Developing Estimates for the Valuation of Air Pollution Removal in Ecosystem Accounts

Final Report

For Office for National Statistics

July 2017

N.B. This document version corrects and updates some model outputs from the previously published final report, as follows:

- Calculations of $PM_{2.5}$ health impacts and value now account for increase in population over time
- NO_2, SO_2, NH_3 have the correct chemical conversions applied for pollution removal (UK and Urban datasets each contained conversion errors)
- Calculations of total pollution removed now correctly exclude $PM_{2.5}$ as this is a subset of PM_{10}
- Urban accounts completely recalculated due to coding error transposing woodlands and grasslands

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CONTENTS

SUMMARY

Aims

The purpose of the study is to produce a natural capital account for air pollution removal by vegetation across the UK. It forms part of the measurement and reporting of natural capital assets and ecosystems services for the development of UK natural capital accounts for the eight UK National Ecosystem Assessment (UKNEA) broad habitat types.

The aim is to capture the benefits of nature in the nation's balance sheet in a way that is consistent with the Defra/ONS natural capital accounting principles (Defra/ONS, 2017) and 2013 System of Environmental-Economic Accounting framework for Experimental Ecosystem Accounting (SEEA-EEA).

This work builds on a scoping phase (Jones et al. 2016) which made recommendations on the methodology to be taken forward. The specific objectives for the study are summarised as:

- Produce natural capital accounts for pollution removal by vegetation, for at least four pollutants ($PM_{2.5}$, SO_2, NO_2, O_3), reporting those accounts by broad habitat, where appropriate.
- Provide a much greater spatial disaggregation of monetary and physical estimates
- Estimate a longer time series
- Provide a more sophisticated accounting of future services in order to calculate asset values

Two sets of accounts are presented:
i) A national UK account for air pollution removal by broad habitat types
ii) A cross-cutting urban account for GB, showing air pollution removal by urban greenspace: woodland, grassland and urban blue space: freshwater/saltwater

Methodology

The pollutants for which accounts have been developed are listed in Table S1 below. In the national account, physical accounts are presented for six pollutants (PM_{10}, $PM_{2.5}$, SO_2, NH_3, NO_2, O_3) 2007, 2011, 2015 and looking forward to 2030. In the urban account, only 2015 was calculated. Health and monetary accounts are presented for four pollutants with damage costs available ($PM_{2.5}$, SO_2, NO_2, O_3) for the same years. The asset values are presented in two forms, with and without income uplift. The asset values are calculated over 100 years, and incorporate the trajectory from 2007 to 2011 to 2015 and 2030, then hold 2030 levels of service constant for subsequent years. Monetary accounts were not calculated for PM_{10} and NH_3 since they are covered by $PM_{2.5}$ which includes the aerosol fraction that derives from NH_3 and is the most damaging component of PM_{10}.

Table S1. Scope of UK Natural Capital Account for air pollution removal, pollutants considered

	Physical accounts		Monetary accounts	
	Tonnes pollutant removed	Change in concentration	Health benefits	Monetary benefit
Sulphur dioxide (SO_2)	✓	✓	✓	✓
Coarse particulate matter (PM_{10})	✓	✓		
Fine particulate matter ($PM_{2.5}$)	✓	✓	✓	✓
Ammonia (NH_3)	✓	✓		
Nitrogen dioxide (NO_2)	✓	✓	✓	✓
Ozone (O_3)	✓	✓	✓	✓

Calculation of the physical flow account uses the EMEP4UK atmospheric chemistry and transport model which generates pollutant concentrations directly from emissions, and dynamically calculates pollutant transport and deposition, taking into account meteorology and pollutant interactions. This differs from the previous draft account which used a static methodology where pollutants were considered in isolation, incorporating only limited effects of meteorology, and where effects of pollutant transport in the atmosphere as well as the feedback of the deposition on air concentration were not considered.

For the national account, the role of vegetation in removing air pollution is assessed using a comparison of two scenarios 'current vegetation' and 'no vegetation' derived from CEH Landcover 2007, where the 'no vegetation' scenario is represented by replacing all UK vegetation with a neutral 'bare soil' cover. The effect of vegetation is calculated by subtracting the 'no vegetation' scenario from the 'current vegetation'.

For the cross-cutting urban account, the same approach was taken but with a new hybrid land cover containing urban green and blue space. All non-urban habitats from CEH Landcover 2007 located within the Urban extent defined by eftec (2017) were classified into three broad categories of green/blue space, based on OS MasterMap:

- Urban woodland
- Urban grassland
- Urban fresh/saltwater

The urban account was only calculated for Great Britain, as we did not have access to data equivalent to OS MasterMap for Northern Ireland. The scenarios compared 'current urban green/blue space' with a 'no green/blue space' scenario as above.

The health benefits were calculated from the change in pollutant exposure from the EMEP4UK scenario comparisons, i.e. the change in pollutant concentration to which people are exposed. Damage costs per unit exposure were then applied to the benefitting population at the local authority level for a range of avoided health outcomes:

- Respiratory hospital admissions
- Cardiovascular hospital admissions
- Loss of life years (long-term exposure effects from $PM_{2.5}$ and NO_2)
- Deaths (short-term exposure effects from O_3)

This differs from the draft account which applied a simple urban or rural damage cost per tonne of pollutant removed. Although not used to calculate the health outcomes, the tonnes of pollutant removed by vegetation are also reported in this study, as is the average deposition velocity of each pollutant (the rate at which pollutants were deposited to the vegetation in each year).

Overview of results for the national account

Tables S2 to S10 below report the physical natural capital account (extent), the physical flow account and the health and monetary accounts over time for the national account.

In 2015, UK vegetation was estimated to have removed 1,262 ktonnes of $PM_{2.5}$, SO_2, NO_2 and O_3, (1,325 ktonnes for all pollutants). Overall, the accounts show a decline in the amount of service provided by UK vegetation over time, i.e. the flow of service as measured by the change in pollutant concentrations (Table S3) and the quantities of pollutant removed (Table S4). This occurs primarily because, in line with emission changes, pollutant concentrations have declined over this period, with the exception of O_3, which as a hemispheric pollutant heavily depends on emission changes in other parts of the world. In other words, there is less pollution for the vegetation to remove, so it provides less service. The pollutant concentrations are the major driver of change in the quantity of service provided, followed to a lesser extent by changes in meteorolology (rainfall, temperature, windspeed) and chemical interactions among pollutants. Changes in vegetation extent (Table S2) are not a factor in this analysis as land cover was held constant over time since changes in land cover are small compared with changes in emissions. The deposition velocities extracted from model outputs are shown in Table S5. They represent a spatial and temporal average across the UK, taking into account pollutant concentrations and interactions with meteorology and other pollutants.

The health and monetary accounts also show a decline over time, with the exception of O_3 effects where there is an increase. These changes in benefit reflect the decline in service provided, even allowing for forecast increases in population. Table S6 shows the avoided mortality and morbidity due to air pollution removal by UK vegetation. In 2015 there were 1900 avoided deaths, 27,800 avoided life years lost, 5,800 fewer respiratory hospital admissions and 1,300 fewer cardiovascular hospital admissions.

The economic value arising from these avoided health costs was substantial, £1,033 m in 2015 (Table S7), declining from a value of £1,755m in 2007. Table S8 shows the breakdown of economic value by broad habitat type, calculated at the UK level based on their relative contribution to the pollutant removal within each grid cell. A full analysis by habitat was not conducted as it would require separate model runs for each habitat. The long-term asset values over a 100 year period are shown in Table S9 with no income uplift, and in Table S10 incorporating income uplift.

Table S2. Extent of UK natural capital

Indicator		Broad habitat	Amount	Unit	Source
Extent	Total UK area		24,903,400	ha	CEH Landcover Map 2007
	Area of 'broad' UKNEA habitats	Woodland	2,887,500	ha	CEH Landcover Map 2007
		Enclosed farmland	12,549,900		
		Semi-natural grassland	3,281,100		
		Mountains, moors and heaths	2,609,600		
		Freshwater[1]	1,437,200		
		Coastal margins	44,500		
		Marine	-		
		Urban	1,473,200		
		Other[2]	620,500		

[1] Includes vegetated wetland areas: fen marsh swamp, + bog (1,110,800 ha) and open freshwater (326,300 ha)

[2] Includes bare ground, littoral and supralittoral sediment and rock, inland rock, saltwater (mainly in estuaries)

Table S3. Average concentrations from EMEP4UK model in the two scenarios, and absolute change in concentration and relative difference (%) which represents the effect of vegetation in the national account. Negative values show a reduction in pollutant concentration due to vegetation (Units: µg m^{-3}).

Pollutant	Habitat	2007	2011	2015	2030
PM10	Current vegetation	11.55	10.74	9.9	8.01
	No vegetation	12.53	11.6	10.55	8.38
	Change in concentration	-0.98	-0.86	-0.65	-0.37
	Difference (%)	-7.8%	-7.4%	-6.2%	-4.4%
PM2.5	Current vegetation	6.36	6.08	4.85	3.31
	No vegetation	7.2	6.83	5.4	3.61
	Change in concentration	-0.84	-0.75	-0.55	-0.3
	Difference (%)	-11.7%	-11.0%	-10.2%	-8.3%
SO2	Current vegetation	1.46	1.07	0.85	0.5
	No vegetation	2.07	1.55	1.21	0.72
	Change in concentration	-0.61	-0.48	-0.36	-0.22
	Difference (%)	-29.5%	-31.0%	-29.8%	-30.6%
NH3	Current vegetation	1.32	1.49	1.33	1.18
	No vegetation	1.78	1.95	1.74	1.55
	Change in concentration	-0.46	-0.46	-0.41	-0.37
	Difference (%)	-25.8%	-23.6%	-23.6%	-23.9%
NO2	Current vegetation	9.33	7.62	5.8	3.16
	No vegetation	9.55	7.69	5.8	3.07
	Change in concentration	-0.22	-0.07	0	0.09
	Difference (%)	-2.3%	-0.9%	0.0%	2.9%
O3	Current vegetation	64.8	63.7	67.2	68.2
	No vegetation	75.3	74.3	77.5	78.7
	Change in concentration	-10.5	-10.6	-10.3	-10.5
	Difference (%)	-13.9%	-14.3%	-13.3%	-13.3%

Table S4. Pollutant capture by UKNEA broad habitat in the national account, as dry deposition of pollutants (ktonnes per year).

