

Technical Appendix 1

Assumptions made on UK hedgerow network and its distribution

Hedgerow lengths

The best available estimate of the total length of managed hedgerows in Great Britain, 477 000 km, is from the Countryside Survey 2007 ¹. In this study we have modelled a 40% increase in the UK hedgerow network, and so to this total needs to be added an estimate of hedgerow length obtained for Northern Ireland, 113 650 km ², giving a UK total of 590 650 km. This figure is for hedgerows in rural environments only, whilst urban and semi-urban hedgerows also deliver important ecosystem services for societal and economic benefit. Taking the assumption that urban hedgerows represent one tenth of the rural hedgerow network ³, we have estimated a UK wide (semi)urban total of 59,065 km, giving a total UK length of 649 715 km for both rural and (semi)urban environments (Table 1).

Table 1: UK hedgerow lengths

Hedgerows	Length (km)	Source
<i>Rural</i>		
Great Britain	477000	Countryside survey 2007
Northern Ireland	113650	McCann (2012)
Total (UK)	590650	
<i>Urban</i>	59,065	10% of total network (Staley et al 2020)
<i>Total UK rural/ (semi)urban</i>	649,715	

Hedgerow distribution

For some ecosystem services delivered by hedgerows in the countryside, it is relevant to know the broad agricultural classes across which they are distributed, in particular their spread between areas of arable and pasture. We have assumed that the great majority of the hedgerow network is in lowland agricultural landscapes, so this is the focus of our modelling. Upland hedgerows do exist but are relatively rare. For example, in the highlands, islands and Southern Uplands of Scotland most of land is unenclosed and enclosed fields tend to be bounded by fences and walls rather than hedges ⁴.

The best available data on lowland agricultural areas come from the Land Cover Map 2015 ⁵. We calculated lowland agricultural areas as comprising the LCM classes arable and four grassland types: improved, neutral, calcareous and acid. The UK values for neutral and calcareous grasslands, which predominate in, but are not exclusive to, lowland areas were adjusted to take into account the small areas of upland hay meadows and upland calcareous grasslands respectively, using data from the UK Biodiversity Action Plan (JNCC). The UK BAP was also the source of acid grassland in lowlands, as such grasslands predominate in uplands. Table 2 gives the total derived areas and percentages of arable and pasture in lowland UK.

Table 2: Lowland agricultural classes

Class	Area (km ²)	Percentage of lowland agricultural area
Arable	56506	42.5
Improved grassland	74466	56.0
Neutral grassland	1137	0.9
Calcareous grassland	578	0.4
Acid grassland	300	0.2
Total grassland (pasture)	76481	57.5
Total lowland agriculture	132987	100

In order to estimate hedgerow distribution across the 42.5% of the lowland agricultural area that is arable and 57.5% that is pasture, respective average field sizes and therefore field boundary density also need to be taken into account. Average field sizes have been reported to differ significantly between arable/horticulture (6.34 ha in 2015) and improved grassland (2.57 ha) ⁶. We adopted two approaches to estimating field boundary densities based on these field size averages:

- By applying a power law equation describing the relationship between patch size and edge density data from a study of four contrasting landscapes ⁷;
- Approximating the perimeter of landscape patches as a function of area as $\sqrt{A^D}$ where A is area and D is the fractal dimension ⁸. D lies in the region of 1.2-1.3 (1.25 used) for coastlines and other linear natural phenomena ⁹.

The results were averaged to arrive at an estimated 188 770 km of hedgerow in arable farmscapes and 401 880 km in pasture farmscapes. To these totals can be added the 59 065 km of hedgerows in (semi)urban areas, which according to the LCM 2015 cover 17 658 km². The estimated total extent of the UK hedgerow network becomes 649 715 km. Table 3 shows what current estimates equate to in terms of the 40% hedgerow network expansion target.

Table 3: Hedgerows distributed across arable, pasture and (semi)urban.

	Current hedgerow network		Network after 40% increase	
	Length km	Density km/km ²	Length km	Density km/km ²
Arable	188 770	3.34	264 277	4.68
Pasture	401 880	5.25	562 633	7.36
(Semi)urban	59 065	3.34	82 691	4.68
Total	649 715	4.89	909 601	6.84

It should be noted here that while we tend to assume a spatially even expansion of hedgerows in the 40% increase scenario, to simplify the analyses presented in the main text, we make many recommendations on where planting should be focused, and in reality planting would vary considerably by region and habitat in attempt to optimise functionality of placements.

