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**
Rural		
Great Britain	477000	Countryside survey 2007
Northern Ireland	113650	McCann (2012)
Total (UK)	590650	
Urban	59,065	10% of total network (Staley et al 2020)
Total UK rural/ (semi)urban	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 (km2)	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 km^2. 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.

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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.

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

Technical Appendix 3

Proportional increase in local organism abundance through hedgerow expansion: derivation

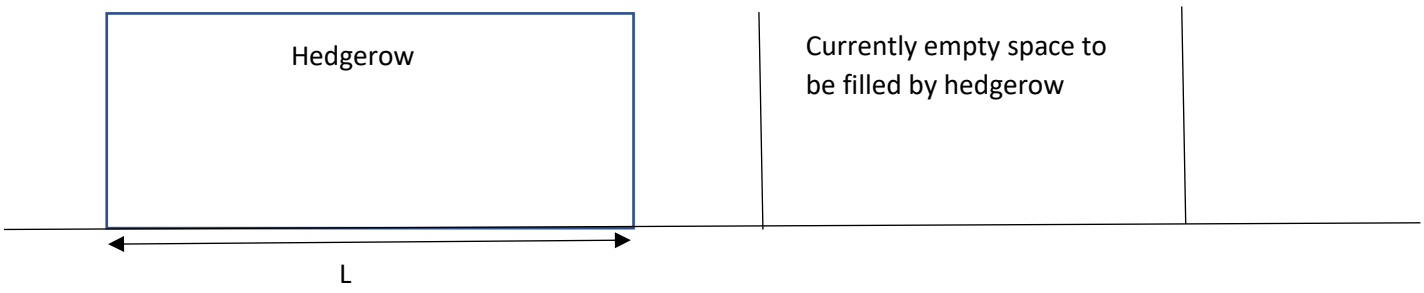
O is the background local occurrence of the organism in the absence of hedgerow, per unit length of empty land

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

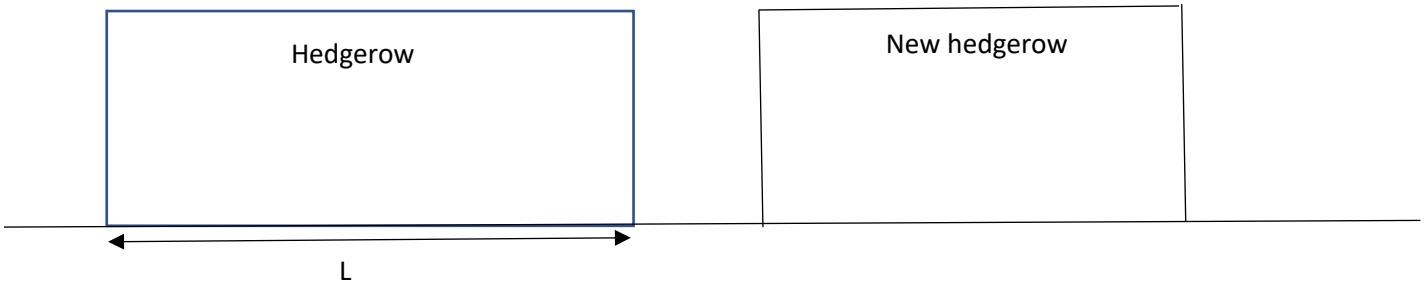
L is the current length of hedgerow

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

$G = (N_2-N_1) / N_1$

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

$= (LOI + LPOI – (LOI + LP0)) / (LOI + LPO)$

$= (LIOP–LOP) / (LIO+LOP)$

$= (IP–P)/(I+P)$

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
Discounted crop output revenue	2,806	1,726	17,702
Discounted grant revenue	9,020	9,020	9,020
Costs	9,415	9,415	9,415
Net present value without grants	-6,609	-7,690	8,287
Net present value with grants	2,411	1,331	17,307

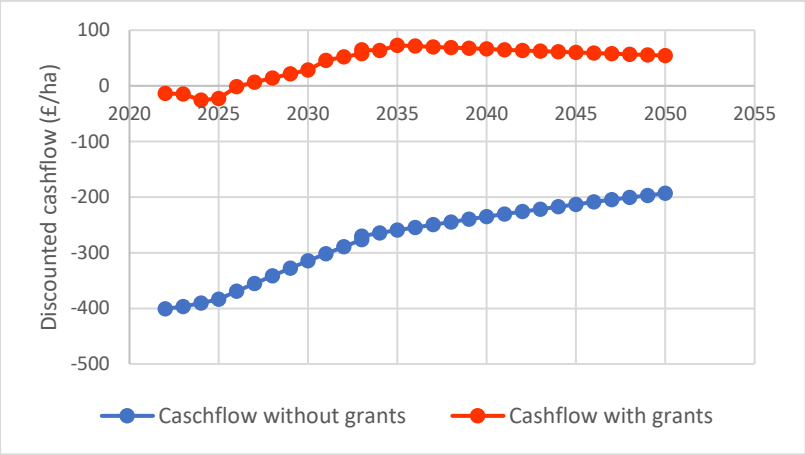


Figure 1. Discounted net cashflow related to the biodiversity benefits arising from the hedgerow network increase (field beans).