Pollutant	Habitat	2007	2011	2015	2030
PM10	Woodland	42.7	39.3	34.4	26.7
	Enclosed farmland	4.3	3.7	3.4	2.5
	Semi-natural grassland	1.8	1.7	1.5	1.2
	Mountain moor & heath	1.3	1.1	1.1	0.9
	Open water, wetland & floodplain	0.7	0.6	0.6	0.5
	Coastal margins	0.04	0.04	0.03	0.02
	Total vegetation	50.8	46.4	41.1	31.8
PM2.5	Woodland	24.9	23.1	17.5	10.9
	Enclosed farmland	3.3	2.8	2.3	1.5
	Semi-natural grassland	1.3	1.2	1.0	0.7
	Mountain moor & heath	0.8	0.8	0.6	0.4
	Open water, wetland & floodplain	0.4	0.4	0.3	0.2
	Coastal margins	0.03	0.03	0.02	0.01
	Total vegetation	30.8	28.3	21.8	13.8
SO2	Woodland	16.9	13.8	11.0	6.5
	Enclosed farmland	34.2	24.8	20.3	11.1
	Semi-natural grassland	5.7	4.7	3.9	2.3
	Mountain moor & heath	2.2	2.1	1.9	1.3
	Open water, wetland & floodplain	1.0	1.0	0.8	0.6
	Coastal margins	0.16	0.12	0.10	0.06
	Total vegetation	60.1	46.6	37.9	21.8
NH3	Woodland	13.2	12.9	12.0	10.3
	Enclosed farmland	24.6	24.0	24.0	20.4
	Semi-natural grassland	4.9	5.0	4.8	4.2
	Mountain moor & heath	1.7	1.9	1.7	1.5
	Open water, wetland & floodplain	0.8	0.9	0.8	0.7
	Coastal margins	0.10	0.10	0.10	0.08
	Total vegetation	45.3	44.8	43.5	37.2

NO2	Woodland	6.4	4.9	4.1	2.3
	Enclosed farmland	26.7	20.5	16.3	8.7
	Semi-natural grassland	3.2	2.6	2.0	1.1
	Mountain moor & heath	1.2	1.0	0.8	0.4
	Open water, wetland & floodplain	0.4	0.4	0.3	0.2
	Coastal margins	0.08	0.07	0.05	0.03
	Total vegetation	38.0	29.4	23.6	12.7
O3	Woodland	211.7	203.4	213.4	213.1
	Enclosed farmland	630.3	612.7	657.1	662.5
	Semi-natural grassland	144.0	137.9	141.4	140.7
	Mountain moor & heath	119.6	112.9	117.0	116.1
	Open water, wetland & floodplain	49.1	46.7	48.3	48.0
	Coastal margins	1.78	1.71	1.81	1.83
	Total vegetation	1156.5	1115.2	1179.0	1182.3
All pollutants*	Woodland	290.9	274.2	275.0	258.9
	Enclosed farmland	720.1	685.8	721.1	705.2
	Semi-natural grassland	159.6	151.9	153.6	149.4
	Mountain moor & heath	126.0	119.1	122.4	120.2
	Open water, wetland & floodplain	52.0	49.5	50.8	49.9
	Coastal margins	2.16	2.04	2.09	2.02
	Total vegetation	1350.7	1282.6	1325.0	1285.8

* excludes $PM_{2.5}$ as subset of PM_{10}

Table S5. Summary of deposition velocities per unit ground surface (mm s^{-1}) extracted from model outputs as a spatial and temporal average over the year. Reported by EMEP4UK vegetation type not for UKNEA broad habitats, for each pollutant.

Pollutant	Habitat	2007	2011	2015	2030
PM10	Coniferous woodland	7.74	7.6	7.88	8.04
	Deciduous woodland	5.23	5.15	5.31	5.46
	Crops	2.15	2.1	2.35	2.64
	Moorland/ grassland	2.34	2.3	2.54	2.82
	Water	2.12	2.05	2.37	2.67
	Bare soil/ desert	2.15	2.08	2.34	2.64
PM2.5	Coniferous woodland	6.35	6.22	5.94	5.48
	Deciduous woodland	4.02	3.82	3.71	3.37
	Crops	0.71	0.59	0.66	0.61
	Moorland/ grassland	0.96	0.94	0.91	0.84
	Water	0.6	0.54	0.58	0.55
	Bare soil/ desert	0.6	0.59	0.57	0.53
SO2	Coniferous woodland	16.06	18.24	17.77	17.85
	Deciduous woodland	15.89	18.1	17.68	17.78
	Crops	5.05	5.51	5.45	5.41
	Moorland/ grassland	6.92	7.65	7.55	7.48
	Water	6.41	6.47	6.75	6.8
	Bare soil/ desert	1.15	1.26	1.17	1.15
NH3	Coniferous woodland	15	12.99	12.81	12.21
	Deciduous woodland	14.63	12.63	12.52	11.9
	Crops	3.53	3.34	3.33	3.27
	Moorland/ grassland	6.79	6.2	6.32	6.14
	Water	6.5	6.27	6.6	6.56
	Bare soil/ desert	1.2	1.27	1.25	1.24
NO2	Coniferous woodland	0.97	0.93	1	1.02
	Deciduous woodland	0.72	0.67	0.77	0.8
	Crops	0.54	0.51	0.54	0.54
	Moorland/ grassland	0.53	0.52	0.53	0.53
	Water	0.05	0.05	0.05	0.05
	Bare soil/ desert	0.05	0.05	0.05	0.05
O3	Coniferous woodland	4.44	4.34	4.32	4.28
	Deciduous woodland	3.91	3.82	3.83	3.77
	Crops	3.5	3.39	3.51	3.48
	Moorland/ grassland	2.78	2.74	2.67	2.63
	Water	0.49	0.49	0.5	0.5
	Bare soil/ desert	0.5	0.5	0.5	0.5

Table S6. Change in mortality and morbidity of UK population as a result of air pollution removal by vegetation, for the national account.

		Change in no. of hospital admissions/life years lost/deaths attributable to presence of UK vegetation			
		2007	2011	2015	2030
		no./yr	no./yr	no./yr	no./yr
PM2.5	Respiratory hospital admissions	-814	-693	-533	-318
	Cardiovascular hospital admissions	-715	-609	-469	-279
	Life years lost	-42,736	-34,759	-26,009	-14,385
SO2	Respiratory hospital admissions	-308	-240	-181	-110
NO2	Respiratory hospital admissions	-346	-188	-125	-3
	Cardiovascular hospital admissions	-294	-160	-106	-3
	Life years lost	-5,618	-2,913	-1,843	-16
O3	Respiratory hospital admissions	-4,679	-4,889	-5,017	-5,861
	Cardiovascular hospital admissions	-722	-755	-775	-905
	Deaths	-1,798	-1,743	-1,899	-2,110
All pollutants combined	Respiratory hospital admissions	-6,146	-6,011	-5,856	-6,291
	Cardiovascular hospital admissions	-1,731	-1,524	-1,349	-1,186
	Life years lost	-48,354	-37,672	-27,851	-14,400
	Deaths	-1,798	-1,743	-1,899	-2,110

Table S7. Annual value of air quality regulation from UK natural capital, for the national account.

		Annual value (2012 prices)			
		2007 £m/yr	2011 £m/yr	2015 £m/yr	2030 £m/yr
PM2.5	Respiratory hospital admissions	£5.4	£4.6	£3.5	£2.1
	Cardiovascular hospital admissions	£4.6	£3.9	£3.0	£1.8
	Life years lost	£1,495.8	£1,216.6	£910.3	£503.5
SO2	Respiratory hospital admissions	£2.1	£1.6	£1.2	£0.7
NO2	Respiratory hospital admissions	£2.3	£1.3	£0.8	£0.02
	Cardiovascular hospital admissions	£1.9	£1.0	£0.7	£0.02
	Life years lost	£196.6	£101.9	£64.5	£0.5
O3	Respiratory hospital admissions	£31.1	£32.5	£33.4	£39.0
	Cardiovascular hospital admissions	£4.7	£4.9	£5.0	£5.8
	Deaths	£10.8	£10.5	£11.4	£12.7
Total		**£1,755.2**	**£1,378.8**	**£1,033.8**	**£566.2**

Table S8. Annual value of air quality regulation from UK natural capital, for the national account, broken down by UKNEA broad habitat.

Pollutant	Habitat	2007	2011	2015	2030
PM2.5 all health effects	Woodland	£1,217,696,000	£999,512,000	£737,952,000	£401,672,000
	Enclosed farmland	£161,255,000	£119,909,000	£97,885,000	£56,396,000
	Semi-natural grassland	£64,182,000	£53,685,000	£41,114,000	£24,348,000
	Mountain moor & heath	£41,458,000	£34,353,000	£26,343,000	£16,499,000
	Open water, wetland & floodplain	£19,750,000	£16,439,000	£12,665,000	£7,947,000
	Coastal margins	£1,449,000	£1,199,000	£914,000	£514,000
	Total vegetation	£1,505,789,000	£1,225,097,000	£916,876,000	£507,376,000
SO2 all health effects	Woodland	£576,000	£473,000	£349,000	£218,000
	Enclosed farmland	£1,168,000	£850,000	£643,000	£370,000
	Semi-natural grassland	£193,000	£162,000	£122,000	£77,000
	Mountain moor & heath	£74,000	£73,000	£60,000	£43,000
	Open water, wetland & floodplain	£34,000	£34,000	£27,000	£19,000
	Coastal margins	£5,000	£4,000	£3,000	£2,000
	Total vegetation	£2,050,000	£1,595,000	£1,204,000	£729,000
NO2 all health effects	Woodland	£33,995,000	£17,198,000	£11,594,000	£104,000
	Enclosed farmland	£140,781,000	£72,686,000	£45,732,000	£400,000
	Semi-natural grassland	£16,938,000	£9,168,000	£5,541,000	£49,000
	Mountain moor & heath	£6,443,000	£3,682,000	£2,218,000	£20,000
	Open water, wetland & floodplain	£2,240,000	£1,263,000	£775,000	£7,000
	Coastal margins	£422,000	£233,000	£142,000	£1,000
	Total vegetation	£200,819,000	£104,230,000	£66,002,000	£582,000
O3 all health effects	Woodland	£8,522,000	£8,725,000	£9,006,000	£10,359,000
	Enclosed farmland	£25,374,000	£26,284,000	£27,731,000	£32,201,000
	Semi-natural grassland	£5,799,000	£5,915,000	£5,969,000	£6,841,000
	Mountain moor & heath	£4,815,000	£4,843,000	£4,936,000	£5,643,000
	Open water, wetland & floodplain	£1,977,000	£2,003,000	£2,039,000	£2,334,000
	Coastal margins	£72,000	£74,000	£76,000	£89,000
	Total vegetation	£46,558,000	£47,844,000	£49,757,000	£57,467,000
Total pollut-ants	Woodland	£1,260,788,000	£1,025,907,000	£758,901,000	£412,353,000
	Enclosed farmland	£328,578,000	£219,729,000	£171,992,000	£89,368,000
	Semi-natural grassland	£87,112,000	£68,931,000	£52,746,000	£31,315,000
	Mountain moor & heath	£52,790,000	£42,951,000	£33,557,000	£22,205,000
	Open water, wetland & floodplain	£24,001,000	£19,738,000	£15,505,000	£10,307,000
	Coastal margins	£1,948,000	£1,510,000	£1,136,000	£606,000
	Total vegetation	£1,755,217,000	£1,378,766,000	£1,033,838,000	£566,155,000