References

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Technical Appendix 2

Cost data used to calculate NPV for pollination and pest control services, the NPV of investment in woodchip biofuel for farmers, and to establish a NPV for the provision of negative emissions to the UK public as a result of increased carbon sequestration.

Table 1. Unit costs for establishment and maintenance of hedgerows.

	£
<i>Labour to plant and guard</i>	3-4/m
<i>Fencing incl. labour</i>	5-6/m
<i>Flail (contract, 3-5 miles/day; every 2-3 years)</i>	40-50/hr
<i>Hedge coppicing</i>	
(i) By hand (100m/day)	6.50-7.50/m
(ii) Contractor (13m/hr)	3.50/m
<i>Hedge laying (every 8-20 years, 20-40m/day)</i>	16/m

Technical Appendix 3

Proportional increase in local organism abundance through hedgerow expansion: derivation

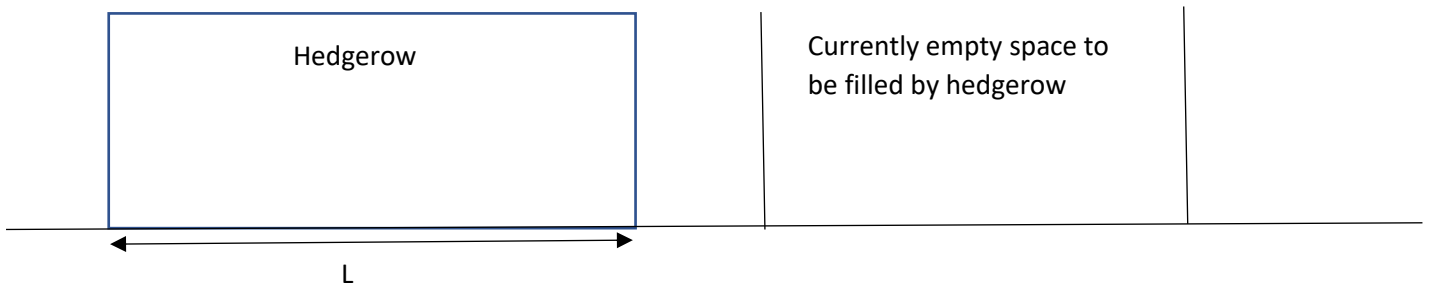
O is the background local occurrence of the organism in the absence of hedgerow, per unit length of empty land

I is the number of times the occurrence of organism is increased by presence of hedgerow compared to its absence (1 = no increase, 2 = a doubling of occurrence, 3 = is a tripling of occurrence etc.)

P is the proposed proportional increase in the length of hedgerow

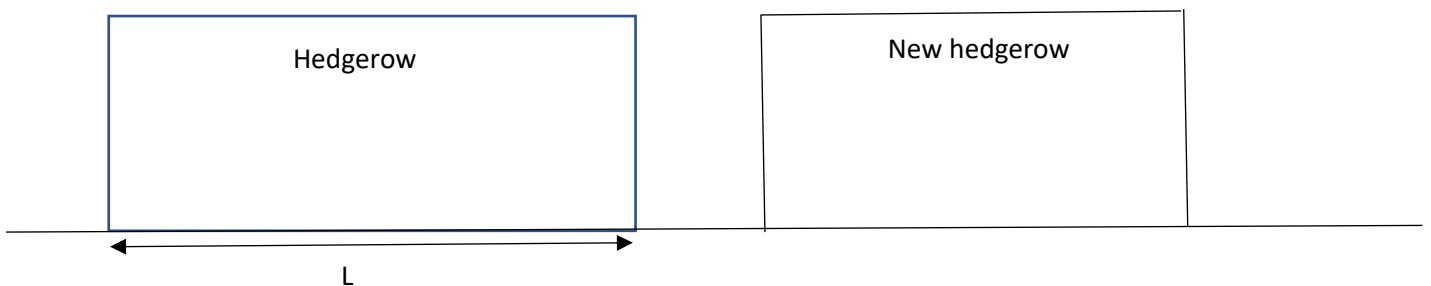
L is the current length of hedgerow

Current local numbers of organisms, N_1



$$N_1 = (L*O)*I + (L*P)*O$$

Future local numbers of organisms with new hedgerow, N_2



$$N_2 = (L*O)*I + ((L*P)*O)*I$$

Proportional increase in local organism abundance through hedgerow expansion, G

$$G = (N_2 - N_1) / N_1$$

$$= (((L*O)*I + ((L*P)*O)*I) - ((L*O)*I + (L*P)*O)) / ((L*O)*I + (L*P)*O)$$

$$= (LOI + LPOI - (LOI + LPO)) / (LOI + LPO)$$

$$= (LIOP - LOP) / (LIO + LOP)$$

$$= (IP - P) / (I + P)$$

Technical Appendix 4

Biodiversity data used in the economic analysis of biodiversity and a visual presentation of findings

Biodiversity data

Table 1. Net present value at 2% discount rate related to biodiversity benefits arising from 40% increase of current hedgerow network in the UK during the period 2022-2050. The benefits are assessed on the three selected crops oilseed rape, field beans and apples.

