{(CO2_{ref} - CO2_{alt})} \qquad (7)$$

Where:
$Cost_{alt} = overall\ supply\ cost\ of\ the\ technology\ scenario (£/\text{yr})$
$Cost_{ref} = overall\ supply\ cost\ of\ the\ reference\ case\ (£/yr)$
$CO2_{alt} = CO_2 emissions\ of\ the\ technology\ scenario\ (tonnes/yr)$
$CO2_{ref} = CO_2\ emissions\ of\ the\ references\ case\ (tonnes/yr)$

If any scenario would increase CO_2 emissions compared to conventional supply it was excluded from this cost effectiveness assessment.

Appendix C: Further details of the energy supply method and assumptions

C1. The energy supply technology options

The choice of the energy supply technologies depended on various factors: such as suitability, sustainability, and adoptability of decentralised technology to a particular dwelling type. The feasibility of these technologies would also depend on patterns of development which are density dependent; and the availability and scope of resources; the technological limitations of scale and advancements; and the temporal energy demands [5, 6, 7]. In view of these factors, the supply technologies were explored for various housing types in Table C1 and whether they would be for Existing housing, Intensification or on New-land and the scale of development. These considerations were taken into account when deciding on the suitability of these technologies shown in Table A5.

Table C1. Decentralised energy technologies – their suitability for different types of housing

Technology	Heat	Power	High-density urban housing	Low-density urban housing	Distributed suburban housing	Rural housing
CHP	✓	✓	Very suitable (due to higher concentrated demand)	Not suitable	Not suitable	Not suitable
Micro-CHP	✓	✓	Not suitable (due to higher demand)	Sometimes suitable	Very suitable	Very suitable
Solar water heating	✓		Very suitable with communal heating or CHP	Very suitable	Very suitable	Very suitable
PV electricity		✓	Sometimes suitable (due to less exposed area)	Very suitable	Very suitable	Very suitable
Wood fuel boilers	✓		Generally suitable with communal heating (local availability)	Sometimes suitable	Sometimes suitable	Very suitable
Ground source heat pumps [1]	✓		Suitable (if in vertical form)	Sometimes suitable for groups of dwellings	Very suitable (in horizontal form)	Very suitable (in horizontal form)

[1] *Only horizontal GSHP were tested by this case study*

The suitability of decentralised energy technologies as per the above patterns of development were also explored with respect to the settlement size as shown below in Table C2.

Table C2. Decentralised energy technologies - their suitability for different settlement sizes

	Settlement Size Bands (No. of dwellings)			
Density	1-10	10-100	100-1,000	1,000-10,000
High	Micro-CHP[1], PV[4], GSHP[2], Biomass Boilers (BB[3])	CHP, PV[4], GSHP[2], BB[3]	CHP, PV[4], GSHP[2], BB[3]	CHP, PV[4], GSHP[2], BB[3]
Medium	Micro-CHP[1], PV, GSHP, BB[3]	CHP, PV, GSHP, BB[3]	CHP, PV, GSHP, BB[3]	CHP, PV, GSHP, BB[3]
Low	Micro-CHP[1], PV, GSHP, BB	Micro-CHP[1], PV, GSHP, BB	Micro-CHP, PV, GSHP, BB	Micro-CHP, PV, GSHP, BB

[1] *If gas grid connections/extension would be possible.*

[2] *Vertical systems would be needed.*

[3] *Subject to the suitability of a community heating system and is constrained by the biomass resource and space.*

[4] *Constrained by solar radiations, roof area, shadow of the neighbouring buildings, etc.*

In view of above constraints, different energy supply technologies were tested for heat and electricity supply for the three types of development (i.e. Existing, Intensification and New-land) and for three different scenarios (i.e. Low-cost, Low-carbon and Highly-electric), and for each one a possible supply solution is shown in Appendix A, Table A1.

C2. Energy supply cost calculations

Tables C3 and C4 show the capital and operating costs of various decentralised supply technologies along with the district heating costs considered for the case study.

Table C3.
Domestic and communal heat technologies [8, 9]

Technology	Cost		Lifetime
	Capital	Operation and maintenance	
Individual Domestic Gas Boilers	£2500/dwelling	£200/year	15 years
Electric Heating	£175/kW	£17/kW	15 years
Biomass Boiler	£528/kW	£18/kW	15 years
Ground Source Heat Pumps	£1200/kW	£9/kW	20 years
Air Source Heat Pumps	£600/kW	£9/kW	20 years
PV Panels	£4000/kW	£40/kW	20 years
Micro-CHP	£850/kW	£125/kW	20 years
Small Gas CHP	£850/kW	£80/kW	20 years
Large Gas CHP	£650/kW	£50/kW	20 years

Table C4.
District heating costs per dwelling type [8]

Dwelling type	Total costs [1]
Small Terrace	£6,347
Medium/Large Terrace	£6,690
Semi-detached Dense	£7,617
Semi-detached less Dense	£8,217
Converted Flat	£3,764
Low Rise Flat	£5,300
High Rise Flat	£4,800

[1] *Total Cost included DHN infrastructure costs, DHN branch Costs, HIU and heat meter costs*

The total cost of energy supply per tile type was estimated by accounting for the decentralised and centralised cost of energy supply. The decentralised cost of energy supply was calculated on the basis of assumed up-take of decentralised technologies. The percentage of decentralized supply was assumed based on our view of the achievable energy supply share in 2031, which would also be constrained by economic viability, scope for building integration, etc. In this case, the initial up-take assumption of the decentralised technologies was 30% (which we considered to be realistic) i.e., around 30% of the total energy demand that would be met through building integrated or community scale technologies for the component of conventional supply (heat or power) relevant to that chosen technology, subject to what would then be achievable after taking into account the factors affecting suitability and system size.