Table S9. Asset value of air quality regulation from UK natural capital, for the national account with no income uplift, as measured by the present value of the stream of (annual) ecosystem services that the asset(s) will provide over the 100 year period selected for the analysis.

		Asset value (2012 prices)			
		2007 £m/yr	**2011** £m/yr	**2015** £m/yr	**2030** £m/yr
PM2.5	Respiratory hospital admissions	£88.9	£79.6	£72.8	£62.9
	Cardiovascular hospital admissions	£75.7	£67.8	£62.1	£53.7
	Life years lost	£22,509.4	£19,730.5	£17,802.8	£15,009.6
SO2	Respiratory hospital admissions	£31.0	£27.3	£25.0	£21.7
NO2	Respiratory hospital admissions	£15.6	£9.5	£6.2	£0.6
	Cardiovascular hospital admissions	£12.9	£7.9	£5.1	£0.5
	Life years lost	£1,254.7	£732.4	£455.2	£16.2
O3	Respiratory hospital admissions	£1,084.3	£1,105.0	£1,123.4	£1,161.9
	Cardiovascular hospital admissions	£162.4	£165.5	£168.2	£174.0
	Deaths	£357.1	£362.8	£368.7	£377.4
Total		**£25,591.9**	**£22,288.3**	**£20,089.5**	**£16,878.5**

Table S10. Asset value of air quality regulation from UK natural capital, for the national account with income uplift, as measured by the present value of the stream of (annual) ecosystem services that the asset(s) will provide over the 100 year period selected for the analysis.

		Asset value (2012 prices)			
		2007 £m/yr	2011 £m/yr	2015 £m/yr	2030 £m/yr
PM2.5	Respiratory hospital admissions	£135.3	£135.6	£138.5	£171.4
	Cardiovascular hospital admissions	£115.3	£115.6	£118.1	£146.1
	Life years lost	£33,585.2	£33,152.4	£33,535.3	£40,866.2
SO2	Respiratory hospital admissions	£47.0	£46.7	£47.7	£59.2
NO2	Respiratory hospital admissions	£16.2	£10.8	£7.5	£1.7
	Cardiovascular hospital admissions	£13.4	£8.9	£6.2	£1.4
	Life years lost	£1,274.9	£800.6	£531.2	£44.2
O3	Respiratory hospital admissions	£1,932.2	£2,112.6	£2,306.8	£3,163.5
	Cardiovascular hospital admissions	£289.4	£316.4	£345.4	£473.7
	Deaths	£632.7	£690.5	£753.6	£1,027.4
Total		**£38,041.5**	**£37,390.0**	**£37,790.4**	**£45,954.7**

Overview of results for the cross-cutting urban account

Tables S11 to S18 below report the physical natural capital account (extent), the physical flow account and the health and monetary accounts over time for the cross-cutting urban account. The urban accounts were only calculated for 2015.

In 2015, urban green and blue space removed 26.6 ktonnes of $PM_{2.5}$, SO_2, NO_2 and O_3, (28.7 ktonnes including combined PM_{10} & $PM_{2.5}$ and NH_3).

The change in concentration due to pollution removal by urban natural capital is much smaller than in the national account, up to a maximum of 1.8% reduction for SO_2, and only 0.44% reduction in concentration for $PM_{2.5}$. Nevertheless, there are still health and monetary benefits.

Table S14 shows the avoided mortality and morbidity due to air pollution removal by UK urban green and blue space. It is estimated that in 2015 there were 239 avoided deaths, 3,600 avoided life years lost, 899 fewer respiratory hospital admissions and 220 fewer cardiovascular hospital admissions. The economic value arising from these avoided health costs was substantial, £136m in 2015 (Table S15). Table S16 shows the breakdown of economic value by urban habitat type, calculated at the GB level based on their relative contribution to the pollutant removal within each grid cell. A full analysis by habitat was not conducted as it would require separate model runs for each habitat. The long-term asset values over a 100 year period are shown in Table S17 with no income uplift, and in Table S18 incorporating income uplift.

As the urban cross-cutting account was calculated based on a bespoke reference land cover, and a different model version, the model results are not directly comparable with those for the national account, and the urban accounts are not a simple subset of the total pollutant removal in the national accounts. However, broad comparisons can still be made between the accounts.

The health benefits from urban green and blue space have an equivalent value of approximately 10% of the estimate for the UK vegetation as a whole, and are greater than might be expected from the urban land area, where the urban extent is only 7% of the UK total land area. This occurs for three reasons. Firstly urban green and blue space reduces air pollution concentrations in neighbouring areas outside of the urban extent, thereby providing benefits outside of the urban area. Secondly, the bulk of the UK population live in urban areas, so the population benefiting from reduced exposure to air pollutants due to pollution removal by urban green/blue space will be greater. Thirdly, $PM_{2.5}$ concentrations are higher in the populated south-east, and the rate of $PM_{2.5}$ removal is greater at higher concentrations.

Table S11. Quantity of urban natural capital. Left-hand columns show extent calculated direct from OS MasterMap, as reported in the urban cross-cutting accounts scoping study (eftec, 2017), right-hand columns show extent calculated after converting to 25 m raster format, used as input to modelling in this study.

Indicator		Broad habitat	Amount	Unit	Source	Amount	Unit	Source
Extent	GB urban extent		1,765,700	ha	eftec (2017) report	1,765,700	ha	Hybrid LCM/ OSMM
	Area of ‘broad’ UKNEA habitats (GB only)	Woodland	99,400	ha	OS MasterMap (GB only)	97,600	ha	OS MasterMap (GB only)
		Grassland	420,400			412,400		
		Freshwater/ saltwater	22,700			19,474		
		Urban and mixed surfaces	1,223,200			1,236,226		

Table S12. Average concentrations from EMEP4UK model in the two scenarios, and absolute change in concentration and relative difference (%) which represents the effect of urban green/blue space. Negative values show a reduction in pollutant concentration due to urban green/blue space (Units: µg m^{-3}).

Pollutant	Habitat	2015
PM10	Current vegetation	13.62
	No vegetation	13.66
	Absolute difference	-0.04
	Difference (%)	-0.29
PM2.5	Current vegetation	6.21
	No vegetation	6.24
	Absolute difference	-0.03
	Difference (%)	-0.44
SO2	Current vegetation	0.77
	No vegetation	0.78
	Absolute difference	-0.01
	Difference (%)	-1.83
NH3	Current vegetation	1.41
	No vegetation	1.42
	Absolute difference	-0.01
	Difference (%)	-0.90
NO2	Current vegetation	4.66
	No vegetation	4.69
	Absolute difference	-0.03
	Difference (%)	-0.61
O3	Current vegetation	66.6
	No vegetation	66.7
	Absolute difference	-0.2
	Difference (%)	-0.25

Table S13. Pollutant capture by urban green and blue space in the urban cross-cutting account, as dry deposition of pollutants (ktonnes per year).

* excludes $PM_{2.5}$ as subset of PM_{10}

Pollutant	Habitat	2015
PM10	Urban trees/woodland	1.23
	Urban grassland	0.45
	Urban water	-0.004
	Total urban natural capital	1.68
PM2.5	Urban trees/woodland	0.70
	Urban grassland	0.31
	Urban water	-0.003
	Total urban natural capital	1.01
SO2	Urban trees/woodland	0.59
	Urban grassland	1.00
	Urban water	0.049
	Total urban natural capital	1.65
NH3	Urban trees/woodland	0.44
	Urban grassland	0.95
	Urban water	0.045
	Total urban natural capital	1.43
NO2	Urban trees/woodland	0.41
	Urban grassland	1.61
	Urban water	0.000
	Total urban natural capital	2.02
O3	Urban trees/woodland	4.97
	Urban grassland	16.94
	Urban water	-0.003
	Total urban natural capital	21.91
All pollutants*	Urban trees/woodland	7.65
	Urban grassland	20.95
	Urban water	0.087
	Total urban natural capital	28.68

Table S14. Change in mortality and morbidity of UK population as a result of air pollution removal by urban green/blue space, for the urban cross-cutting account.

		2015
		no./yr
PM2.5	Respiratory hospital admissions	-58
	Cardiovascular hospital admissions	-51
	Life years lost	-2,733
SO2	Respiratory hospital admissions	-30
NO2	Respiratory hospital admissions	-63
	Cardiovascular hospital admissions	-53
	Life years lost	-908
O3	Respiratory hospital admissions	-749
	Cardiovascular hospital admissions	-116
	Deaths	-239
All pollutants combined	Respiratory hospital admissions	-899
	Cardiovascular hospital admissions	-220
	Life years lost	-3,641
	Deaths	-239

Table S15. Annual value of air quality regulation from urban green/blue space, for the cross-cutting urban account

		2015
		no./yr
PM2.5	Respiratory hospital admissions	£390,000
	Cardiovascular hospital admissions	£330,000
	Life years lost	£95,660,000
SO2	Respiratory hospital admissions	£200,000
NO2	Respiratory hospital admissions	£420,000
	Cardiovascular hospital admissions	£340,000
	Life years lost	£31,780,000
O3	Respiratory hospital admissions	£4,980,000
	Cardiovascular hospital admissions	£750,000
	Deaths	£1,430,000
All pollutants combined	**Total**	**£136,280,000**

Table S16. Annual value of air quality regulation from urban green/blue space, for the cross-cutting urban account, broken down by urban green/blue habitat type.