£ ha ⁻¹	Oilseed rape	Field beans	Apple
<i>Discounted crop output revenue</i>	2,806	1,726	17,702
<i>Discounted grant revenue</i>	9,020	9,020	9,020
<i>Costs</i>	9,415	9,415	9,415
<i>Net present value without grants</i>	-6,609	-7,690	8,287
<i>Net present value with grants</i>	2,411	1,331	17,307

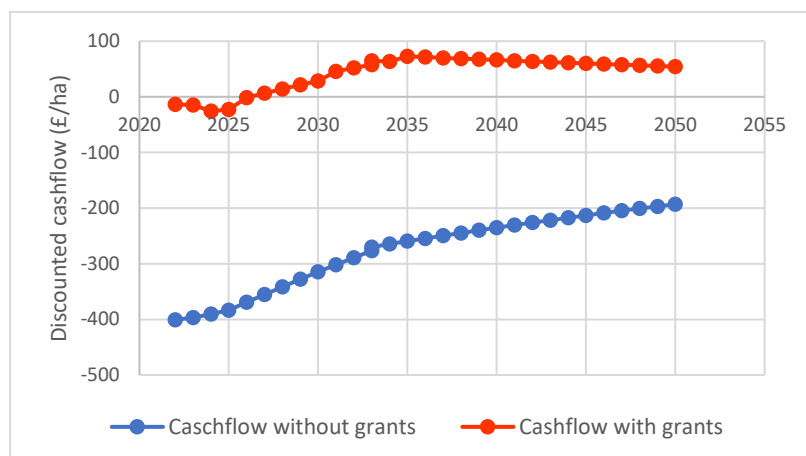


Figure 1. Discounted net cashflow related to the biodiversity benefits arising from the hedgerow network increase (field beans).

Technical Appendix 5

Table 1. Revenues and costs associated with hedgerows management on a £ m⁻¹ hedge and a £ m³ woodchip basis (based on Smith *et al.* 2021)¹.

	£ m ⁻¹ hedge	£ m ³ woodchip
<i>Revenue</i>		
Hedgerow grant	0.16	
Coppicing grant	4	
Woodchip sale to woodfuel cooperative		7.59
Equivalent heating oil replacement cost		34.80
<i>Costs</i>		
Flailing	0.25	
Tree shears and chipping	4.46	17.80

Table 2. GHG emission reduction at 10% and 30% of the UKs hedgerows managed for bioenergy (based on Smith *et al.* 2021)¹.

	Unit	Percentage of woody linear features managed for woodchip bioenergy production	
		10%	30%
Total UK woody linear features	km	813,719	813,719
Total in 15-year coppice rotation	km	81,372	244,116
Annual length coppiced ¹	km	5,425	16,274
Annual length coppiced ¹	m ³ *10 ³	1,356	4,068
Annual energy generated by hedgerow woodchip ²	MWh	1,162	3,486
Annual emissions from hedgerow woodchip ²	Gg CO ₂ e	18	53
Annual emissions from heating oil equivalent ²	Gg CO ₂ e	321	964
Emissions reduction by replacing heating oil with woodchip	Gg CO ₂ e	304	912

¹Based on trials at Elm Farm and Wakelyns carried out by ORC (Smith *et al.* 2021)¹

²Conversion value of energy generated by woodchip (kWh): 857

²Emission factor woodchip combustion (kg CO₂e/kWh): 0.01506

²Emission factor heating oil (kg CO₂e/kWh): 0.27652

Table 3. Sources and data used in carbon sequestration calculations

	Carbon Sequestration/storage level used (t C/ha)	Widths Used	Proportion of the new network (Countryside Survey, 2007 and high ambition scenario recommendations)	Amount of hectares of hedgerows in new network (ha)	Carbon total value (Mt)
Aboveground (managed)	32.2 (ref ²)	1.9m (ref ²)	35.47%	58555.55	1.8855
Aboveground (unmanaged)	45.08 (ref ³)	3.5m (ref ³)	34.53%	110901.04	4.9994