The energy supply systems were sized with respect to their connected energy demand, technical efficiencies, availability of space, operating hours, etc. For example, in case of sizing PV systems, the constraints such as south facing roof area, size of the panel, capacity factor, average sunshine hour, etc. were used to estimate the system size and its annual output. Similarly, in case of ground source heat pumps, the constraints such as garden area, seasonal coefficient of performance, capacity factor, hours of operation, etc. were used.

The unit cost of heat and electricity supply per tile, C_t for different decentralised energy technologies was estimated in 2009 prices based on the net present value of the capital, operation and maintenance costs over the lifetime of the technology; the expected energy output over the lifetime of the technology; and the assumed discount rate of 3.5%. This was used to calculate the decentralised energy supply cost C_d:

$$C_d = x_1 * D_t * C_t * z_t \tag{8}$$

Where,
$x_1 = Assumed\ uptake\ of\ decentralised\ supply\ technologies$
$D_t = Annual\ heat/electricity\ \ demand\ for\ tile\ type\ t\ in\ kWh/yr\ per\ dwelling$
$C_t = Unit\ cost\ of\ decentralised\ heat/electricity\ supply\ for\ tile\ type\ t\ in\ p/kWh$
$z_t = density\ of\ tile\ type\ t$

For calculating the overall cost including the centralised energy supply, it was assumed that the remaining energy demand would be met through the use of existing grid and gas networks. The cost of conventional grid and gas supply was assumed to be 0.1397 £/Kwh and 0.0398 £/kWh, respectively in 2009 prices [10].

C3. The CO_2 savings calculations

Table C5 and C6 shows the average fuel mix of conventionally supplied dwellings based on their total fuel consumption for space heating, water heating, cooking, appliances, lighting, pumps and fans for dwellings in the base year 2009 and for the forecast year of 2031 [3].

Table C5. Fuel mix for Existing dwellings in 2009 (Base Year) for a selection of the tile types

Tile type	Gas (%)	Oil (%)	Solid (%)	Biomass (%)	Electric for heating (%)	Electric for power (%)
D1	42	28	14	1	5	11
D4	73	4	3	0	7	13
S1	66	9	7	0	7	11
S4	74	2	3	0	8	14
T1	77	1	3	0	6	13
T4	76	0	2	0	9	13
F1	68	0	1	0	16	15
F5	56	0	0	0	27	17
C1	75	0	4	0	9	13
C3	66	0	1	0	19	14

Table C6. Fuel mixes of conventionally supplied dwellings (Existing ~ New-build) in 2031

Tile type	Gas (%)	Oil (%)	Solid (%)	Biomass (%)	Electric for heating (%)	Electric for power (%)
D1	40~33	28~22	13~11	1~0	5~5	14~29
D4	72~59	4~3	3~2	0	8~7	15~29
S1	64~52	9~7	6~5	0	8~7	14~28
S4	71~60	2	2	0	9~8	16~28
T1	74~60	1	2~3	0	7~6	15~31
T4	73~62	0	2	0	10~8	15~28
F1	65~53	0	1	0	17~15	18~31
F5	54~38	0	0	0	29~29	19~33
C1	74~59	0	2~3	0	10~9	15~30
C3	66~50	0	1	0	21~18	16~31

The calculations used a generalised seasonal coefficient of performance of 2.5 for GSHP. The heating efficiencies of the decentralised technologies were consistent with SAP 2009 Table 4 [11].

The CO_2 savings (in tonnes/kWh) were estimated on the basis of the amount of decentralised energy supply per tile type along with their emission factors (shown in Table C5) as below:

$$CO_{2\,Savings} = E_c - E_d \tag{9}$$

Where:

$E_c = CO_2\ for\ the\ amount\ of\ decentralised\ supply\ if\ based\ on\ the\ conventional\ supply\ fuel\ mix$

$E_d = CO_2\ emissions\ of\ the\ decentralised\ supply\ technology$

Table C7. Emission factors [4]

Fuel	*Emission Factors (kg/Kwh)*
Gas (e.g. for conventional heating and CHP technologies)	0.206
Biomass (e.g., for biomass boilers)	0.019
Solar PV	0.0
Oil (e.g. for conventional heating in areas without gas supply)	0.259
Solid fuel (e.g. for conventional heating)	0.311
Electricity (e.g. for power, GSHP and resistive heating)	0.482 in 2009 & 0.25 in 2031

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