Pollutant	Habitat	2015
PM2.5 all health effects	Urban woodland	£67,011,184
	Urban grassland	£29,650,906
	Urban fresh/saltwater	-£285,668
	Total urban natural capital	£96,376,422
SO2 all health effects	Urban woodland	£70,936
	Urban grassland	£119,903
	Urban fresh/saltwater	£5,861
	Total urban natural capital	£196,701
NO2 all health effects	Urban woodland	£6,586,339
	Urban grassland	£25,964,428
	Urban fresh/saltwater	-£5,337
	Total urban natural capital	£32,545,430
O3 all health effects	Urban woodland	£1,625,505
	Urban grassland	£5,535,672
	Urban fresh/saltwater	-£1,002
	Total urban natural capital	£7,160,174
Total pollutants	Urban woodland	£75,293,964
	Urban grassland	£61,270,909
	Urban fresh/saltwater	-£286,146
	Total urban natural capital	£136,278,727

Table S17. Asset value of air quality regulation from urban green/blue space, for the cross-cutting urban account with no income uplift, as measured by the present value of the stream of (annual) ecosystem services that the asset(s) will provide over the 100 year period selected for the analysis.

		2015
		no./yr
PM2.5	Respiratory hospital admissions	£8,450,000
	Cardiovascular hospital admissions	£7,210,000
	Life years lost	£1,995,080,000
SO2	Respiratory hospital admissions	£3,980,000
NO2	Respiratory hospital admissions	£5,970,000
	Cardiovascular hospital admissions	£4,920,000
	Life years lost	£436,360,000
O3	Respiratory hospital admissions	£177,430,000
	Cardiovascular hospital admissions	£26,570,000
	Deaths	£48,560,000
All pollutants combined	**Total**	**£2,714,530,000**

Table S18. Asset value of air quality regulation from urban green/blue space, for the cross-cutting urban account with income uplift, as measured by the present value of the stream of (annual) ecosystem services that the asset(s) will provide over the 100 year period selected for the analysis.

		2015
		no./yr
PM2.5	Respiratory hospital admissions	£16,290,000
	Cardiovascular hospital admissions	£13,880,000
	Life years lost	£3,808,450,000
SO2	Respiratory hospital admissions	£7,550,000
NO2	Respiratory hospital admissions	£10,350,000
	Cardiovascular hospital admissions	£8,540,000
	Life years lost	£746,960,000
O3	Respiratory hospital admissions	£366,630,000
	Cardiovascular hospital admissions	£54,900,000
	Deaths	£99,780,000
All pollutants combined	**Total**	**£5,133,330,000**

Future work to refine and expand the UK and urban natural capital accounts

This UK natural capital account shows the significant value of air pollution removal provided by vegetation in the UK, in terms of the quantities of pollutants removed, the health benefits arising from the resulting change in pollutant concentrations, and the economic value of that avoided mortality and morbidity.

Table S18 shows the physical and monetary value estimated for the environmental benefit and the certainty associated with those estimates. In the case of air pollution removal, while the science is fairly robust, different models and different approaches may produce widely varying estimates. There is a trade-off inherent between the accuracy of incorporating atmospheric transport and pollutant interactions at national scale, and the fine detail required to populate information about the type and location of vegetation on the ground. The approach taken here is robust, but emphasises pollutant transport and chemistry over fine-scale granularity.

Further work to improve the methodology could:

- Conduct separate model runs for each broad habitat type to more accurately estimate the health and economic benefits of each in isolation
- Add additional habitat classes into the EMEP4UK model to improve modelling of each habitat type and/or to allow consideration of habitat condition

- Improve the spatial resolution of EMEP4UK by running at 2 km x 2 km
- Add in land cover change, although the effect of this is likely to be small
- Review and update as necessary the damage cost functions

Table S18. Overview of certainty associated with physical and monetary value estimates

Environmental benefit	Scale	Physical estimate	RAG	Monetary (2012 prices)	RAG
National account: Air quality regulation, 2015, $PM_{2.5}$, SO_2, NO_2, O_3 (& including PM_{10} and NH_3)	UK	1,262 ktonnes pollutants removed (1,325 ktonnes including combined PM_{10} & $PM_{2.5}$ and NH_3)		£1,033m	
Cross-cutting urban account: Air quality regulation, 2015, $PM_{2.5}$, SO_2, NO_2, O_3 (& including PM_{10} and NH_3)	Urban extent, GB	26.6 ktonnes pollutants removed (28.7 ktonnes including combined PM_{10} & $PM_{2.5}$ and NH_3)		£136m	

RAG	Description
	Evidence is partial and significant assumptions are made that require further research
	Evidence is based on assumptions grounded in science and using published data but with some uncertainty regarding the combination of assumptions
	Evidence is peer reviewed or based on published guidance

1. INTRODUCTION

1.1. Background

This report is concerned with the estimation and reporting of natural capital assets and ecosystems services as part of the development of UK natural capital accounts for the eight UK National Ecosystem Assessment (UKNEA) broad habitat types. It follows from the Office for National Statistics (ONS) 2020 Natural Capital Accounting Roadmap published (ONS, 2012 and 2015). The Roadmap sets out key proposals and timings to produce experimental national natural capital accounts within the framework of the ONS UK Environmental Accounts, which are satellite accounts to the main National Accounts (ONS, 2014). The aim is to capture the benefits of nature in the nation's balance sheet in a way that is consistent with the Defra/ONS natural capital accounting principles (Defra/ONS, 2017) and 2013 System of Environmental-Economic Accounting framework for Experimental Ecosystem Accounting (SEEA-EEA).

The framework features a set of accounting schedules based around two main types of account (i) stock accounts which capture information on the natural capital assets (e.g. freshwaters, grasslands) and (ii) flow accounts which report information on the annual benefits produced by the natural capital assets. Both stock (asset) accounts and flow (services) accounts may be recorded in either monetary or physical terms, as shown in Figure 1. The accounts are developed by drawing on and organising financial, economic, social and environmental data on natural capital across the UK, including via the use of Geographical Information Systems (GIS).

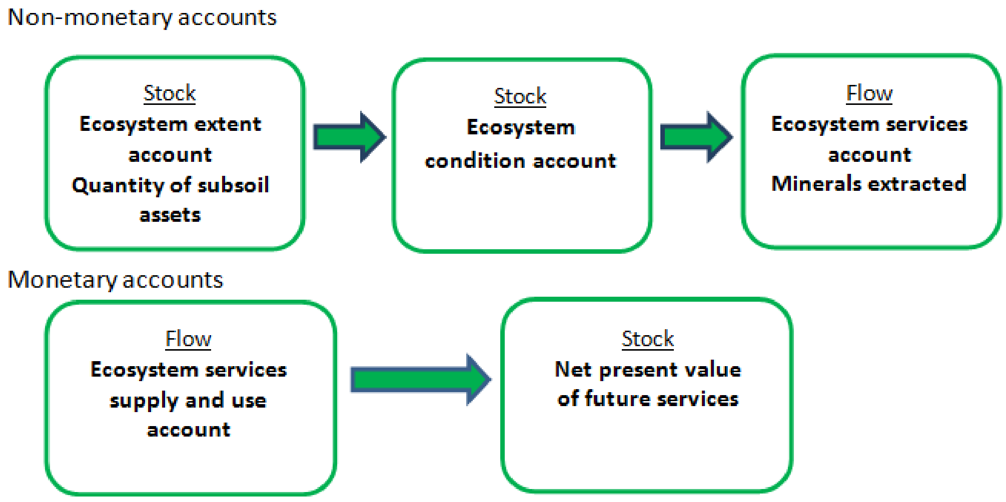


Figure 1. The framework of national natural capital accounting schedules (Defra/ONS, 2017)

Tracking these accounts over time enables assessments of changes in the extent and condition of natural capital assets, along with associated changes in the level of provision of environmental benefits. This can inform strategic priorities and policy objectives for natural capital management at UK level.

The purpose of the study is to produce a natural capital account for pollution removal by vegetation across the UK. This work will enable Defra and the Office for National Statistics (ONS) to make further progress in developing a full set of natural capital accounts for the UK in line with the 2020 Natural Capital Accounting Roadmap. The methodological development, outputs and practical experience from this study will also help inform the UK's continuing contribution to the development of international standards in natural capital accounting, such as the SEEA-EEA.

The approach previously used to develop the draft air pollution removal accounts (see Annex 1: Background and methods for experimental pollution removal estimates[1]) was as follows, based largely on Powe & Willis (2004): It overlaid an annual average concentration field (map) of a pollutant on a land-cover grid at 1 km x 1 km, and calculated the pollutant removed within each grid cell as a function of the deposition velocity[2] appropriate to the vegetation type, seasonally adjusted (FLUX), a scaling factor for leaf area index (SURFACE), and the regional climatology (number of days with <1 mm rainfall) (PERIOD). It then applied a damage cost per tonne of pollutant emitted, varied according to whether the grid cell is rural, urban, or classified as within London. The asset value of the UK's Natural Capital was then estimated over a 50-year period applying Green Book discount rates and holding unit values constant.

When reviewed, a number of improvements were recommended for this initial methodology, to address the following issues identified:

- double counting by additional scaling of deposition velocity by leaf surface area, due to a mis-interpretation of the deposition velocity literature by Powe & Willis[3]
- the relatively simple methodology which does not take into account dynamic interactions with meteorology (temperature, rainfall, windspeed etc.) and other pollutants, and does not account for atmospheric transport
- poor spatial disaggregation of benefits
- static assumptions in calculating the asset value
- reliance on the emission damage cost rather than a more direct assessment through changes in exposure.

The new air pollution removal account presented here addresses these issues.