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Aboveground (managed for woodchip biofuel)	52.68 (ref ⁴)	1.5m (ref ⁴)	30%	41345.37	2.1781
Belowground (mean average for all)	92.7 (ref ⁵)	1.5, 1.9 and 3.5m (corresponding to the above)	All	210801.96 (Sum of the above)	19.5413

Reference

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Technical Appendix 6

Detailed description of economic analysis of hedgerows and UK urban air pollution

Two comprehensive studies^{1,2} have undertaken a detailed analysis of the weight of accumulated particulate matter accumulated by urban roadside hedgerows and trees. The most relevant for our purposes is that of Blanuša *et al.* 2020¹ who studied accumulation of particulate matter within several species of mostly perennial hedgerow plants grown in clean conditions and placed at major and minor roadsides in Reading, UK for 12 days in summer. We use this data to represent UK cities as a whole and this is probably justified as urban PM_{2.5} varies surprisingly little between UK cities (hovering around the 10µg/m³ mark) and season variation is also surprisingly slight³. Across three species of hedgerow, total particulate matter accumulated beside major roads at an average rate of 0.112mg/cm² leaf tissue/12days and at minor roads, 0.072mg/cm² leaf tissue/12days. Assuming evergreen characteristics and constant accumulations of material throughout the year, this equates to accumulation at major of 3.41mg/cm² leaf tissue/year and at minor roads, 2.19mg/cm² leaf tissue/year.

We treat hedgerows in our model simply as a continuous cuboid with half the length⁴ of hedgerow displaying an open bottom that does not contribute to surface area. Leaf area is assumed conservatively to be the surface area of the three-sided cuboid x2 (internal and external area) + the half bottom inner and outer area. Hedgerow dimensions are taken from average values of urban hedgerows samples in the Blanuša *et al.* 2020¹ which correspond to a height of 1.6m and a width of 1.6m. This appears to correspond favorably to a recent citizen science survey of urban and rural hedges (roughly in equal proportion) whose dimensions are reported as: “63.2 % of hedges were taller than 2 m and 43.8 % of hedges were wider than 2 m”⁴.

There is around 59,065km of urban hedgerow in the UK (see Technical Appendix 1) and 156,000km (156,122km) of urban road^{5,6}. The split of urban major (A roads) to minor roads (B, C and U roads) is roughly 7.6% major road and the remainder minor⁵ (GB-only figures used to calculate split). This equates to 11,844km of urban major road and 144,278km of minor road. There is no accurate data on the distribution of urban hedgerows (roadside vs elsewhere) but it is generally assumed that they occur mainly in residences and parks⁷. We therefore make “proportion of urban hedgerows that are roadside” a variable in our analysis and assume a low range of 5 to 20% and repeat our analysis within this range.

Worksheet 1 (below) shows calculations and total accumulated tones of PM_{2.5} sequestered across the UK urban roadside hedgerow network per year according to the above framework. Please note that we assume the PM_{2.5} is 5% of total PM accumulated by leaves². Assuming 5% of urban hedgerows occur along roadsides, we calculate that hedgerows sequester 38 tonnes of PM_{2.5} (the most health damaging type of airborne pollution) per year. This equates to a damage reduction value⁸ of £2,771,116. Adding an extra 40% to the urban hedgerow network adds an extra £1,108,446 in damage reduction. If we assume that 20% of urban hedgerows occur along roadsides, we calculate that hedgerows sequester 151 tonnes of PM_{2.5} per year. This equates to a damage reduction value of £11,084,464. Adding an extra 40% to the urban hedgerow network adds an extra £4,433,785 in damage reduction. It would clearly be beneficial for the UK to obtain improved statistics of the distribution of hedgerows within cities.

References

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Technical Appendix 6 – worksheet 1

‘Calculations and total accumulated tones of PM2.5 sequestered across the UK urban roadside hedgerow network per year’