Technical Appendix 5

Table 1. Revenues and costs associated with hedgerows management on a £ m^{-1} hedge and a £ m^3 woodchip basis (based on Smith *et al.* 2021)[1].

	£ m^{-1} hedge	£ m^3 woodchip
Revenue		
Hedgerow grant	0.16	
Coppicing grant	4	
Woodchip sale to woodfuel cooperative		7.59
Equivalent heating oil replacement cost		34.80
Costs		
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].

		Percentage of woody linear features managed for woodchip bioenergy production	
	Unit	**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_2e	18	53
Annual emissions from heating oil equivalent[2]	Gg CO_2e	321	964
Emissions reduction by replacing heating oil with woodchip	Gg CO_2e	304	912

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

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

[2]Emission factor woodchip combustion (kg CO_2e/kWh): 0.01506

[2]Emission factor heating oil (kg CO_2e/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

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

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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.* 2020[1] 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 PM2.5 varies surprisingly little between UK cities (hovering around the 10µg/m^3 mark) and season variation is also surprisingly slight[3]. Across three species of hedgerow, total particulate matter accumulated beside major roads at an average rate of 0.112mg/cm^2 leaf tissue/12days and at minor roads, 0.072mg/cm^2 leaf tissue/12days. Assuming evergreen characteristics and constant accumulations of material throughout the year, this equates to accumulation at major of 3.41mg/cm^2 leaf tissue/year and at minor roads, 2.19mg/cm^2 leaf tissue/year.

We treat hedgerows in our model simply as a continuous cuboid with half the length[4] 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. 2020[1] 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 minor[5] (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 parks[7]. 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 PM2.5 sequestered across the UK urban roadside hedgerow network per year according to the above framework. Please note that we assume the PM2.5 is 5% of total PM accumulated by leaves[2]. Assuming 5% of urban hedgerows occur along roadsides, we calculate that hedgerows sequester 38 tonnes of PM2.5 (the most health damaging type of airborne pollution) per year. This equates to a damage reduction value[8] 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 PM2.5 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.

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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	10041.05	10631.7	11222.35	11813
km hedgerow next to major road	224.447	269.3364	314.2258	359.1152	404.0046	448.894	493.7834	538.6728	583.5622	628.4516	673.341	718.2304	763.1198	808.0092	852.8986	897.788
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	10369.4514	10915.212
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)	25138806.4	30165568	35193328.96	40220090.24	45248851.52	50276612.8	55303374.08	60330135.36	65356896.64	70383657.92	75410419.2	80437180.48	85463941.76	90490703.04	95517464.32	100544225.6
surface area of urban hedgerow across all minor roads (m2)	30562593.6	36675112	42787631.04	48900149.76	55012668.48	61125187.2	67237705.92	73350224.64	79462743.36	85575262.08	91687780.8	97800299.52	103912818.2	110025337	116137855.7	122250374.4
Total weight (mg) accumulated PM across urban major road hedgerow network per year	857207980240	1.03E+11	1.20009E+11	1.37153E+11	1.54297E+11	1.71442E+11	1.88586E+11	2.057 3E+11	2.22874E+11	2.40018E+11	2.57162E+11	2.74307E+11	2.91451E+11	3.08595E+11	3.25739E+11	3.42883E+11

Total weight (mg) accumulated PM across urban minor road hedgerow network per year	6.69321E+11	8.03E+11	9.37049E+11	1.07091E+12	1.20478E+12	1.33864E+12	1.47251E+12	1.60637E+12	1.74023E+12	1.8741E+12	2.00796E+12	2.14183E+12	2.27569E+12	2.40955E+12	2.54342E+12	2.67728E+12
Total weight (tonnes) accumulated PM across whole urban road hedgerow network per year	755.041581	906.0499	1057.058237	1208.066557	1359.074877	1510.083196	1661.091516	1812.099835	1963.108155	2114.116475	2265.124794	2416.133114	2567.141433	2718.149753	2869.158073	3020.166392
Total weight (tonnes) accumulated PM2.5 across whole urban road hedgerow network per year	37.752079	45.3025	52.852911	60.403327	67.953743	75.504159	83.054575	90.604991	98.155407	105.70582	113.25623	120.80665	128.35707	135.90748	143.45790	151.00831
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	10,530,241	11,084,464
Total weight of PM2.5 sequestered across whole urban hedgerow network per year due to a 40%	52.852911	63.42349	73.994076	84.564658	95.135241	105.70582	116.27640	126.84698	137.41757	147.98815	158.55873	169.12931	179.69990	190.27048	200.84106	211.41164
Total value of urban hedgerow network in term of damage reduction due to	3879562.29	4655475	5431387.206	6207299.663	6983212.121	7759124.579	8535037.037	9310949.495	10086861.95	10862774.41	11638686.87	12414599.33	13190511.78	13966424.24	14742336.7	15518249.16

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