1.2. Study objectives

This report focuses on the development of natural capital accounts for pollution removal by vegetation in the UK. This work builds on a scoping phase (Jones et al. 2016) which made recommendations on the methodology to be taken forward. The specific objectives for the overall study are summarised as:

- Include additional pollutants beyond coarse particulate matter (PM_{10}) and sulphur dioxide (SO_2) originally valued, to include at least nitrogen dioxide (NO_2), ammonia (NH_3) and ozone (O_3)
- Provide a much greater spatial disaggregation of monetary and physical estimates
- Estimate a longer time series
- Provide a more sophisticated accounting of future services in order to calculate asset values

For producing the natural capital accounts, it was agreed to:

[1] https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/annex1backgroundandmethodsforexperimentalpollutionremovalestimates

[2] The rate at which a pollutant deposits onto a surface. This is a combination of physical deposition and chemical reaction onto a surface and direct uptake by the plant via the stomata

[3] Deposition velocities can be reported per unit ground surface area or per unit leaf area. If reported by leaf area, then an additional scaling by Leaf Area Index (LAI) is required to calculate per unit ground surface area. However, in the literature it is not always stated explicitly which units are being used, hence the potential for misinterpretation.

- Produce natural capital accounts for pollution removal by vegetation, for five pollutants (fine particulate matter - $PM_{2.5}$, SO_2, NH_3, NO_2, O_3), reporting those accounts by broad habitat, where appropriate.
- Checking results with external sources, such as the itree studies
- Make recommendations for areas of further work

1.3. Report structure

The remainder of this report is structured as follows:

Section 2 Overview: this sets out the background to the project, as well as the review of existing approaches and guidance which informed the development of the natural capital account.

Section 3 Method: this describes the practical steps undertaken to develop the natural capital account, including the approach to quantifying and valuing natural capital stocks and flows.

Section 4 Results: accounts capturing the air quality regulating function of UK vegetation including accounts for extent of vegetation, condition of vegetation, physical account of pollutant captured, resulting changes in pollutant concentrations, the health benefits arising from this and the monetary account of the value of this pollutant removal for the UK.

Section 5 Discussion: proposes how to deal with a number of key issues associated with the development of natural capital accounts (specific or cross-cutting) including baseline definition and reconciliation with other natural capital accounts.

Section 6 Conclusions and recommendations: this summarises the approach taken, acknowledging the current limitations of data and making suggestions for future refinement of the accounts.

Annex 1 provides a look up table to allow cross-matching of the CEH Landcover Map 2007 vegetation classes with those used in the EMEP4UK model, and those used to report against UKNEA broad habitats.

2. OVERVIEW

2.1. Impacts of poor air quality, and the role of vegetation in pollution removal

Poor air quality is estimated to result in 40,000 (+/-25%) equivalent attributable deaths in the UK every year and is a major cause of morbidity (RCPCH 2016). It also impacts negatively on the status of habitats and species. By improving air quality, vegetation helps to mitigate these impacts on individuals' health and wellbeing as well as supporting habitat function and species survival. Although some atmospheric pollutants have reduced in concentration (such as sulphur dioxide and nitrogen dioxide) over recent years, particulate matter (PM_{10} and $PM_{2.5}$) and ozone remain a considerable concern, and ammonia concentrations have changed little over the last decade. Furthermore, climate change is expected to exacerbate other atmospheric pollutants such as ozone (UKNEA 2011), which is common downwind of major metropolitan areas (Freer Smith, Broadmeadow and Lynch, 2007).

Vegetation provides an air quality regulating service (UKNEA, 2011) by capturing airborne pollutants and removing them from the atmosphere through: (a) the internal absorption of pollutants via stomatal uptake; and (b) the deposition of pollutants on external surfaces such as leaves and bark (Bignal et al., 2004). A number of local councils in the UK are considering the active use of vegetation for reducing pollutant levels, though evidence on the effectiveness of such actions is currently limited. The location of vegetation is an important determinant of the amount and value of air quality regulation or 'purification' it provides because the amount of service provided is dependent on:

- *Ambient air quality*: urban areas tend to have higher levels of pollution, meaning urban vegetation will remove more pollutant than the same vegetation in a rural area; meanwhile rural areas remove more ammonia;
- *The amount of vegetation*: urban areas tend to have less vegetation per hectare than rural areas. This scarcity, combined with considerable local pollution sources, contributes to lower ambient air quality, and a higher relative value of pollution mitigation that does take place;
- *Population densities*: the total benefit being delivered by vegetation removing one tonne of pollution is higher in areas of high population density. This is because more people benefit from improvements in air quality
- *Pollutant transport*: The health benefits resulting from pollutant removal can be experienced in a different location to where the removal happens. For example, a large forested area upwind of London will provide substantial pollutant removal, thereby lowering the background levels of pollution that people in London are exposed to. This 'transported benefit' is not captured in static assessment methods.

2.2. Scope of natural capital accounts

Natural capital accounting incorporates the elements of environmental accounting covered by the System of Environmental-Economic Accounting Central Framework (SEEA-CF, 2012). This is an international standard for environmental-economic accounting that is within the framework of the System of National Accounts (SNA). It applies a standard asset accounting model (for produced assets) to the measurement of 'individual environmental assets' and expected flow of benefits as reported in basic resource accounts (e.g. for timber and fossil fuels). 'Individual environmental assets' are defined as "the naturally occurring living and non-living components of the Earth, together constituting the biophysical environment, which may provide benefits to humanity" (SEEA-CF, 2012). This includes ecosystems (e.g. woodlands, grassland, and freshwaters) and the 'ecosystem service' benefits produced from these such as timber, fish and flood protection, as well as abiotic/non-living resources such as fossil fuels and aggregates.

Defra/ONS (2017)[4] outline the key principles to be followed when developing natural capital accounts in the UK as part of the ONS Environmental Accounts. Whilst the scope of natural capital accounts is consistent with the SEEA-CF (i.e. biotic and abiotic resources), the accounting principles are consistent with the System of Environmental-Economic Accounting Experimental Ecosystem Accounting (SEEA-EEA, 2012), which takes an 'ecosystem approach'[5]. This considers how different ecosystem characteristics interact through/within an ecological system (stock) to provide a range of environmental benefits (flows). Overall this perspective is concerned with reporting the state of the natural environment in terms of the capacity of ecosystems to produce flows of services over time and 'ecological dynamics' including thresholds.

2.3. Principles of natural capital accounting

A formal way to describe the ecosystem approach to accounting for natural capital stock and flows in this way is provided by 'logic chains'. These characterise – in a structured manner – the conceptual 'pathway' by which natural capital assets generate benefits for society. The starting point is to appropriately identify the 'natural capital asset characteristics' that represent the key determinants of the status and productive capacity of an asset. These characteristics not only relate directly to the ecological functioning of an asset, but also to its spatial configuration (e.g. proximity to population), which is an important determinant of the value derived by society as a result of these environmental benefits. As an example, Figure 2 illustrates the logic chain for the air quality regulation provided by woodland, from which society benefits in terms of improved health outcomes.

In order to derive health benefits from the pollutant capture by vegetation (i.e. the final environmental benefit), this requires a combination of an ecosystem asset (woodland) along with management actions and other forms of capital input (e.g. planting trees that absorb lots of pollution in locations with high pollution concentrations). The characteristics that are deemed to be of most relevance to the production of the environmental benefits[6] are deemed to be impacted significantly by extent, type (e.g. woodland versus grassland), and location.

The logic chains provide a comprehensive structure for measuring ecosystems and the flow of services into economic and other human activity. Importantly the approach recognises that environmental benefit provision (flows) and the economic benefits that are generated are dependent on the underlying ecosystems (stocks), their status and their characteristics/attributes which govern the amount of service they provide. The practical use of the logic chain is not to develop deterministic functions/models, but rather to establish the appropriate evidence needed to measure and report on the status of the various links along the pathway from ecosystem assets to economic goods and benefits. The Defra/ONS (2017) principles paper complements this by setting out the composition of

[4] https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/principlesofnaturalcapitalaccounting

[5] SEEA-EEA takes an "ecosystem accounting" approach which is a slightly narrower concept than the SEEA-CF's coverage of environmental assets which is consistent with a "natural capital accounting" approach because the latter also includes abiotic assets (such as minerals and sub-soil assets).

[6] The metrics that are considered to be of 'relevance' will depend on the resolution (aggregated vs disaggregated) and scale (national vs local) of accounting and the potential use of the account for decision-making. Where decisions are being made regarding optimising the benefits of natural capital nationally and/or spatially explicit (disaggregated) accounts are being developed, it is relevant to note the distribution of factors like wind speed, soil type, solar exposure, precipitation because these influence the distribution of air quality regulating capacity from existing or potential woodland (for example) across the UK. Therefore, understanding these factors is important when assessing the benefits of woodland locations. Where aggregated accounts are produced at the national level, reporting such metrics (e.g. average wind speed across all UK woodland locations) is essentially meaningless. For local level accounts/decision-making (i.e. site level), these ecosystem characteristics are fixed (i.e. they cannot be influenced through management) and so are less relevant to account for, instead the account should focus on reporting metrics such as tree species, or location, which can be influenced through local level management.

a natural capital account in compatible terms to the logic chain relationship via the five types of accounts:

1. **Physical account of natural capital extent** (stock account): reporting data on the extent of natural capital assets within the defined boundary;

2. **Physical account of natural capital condition** (stock account): reporting bio-physical data on the condition of natural capital assets through key characteristics;

3. **Physical account of environmental benefit provision and use** (flow account): reporting data on the physical flow of environmental benefits linking natural capital assets to economic and other human activity. Where possible the (spatial) area within which the environmental benefits are generated and the areas in which environmental benefits are used should be distinguished. This data includes the amount of pollutant removed by vegetation, and the resulting change in pollutant concentrations.

4. **Monetary account of annual provision of environmental benefit** (flow account): reporting the values of annual environmental benefits produced. This includes quantifying the health benefits arising from pollutant removal, and the economic value associated with that.

5. **Monetary account of future provision of environmental benefit** (stock account): deriving values for the assets themselves by forecasting future flows into the future (100 years)

Tracking these accounts over time enables assessments of changes in the extent and condition of ecosystem assets, along with associated changes in the level of provision of environmental benefits. An account typically reports the opening and closing value of a stock of natural capital assets as well as the reconciliation of these stocks by recording intervening (net) changes to assets over the accounting period.

2.4. Scope of natural capital benefits

The pollutants for which accounts have been developed are listed in Table 1 below.