% of urban hedgerow assumed next to roadside (5 to 20%)	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
km hedgerow next to urban road	2953. 25	3543. 9	4134. 55	4725. 2	5315. 85	5906. 5	6497. 15	7087. 8	7678. 45	8269. 1	8859. 75	9450. 4	1004 1.05	1063 1.7	1122 2.35	1181 3
km hedgerow next to major road	224.4 47	269.3 364	314.2 258	359.1 152	404.0 046	448.8 94	493.7 834	538.6 728	583.5 622	628.4 516	673.3 41	718.2 304	763.1 198	808.0 092	852.8 986	897.7 88
km hedgerow next to minor road	2728. 803	3274. 564	3820. 3242	4366. 0848	4911. 8454	5457. 606	6003. 3666	6549. 1272	7094. 8878	7640. 6484	8186. 409	8732. 1696	9277. 9302	9823. 6908	1036 9.451 4	1091 5.212
surface area of urban hedgerow per m (m2)	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
surface area of urban hedgerow across all major roads (m2)	2513 806.4	3016 568	3519 328.9 6	4022 090.2 4	4524 851.5 2	5027 612.8	5530 374.0 8	6033 135.3 6	6535 896.6 4	7038 657.9 2	7541 419.2	8044 180.4 8	8546 941.7 6	9049 703.0 4	9552 464.3 2	1005 5225. 6
surface area of urban hedgerow across all minor roads (m2)	3056 2593. 6	3667 5112	4278 7631. 04	4890 0149. 76	5501 2668. 48	6112 5187. 2	6723 7705. 92	7335 0224. 64	7946 2743. 36	8557 5262. 08	9168 7780. 8	9780 0299. 52	1039 1281 8.2	1100 2533 7	1161 3785 5.7	1222 5037 4.4
Total weight (mg) accumulated PM across urban major road hedgerow network per year	8572 0798 240	1.03E +11	1.200 09E+ 11	1.371 53E+ 11	1.542 97E+ 11	1.714 42E+ 11	1.885 86E+ 11	2.057 3E+1 1	2.228 74E+ 11	2.400 18E+ 11	2.571 62E+ 11	2.743 07E+ 11	2.914 51E+ 11	3.085 95E+ 11	3.257 39E+ 11	3.428 83E+ 11

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Total weight (mg) accumulated PM across urban minor road hedgerow network per year	6.693 21E+ 11	8.03E +11	9.370 49E+ 11	1.070 91E+ 12	1.204 78E+ 12	1.338 64E+ 12	1.472 51E+ 12	1.606 37E+ 12	1.740 23E+ 12	1.874 1E+1 2	2.007 96E+ 12	2.141 83E+ 12	2.275 69E+ 12	2.409 55E+ 12	2.543 42E+ 12	2.677 28E+ 12
Total weight (tonnes) accumulated PM across whole urban road hedgerow network per year	755.0 4159 81	906.0 499	1057. 0582 37	1208. 0665 57	1359. 0748 77	1510. 0831 96	1661. 0915 16	1812. 0998 35	1963. 1081 55	2114. 1164 75	2265. 1247 94	2416. 1331 14	2567. 1414 33	2718. 1497 53	2869. 1580 73	3020. 1663 92
Total weight (tonnes) accumulated PM2.5 across whole urban road hedgerow network per year	37.75 2079 9	45.30 25	52.85 2911 87	60.40 3327 85	67.95 3743 83	75.50 4159 81	83.05 4575 79	90.60 4991 77	98.15 5407 75	105.7 0582 37	113.2 5623 97	120.8 0665 57	128.3 5707 17	135.9 0748 77	143.4 5790 36	151.0 0831 96
Total value of urban hedgerow network in term of damage reduction due to PM2.5 reduction per year	2,771 ,116	3,325 ,339	3,879 ,562	4,433 ,785	4,988 ,009	5,542 ,232	6,096 ,455	6,650 ,678	7,204 ,901	7,759 ,125	8,313 ,348	8,867 ,571	9,421 ,794	9,976 ,017	10,53 0,241	11,08 4,464
Total weight of PM2.5 sequestered across whole urban hedgerow network per year due to a 40%	52.85 2911 87	63.42 349	73.99 4076 61	84.56 4658 98	95.13 5241 36	105.7 0582 37	116.2 7640 61	126.8 4698 85	137.4 1757 09	147.9 8815 32	158.5 5873 56	169.1 2931 8	179.6 9990 03	190.2 7048 27	200.8 4106 51	211.4 1164 75
Total value of urban hedgerow network in term of damage reduction due to	3879 562.2 9	4655 475	5431 387.2 06	6207 299.6 63	6983 212.1 21	7759 124.5 79	8535 037.0 37	9310 949.4 95	1008 6861. 95	1086 2774. 41	1163 8686. 87	1241 4599. 33	1319 0511. 78	1396 6424. 24	1474 2336. 7	1551 8249. 16

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PM2.5 reduction per year																
Extra damage reduction value of 40% increase in urban hedgerow network per year	1,108,446	1,330,136	1,551,825	1,773,514	1,995,203	2,216,893	2,438,582	2,660,271	2,881,961	3,103,650	3,325,339	3,547,028	3,768,718	3,990,407	4,212,096	4,433,785