Table 1. Scope of UK Natural Capital Account for air pollution removal, pollutants considered

	Physical accounts		Monetary accounts	
	Tonnes pollutant removed	Change in concentration	Health benefits	Monetary benefit
Sulphur dioxide (SO_2)	✓	✓	✓	✓
Particulate matter - coarse (PM_{10})	✓	✓		
Fine particulate matter ($PM_{2.5}$)	✓	✓	✓	✓
Ammonia (NH_3)	✓	✓		
Nitrogen dioxide (NO_2)	✓	✓	✓	✓
Ozone (O_3)	✓	✓	✓	✓

Physical accounts are provided for six pollutants (SO_2, PM_{10}, $PM_{2.5}$, NH_3, NO_2 and O_3), since these are output from the EMEP4UK dynamic air pollutant transport model used in this analysis. Health and monetary benefits are only provided for four pollutants (SO_2, $PM_{2.5}$, NO_2 and O_3). This is because only these pollutants currently have health damage costs assigned.

Two sets of accounts are presented:
i) A national UK account for air pollution removal by broad habitat types
ii) A cross-cutting urban account for GB, showing air pollution removal by urban greenspace: woodland, grassland and urban blue space: freshwater

2.5. Time frame of accounts

Natural capital accounts at the national scale were created for four years: 2007, 2011, 2015 and 2030. Accounts for the cross-cutting urban account were produced for 2015. The time series for both the physical accounts, and the economic accounts shows how the level of service has changed over time.

2.6. Health impacts of the selected pollutants

The pollutants of most concern for health impact assessment are fine particles ($PM_{2.5}$), NO_2 and O_3. $PM_{2.5}$ includes particles that are directly emitted (primary particles) and particles formed in the atmosphere from emissions primarily NH_3, NO_x and SO_2. The role of SO_2 in terms of generating health impacts has greatly declined over the last 60 years due to the success of emission control policies in urban areas.

For PM, the majority of health impacts attributed to particulate matter are caused by the $PM_{2.5}$ fraction, which are a component of the PM_{10} definition. $PM_{2.5}$ comprises the fine fraction of particulate matter considered most damaging to human health, as its size means that it can penetrate deep into the lung. It includes aerosols of nitrate, sulphate and ammonium as well as black carbon and other organic compounds and trace metals (World Health Organization, 2006). For NH_3, the primary health effects occur via ammonium aerosols which are a component of the $PM_{2.5}$ fine particulate fraction. Therefore, the health effects are considered within the $PM_{2.5}$ assessment, rather than separately.

3. METHODOLOGY

This note outlines the method used to quantify and value the environmental benefits from broad habitats in the UK.

3.1. Review evidence and develop logic chains (Step 1)

Overall, the logic chain provides the fundamental basis for developing a natural capital account in that it explicitly provides the link between the characteristics of an ecosystem asset and the provision of environmental benefits and societal benefits. Therefore, the first step in developing natural capital accounts is to develop (scientifically-grounded) logic chain models for the environmental benefit. The logic chain for air pollution removal by vegetation is shown in **Figure 2**.

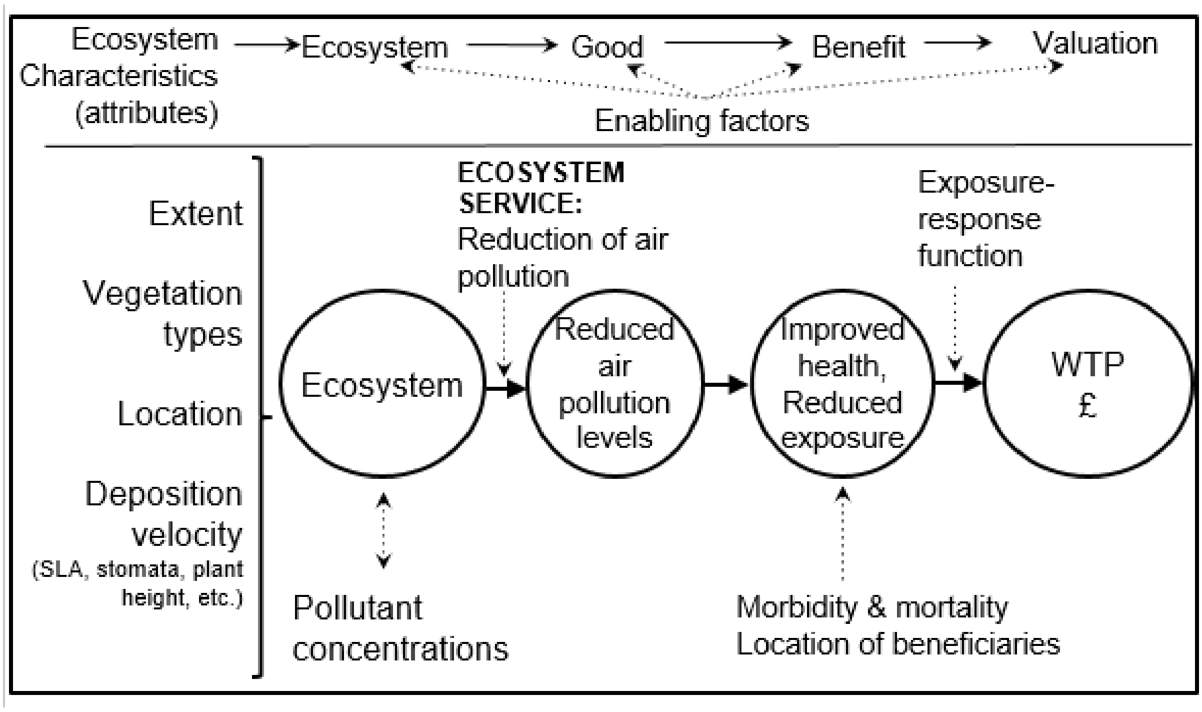


Figure 2. Logic chain for the environmental benefit of air pollution removal. WTP = Willingness to pay

3.2. Physical account of natural capital extent (Step 2)

The first component of the logic chain is the physical account. The stock of natural capital providing the service is the natural or semi-natural surfaces in the UK, including vegetation and water bodies, with stock defined in terms of its extent. Indicators of natural capital extent refer to the quantity of natural capital assets. The basic units for data collection are typically hectares of land cover (e.g. woodland, grassland) or km for linear features (e.g. rivers) and number of small features (e.g. street trees).

In the national account, the following are the proposed indicators for the extent of UK natural capital for air pollution removal:

- **Area of all 'broad' UKNEA habitats:** Provides detail to distinguish characteristics of land that link to all environmental goods and services;

Within the urban extent, natural capital comprises multiple elements including woodland, grassland of varying types as well as freshwater and saltwater. Therefore, a separate cross-cutting account is necessary to capture these elements of urban green- and blue-space and the services they provide. The report by eftec (2017) sets out the rationale for a cross-cutting urban account and gives an overview of how the account is constructed. For the cross-cutting urban account at GB level, extent is therefore defined for three green/blue space categories. These are derived from the OSMasterMap 'natural surface' category, with woodlands identified as any objects with the term 'trees' or 'woodland' in the main descriptor field. The three categories are:

- Urban woodland
- Urban grassland

- Urban freshwater[7]

3.3. Physical account of natural capital condition (Step 3)

Typically the condition account is the fundamental basis of the natural capital account. It plays a critical role in representing the role of natural capital in providing broad benefits, not all of which are able to be included in the physical or monetary account. However, in this study, because of the complexity of multiple vegetation attributes and their interactions with meteorology and other pollutants in determining the amount of pollutant removed, no condition indicators are reported.

3.4. Physical account of environmental benefit provision and use (Step 4)

The physical flow account captures the physical quantity of environmental benefit produced by natural capital within the defined UK boundary. Two approaches were considered:

The simpler Tier 1 approach works on a grid cell basis similar to that used in the draft account, applying a deposition velocity to each vegetation type moderated by simple climatic factors and timings of canopy development for deciduous species. However, this approach is static and does not consider atmospheric transport, or interactions among pollutants and a wider set of meteorological factors including temperature, rainfall and windspeed. This approach can only calculate the quantity of pollutant removed by each vegetation type.

The more sophisticated Tier 2 approach incorporates full interactions with meteorology and other pollutants which play a substantial role in moderating the deposition velocity at any point in time. It also includes atmospheric transport allowing a more robust assessment of the locations where the benefits of improved air quality are realised. Because this approach uses dynamic modelling (using the EMEP4UK model), it can calculate the change in pollutant concentration as well as the quantity of pollutant removed by each vegetation type. This in turn allows a more sophisticated approach to valuing the health benefits directly from changes in pollutant exposure.

Therefore, the environmental benefits to be included in this study were:

- **Quantity of pollutant removed by each vegetation type**
- **Resulting change in pollutant concentrations**

We also report the deposition velocity for a given vegetation type per unit land area. This determines the rate at which a pollutant deposits to a vegetation type. In this study we extract from the EMEP4UK model outputs the average dry deposition velocity across the UK for a given year. This is a spatial average of the annual average flux, divided by the annual average concentration and therefore reflects interactions between meteorology in that year and the concentrations of other pollutants. It should be noted that these values are not the same as the temporal average of the dry deposition velocity as calculated by the model for each model time step.

The physical flow account is calculated using the EMEP4UK atmospheric chemistry transport model. This model incorporates aspects of chemical transport and transformation, and dynamic interactions with meteorology and other land cover on an hourly timestep.

[7] This may include some saltwater in tidal river reaches occurring within the urban extent

EMEP4UK has been developed with funding by Defra (AQ0727), CEH and related research projects. It is capable of representing UK atmospheric composition in greater detail than larger i.e. European-scale models, with the ability to simulate hourly air pollution interactions over decadal time scales using a 5km grid or finer (can be run at a resolution of 2km). For this study, it was run at 5km grid due to constraints on model run-time and data processing. The Weather Research Forecast (WRF) model is used as the main meteorological driver.

The operational version of the EMEP4UK used for the national run was rv4.4, which is based on the EMEP MSC-W rv4.4. The version used for the new urban runs was rv4.17. The model core code is open source and available for download from the EMEP website. The EMEP MSC-W model is currently used to support European policy development by the UNECE Convention on Long-range Transboundary Air Pollution (CRLTAP) and the European Commission. More information on the horizontal and vertical resolution and the domain set up of the model, including extensive information on validation and model performance, can be found on the EMEP4UK website.

EMEP4UK simulates hourly to annual average atmospheric composition and deposition of various pollutants; including PM_{10}, $PM_{2.5}$, secondary organic aerosols (SOA), elemental carbon (EC), secondary inorganic aerosols (SIA), SO_2, NH_3, NO_x, and O_3. Dry and wet deposition of pollutants are routinely calculated by the model. In the EMEP4UK model, $PM_{2.5}$ concentrations from both primary and secondary sources are calculated within the model, based on primary industrial and agricultural emissions of precursor compounds within the UK, import of precursors from abroad via hemispheric transport as well as Volatile Organic Compounds (VOC) emissions from vegetation and other sources.

Parameters for EMEP4UK model runs for this work

Table 2 shows the emission years and the meteorology used in the model runs for this work. Full emissions for 2015 were not yet available so 2014 was used. The future scenario to 2030 used projected emissions under the NECD NFR emissions scenario (Amann et al. 2014), but held meteorology constant using 2015 data. These emissions scenarios also incorporate projections of population growth.

Table 2. Emissions and meteorology data used in EMEP4UK model runs.

Account year	Emissions year	Meteorology year
2007	2007	2007
2011	2011	2011
2015	2014	2015
2030	2030	2015

Evaluating the role of vegetation in pollutant removal:

The complexity of the model means that a scenario approach is required to establish the role of vegetation in pollutant removal. For each year, two scenarios are run, the first with current UK land cover, derived from CEH Landcover 2007, the second with all vegetated land classes removed and replaced with a neutral surface equivalent to bare soil. In order to calculate the effect of vegetation, outputs from the second scenario are extracted from the first. This approach allows all of the interactions with meteorology and other pollutants to continue as normal, while controlling for the presence and type of vegetation.

For the cross-cutting urban account, the same approach was taken but with a new hybrid land cover containing urban green and blue space. All non-urban habitats from CEH Landcover 2007 located within the Urban extent defined by eftec (2017) were classified into three broad categories of green/blue space, based on OS MasterMap (urban woodland, urban grassland, urban freshwater/saltwater). The hybrid land cover for the reference scenario therefore comprised the CEH LandcoverMap 2007 outside of the urban extent, while inside the urban extent, natural capital land covers were derived from the OSMM data containing the three categories above, with the remainder defined as 'Urban'. From the OSMM descriptors it was not possible to differentiate coniferous and deciduous woodland, therefore all woodland was assigned as deciduous, since deciduous trees are more common than conifers in UK cities. OSMM data was converted to raster, and Landcover was aggregated up from 25m pixels to the 1 km input data required for the EMEP4UK model. The alternative scenario retained CEH LandcoverMap 2007 outside the urban extent, but all urban natural capital was converted to 'bare soil' as in the main air pollution account. The scenarios compared 'current urban green/blue space' with a 'no green/blue space' scenario as described for the national account. The urban account was only calculated for Great Britain, as we did not have access to data equivalent to OS MasterMap for Northern Ireland.

While the model runs at a 5 km resolution for all pollutant interactions, the underlying landcover pattern i.e. the area of each vegetation type, is assembled from data at 25 m resolution from the CEH Landcover map 2007 (Morton et al. 2011), and projected at a 1 km grid cell resolution.

For each 5 km grid cell, the model calculates the dry deposition to each vegetation type present. EMEP4UK uses a simplified vegetation classification comprising 6 classes (Table 3), which differs from the UKNEA reporting categories. Therefore, in order to calculate the dry deposition to UKNEA broad habitats, the data for each grid cell were disaggregated back to the more detailed LCM2007 classes, then reassembled to the NEA broad habitat reporting classes (see lookup table in Annex 1).

The model also outputs the pollutant concentration within each 5 km grid cell. The effect of pollution removal by vegetation was calculated by subtracting the concentration values in the 'no vegetation' scenario from the 'current landuse' scenario.

Table 3. The seven landcover classes used in the UK EMEP4UK model runs

EMEP4UK land cover classes
Deciduous forest
Conifer forest
Crops
Semi-natural
Water
Bare soil/Desert
Urban

3.5. Health benefit and monetary account of annual provision of environmental benefit (Step 5a,b)

The economic calculations can take two approaches. i) Application of damage costs to generate an economic benefit from the quantity of pollutant removed (Tier 1 approach); ii) Applying a health analysis to the data on change in concentration to calculate economic benefit based on the exposure of the population (Tier 2 approach). In this account, we apply the more complex (**Tier 2**) approach, based on damage cost per unit exposure, directly assessing the health benefit of the receiving population. This follows the impact pathway guidance published by Defra in 2013[8], with some recent updates, and calculates the economic benefit directly from mortality and morbidity data and the change in pollutant exposure of the receiving population. The monetary account is therefore split into three components:

- **The health benefit** arising from the service of air pollution removal (Step 5a)
- **The monetary account** of that health benefit (Step 5b)
- **The future asset value** of that health benefit (Step 6)

Health benefits (Step 5a)

Quantification of health impacts requires the following:

1. Estimates of pollution exposure from the dispersion modelling, as described elsewhere in this report, and provided at local authority resolution.
2. Response functions relating exposure to death and illness derived from numerous epidemiological studies carried out in the UK, Europe, the USA and other locations.
3. Information on the underlying incidence or prevalence of illness and death, derived from national statistics on death and hospital admissions.
4. Unit values describing the monetary equivalent of health impacts. These may include up to three elements describing lost productivity, healthcare costs, and most importantly, lost utility, relating to the value that we place on living a healthy and long life.

Selection of response functions

Reviews have been conducted by various organisations at national and regional scale to identify health response functions. For the purpose of this assessment the recommendations of COMEAP (the UK's Committee on the Medical Effects of Air Pollutants, reporting the Department for Health) have been used, in line with accepted practice in UK government sponsored policy analysis. The COMEAP work has been reported in a series of papers available on their website (principally COMEAP 2010, 2015, 2016, 2017), recommending quantification of the effects listed in Table 4.

Table 4. Health effects recommended for quantification by COMEAP

Effect	$PM_{2.5}$	SO_2	NO_2	O_3
Mortality from long term exposure (life years lost)	✓		✓	
Mortality from short term exposure (deaths)				✓
Cardiovascular hospital admissions	✓		✓	✓
Respiratory hospital admissions	✓	✓	✓	✓

There are alternative recommendations for the functions to be used for quantification of impacts:

- WHO (2013): HRAPIE study (Health Response to Air Pollutants in Europe), which was adopted for analysis by the European Commission in the revision of its Thematic Strategy on Air Pollution.
- USEPA (2011): For analysis of various measures for air quality improvement.
- GBD for assessment of the global burden of disease [9].

WHO and USEPA both recommend quantification of a significant number of additional morbidity effects, including chronic bronchitis [10], exacerbation of respiratory conditions and 'restricted activity days' including lost work days. These effects are, to a large extent, yet to be considered by COMEAP, though work on cardiovascular morbidity and restricted activity days is ongoing.

[8] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197900/pb13913-impact-pathway-guidance.pdf

[9] http://www.healthdata.org/gbd

[10] COMEAP, 2015, recommends chronic bronchitis only for sensitivity analysis and hence it is not included in their analysis.

The functions adopted for the Global Burden of Disease study were not considered here as they are considered less robust than the functions recommended at the national level for the UK. This is no criticism of their use in the global analysis.

For the present study the functions (and hence list of effects) recommended for quantification by COMEAP / Defra are adopted. These functions are reliant on epidemiology studies that investigate associations between levels of one or more pollutants and health outcomes at the population level. Separating out the effects of individual pollutants from the mix that anyone is exposed to is complex, but the recommendations made by COMEAP have considered the potential for double counting (for example when considering mortality) and eliminated it to the extent possible. Any residual tendency for double counting, should it exist, would be countered by the omission of various types of impacts on morbidity.

$PM_{2.5}$ deaths and NO_2 deaths are from long term exposure to air pollutants leading to a significant loss of life expectancy, expressed most clearly in terms of life years lost (derived from the life tables). The life tables also permit an estimate of deaths to be generated, but interpretation of this figure is complicated. On COMEAP it has been defined as: “The number of 'equivalent attributable deaths' from PM (etc.) exposure”

This terminology is important and reflects something of the action of air pollution on health. With extremely high pollutant levels it is accepted that air pollution can kill with no contribution from other factors. However, for the majority of cases, air pollution will be one of a number of factors affecting the cardiovascular and respiratory systems, along with diet, exercise levels, smoking behaviour, etc. The number of deaths that may be associated with air pollution to any degree is thus likely to be higher than the number quantified by analysis (in the order of 30-40k people per year in the UK (RCPCH 2016)). However, to claim that this higher figure (which could be around 200,000 deaths per year or more for the UK alone) is entirely attributable to air pollution would be quite wrong. The lower estimate is considered to take account of the contribution of air pollution to the mortality burden.

O_3 deaths are linked in the analysis to short term fluctuations in O_3 levels. Whilst the underlying epidemiology gives an estimate of the number of deaths associated with short term fluctuations of O_3, it tells us nothing about the associated life years lost. Given that illness may again be initiated by other agents (diet, lack of exercise, smoking behaviour, other environmental stresses, etc.) it is considered inappropriate under UK guidance to apply the Value of Statistical Life to these deaths. It is estimated that the loss of life expectancy attributable to short term fluctuations in O_3 is 4 months per death. Hence O_3 deaths are quantified, but valued lower (by 2 thirds) than ‘life years lost’.

The quantification of short term impacts on mortality and on hospital admissions is a straightforward multiplication of population weighted concentrations, population, rate of illness and response function. Quantification of long term impacts on mortality instead uses a life table approach (Hurley et al, 2005; COMEAP, 2010; Miller et al, 2011). Life tables describe the structure of the population, accounting for inputs (births and immigration) and outputs (deaths and emigration). Changes in the risk of mortality (calculated by combining pollution data and response functions) affect the number of people moving from one age class to the next in successive years. Deaths from non-natural causes are excluded from the analysis (3.1% of all UK deaths[11]). Health functions and values used are summarised in Table 5.

[11] http://www.endoflifecare-intelligence.org.uk/view?rid=117

Table 5. Mortality and morbidity functions used in the evaluation of health benefits.

		Change in risk per 10 µg/m3	Age group	Rate per person	Value, £ (2012)	Source
PM2.5	Respiratory hospital admissions	1.09%	All age	0.01139	6,650	Atkinson et al. 2014
	Cardiovascular hospital admissions	0.91%	All age	0.01300	6,450	Atkinson et al. 2014
	Life years lost (as a result of long-term exposure)	6.00%	All [1]	1.00000	35,000	COMEAP 2010
SO2	Respiratory hospital admissions	0.50%	All age	0.01139	6,650	COMEAP 1998
NO2	Respiratory hospital admissions	0.52%	All age	0.01139	6,650	Mills et al. 2016
	Cardiovascular hospital admissions	0.42%	All age	0.01300	6,450	Mills et al. 2016
	Life years lost (as a result of long-term exposure)	0.92%	All [1]	1.00000	35,000	COMEAP 2017 (draft)
O3	Respiratory hospital admissions	0.75%	All age	0.01139	6,650	COMEAP 2015 ozone
	Cardiovascular hospital admissions	0.11%	All age	0.01199	6,450	COMEAP 2015 ozone
	Deaths (as a result of short term exposure)	0.34%	All age [2]	0.00915	6,000	COMEAP 2015 ozone

1 % change fed into life tables to generate adjustment factor
2 Calculated as £18,000 per life year * 4 months/ death

'Life years lost' is calculated from the life tables as the aggregate loss of life expectancy attributable to pollution exposure. Unlike 'quality adjusted life years' (QALYs), it is not weighted for health status in any way.

Valuation data are taken from Defra recommendations. Mortality and hospital admissions are valued from the perspective of willingness to pay, drawing on an earlier study by Chilton et al (2004) for Defra.[12]

For ozone, deaths are valued at £6,000 (2012 price), calculated by assuming that each ozone related death leads to the loss of (on average) 4 months of life, using a VOLY of £18,000 assuming that those affected are already in poor health. Life years lost associated with exposure to $PM_{2/5}$ and NO_2 are valued at £35,000 (2012 price), assuming those affected are in 'normal health'. It is noted that

12 http://webarchive.nationalarchives.gov.uk/20130403215617/http://archive.defra.gov.uk/environment/quality/air/airquality/publications/healthbenefits/airpollution_reduction.pdf

outside of the UK the use of the value of statistical life (VSL) is far more widespread. Using this approach the estimated values would be significantly higher (by roughly a factor 4 if using the recommendations from OECD, 2012).

Data on incidence and prevalence of disease

Data on mortality rates are taken from national statistics, providing data on the number of deaths for 2007, 2011 and 2015, and a projection for 2030 (the principal projection has been used).

Data on UK incidence of hospital admissions is taken from WHO's European Hospital Morbidity Database[13].

Data on the variation in hospital admissions around the country, by Local Authority, are taken from work carried out by the British Lung Foundation (BLF, 2017). The BLF study focused on respiratory hospital admissions, but it is assumed here that the same pattern of disease applies also to cardiovascular admissions. Population data have been taken from various sources[14].

For each pollutant, a population-weighted average change in concentration was calculated at local authority level, using a spatially attributed population map from the CEH Environmental Information Data Centre[15] (Reis et al. 2016) at 1 km resolution and EMEP4UK pollutant data. The exposed population was calculated using the population-weighted change in concentration, and population hind-casts or projections for each of the four years, by local authority.

To illustrate the calculation with some examples.

For $PM_{2.5}$, the value of avoided respiratory hospital admissions (RHAs) is calculated as (Table 6a):

- Change in concentration x Baseline RHA x Adjusted function per µg pollutant x Value of RHA

For $PM_{2.5}$, the value of avoided Loss of Life Years is calculated as (Table 6b):

- Change in concentration x Population x Adjusted function per µg pollutant x Value derived from life tables

For O3, the value of avoided deaths is calculated as (Table 6c):

- Change in concentration x Adjusted function per µg pollutant x All natural deaths x Adjusted value per life year

[13] http://data.euro.who.int/hmdb/

[14] https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/datasets/localauthoritiesinenglandtable2
https://www.nisra.gov.uk/sites/nisra.gov.uk/files/publications/SNPP14-LGD14-Tot-1439.xlsx
https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/population/population-projections/sub-national-population-projections/2014-based
https://statswales.gov.wales/Catalogue/Population-and-Migration/Population/Projections/Local-Authority/2014-based/populationprojections-by-localauthority-year

[15] https://catalogue.ceh.ac.uk/eidc/documents

Table 6. Examples of monetary calculations of avoided health outcomes.

a)

Location	Change in concentration of PM25 (µg/m3)	Baseline Respiratory Hospital Admission (RHA)	Adjusted function per µg/m3	Value per RHA, £ (2012)	Value, £2012
Wycombe	-0.87	1,551	0.00109	£6,650	-£9,742

b)

Location	Population	Change in concentration of PM25 (µg/m3)	Adjusted function per µg/m3	Value per Life Year Lost, £ (2012)	Value, £2012
Wycombe	172,797	-0.87	0.0006	35,000	-£3,151,722

c)

Location	Change in concentration of O3 (µg/m3)	Adjusted function per µg/m3	All natural deaths	Adjusted value of life year, £ (2012)	Value, £2012
Wycombe	-11.31	0.00034	1,262	6,000	-£29,128

Monetary value (Step 5b)

The monetary account captures the **economic** value (£) of the environmental benefits that have been quantified in the physical flow account. For commensurability with other national accounting data, this should be the 'exchange value' observed in markets or 'imputed exchange value' (i.e. indirectly measured or estimated) where markets do not exist. In practice, alternative welfare-based measures including consumer surplus can be provisionally included as if they were proxy exchange values (Day, 2013; Defra/ONS, 2017) with an indication given of the likely overestimation of value. This section provides a summary of the approach taken to valuing (£) the physical flow of air quality regulating benefits. Valuations used are shown in Table 5.

The economic value is attributed to the UKNEA broad habitats at a UK level, by allocating the total economic value of pollutant removal at the UK level by the proportion of pollutant removed by each vegetation type. This physical estimate was calculated for the UKNEA broad habitats at the grid square level by first disaggregating the quantity of pollutant removed by each CEH Landcover class and then re-aggregating these estimates up to the UKNEA broad habitats.

3.6. Monetary account of future provision of environmental benefit (Step 6)

This account values the natural capital asset(s) based on the present value of the stream of (annual) environmental benefits that the asset(s) will provide over a future period of time. Estimation of long-term asset values is calculated over a 100 year period with and without income uplift.

The Defra/ONS principles paper states that a 100-year asset life should be used to reflect the longevity of renewable natural assets. In principle, the asset value estimate should account for expected variations in both the physical and monetary flow of environmental benefits over the 100-year period. This could be significant for areas air quality regulation as the UK population is estimated to grow by 9.7 million over the next 25 years (ONS, 2014) making the importance of natural capital for air quality regulation even greater.

However, in practice, forecasting future flows of benefits and market prices/values is subject to significant uncertainty. For this study, physical and monetary estimates are produced for 4 time periods (2007, 2011, 2015 and 2030) taking into account changes in the following variables each year (either from existing data for previous years or forecasts for future years):

1. Physical flow – the profile of reductions in pollutant concentrations due to capture by vegetation accounts for the four years, each incorporating the pollutant emissions and meteorology for that year. Land cover was kept constant throughout all years.

2. Monetary value – this consists of three components

    a. Beneficiary population – this will vary according to the UK population that are exposed. Population growth over time is incorporated into the assessment.

    b. Dose-response functions for health - these are assumed to remain constant over time.

    c. Value of impacts – the impact of changes in pollution concentrations ($PM_{2.5}$, NO_2, SO_2, 0_3) on respiratory hospital admissions, cardiovascular hospital admissions, life years and deaths are reported (the coverage of impacts varies according to pollutant).

Discounting future flows of ecosystem service value requires the application of a discount rate. In line with Defra/ONS (2014), Green Book guidance for project appraisal (HM Treasury, 2011) will be applied, including a declining discount rate starting at 3.5%.

Where uplift is incorporated, we have made an adjustment to the estimated value of pollutant capture into the future that aligns with Defra (2014) air pollution valuation guidance. This guidance states that "health values are uplifted by 2% per year for analyses spanning a number of years" and that this is in line with Department of Health guidance to reflect increases in wealth measured by GDP growth. The reason being that willingness to pay (WTP) is likely to increase over time in line with increases in wealth (Defra, 2014). However, we suggest that the link to WTP would be better made through an adjustment based on median incomes (which have declined at certain points between 2007 and 2015) rather than GDP/capita. Nevertheless, the approach taken in this study is to adjust the values for the period 2007 to 2015 based on the GDP deflators (HM Treasury, 2017) and to then use a 2% uplift in line with the Defra guidance.

4. RESULTS FOR THE NATIONAL ACCOUNT

4.1. Physical account of natural capital extent, national account

Table 7 reports the total UK area as defined within this study is 249,034 km^2. The greatest landcover class is enclosed farmland, followed by semi-natural grassland, woodland, and mountain moors and heath.

Table 7. Extent of UK natural capital

Indicator		Broad habitat	Amount	Unit	Source
Extent	Total UK area		24,903,400	ha	CEH Landcover Map 2007
	Area of 'broad' UKNEA habitats	Woodland	2,887,500	ha	CEH Landcover Map 2007
		Enclosed farmland	12,549,900		
		Semi-natural grassland	3,281,100		
		Mountains, moors and heaths	2,609,600		
		Freshwater[1]	1,437,200		
		Coastal margins	44,500		
		Marine	-		
		Urban	1,473,200		
		Other[2]	620,500		

[1] Includes vegetated wetland areas: fen marsh swamp, + bog (1,110,800 ha) and open freshwater (326,300 ha)

[2] Includes bare ground, littoral and supralittoral sediment and rock, inland rock, saltwater (mainly in estuaries)

4.2. Physical account of environmental benefit provision, national account

This account captures two measures of the annual physical quantity of air quality regulation produced by natural capital within the UK, as i) change in pollutant concentrations (Table 8) and ii) tonnes pollutant removed (Table 9, and shown visually in Figure 3).

The change in concentration attributable to UK vegetation varied by pollutant, ranging from a 30% decrease in SO_2 to virtually no change in NO_2 concentration. There was a ~10% decrease in $PM_{2.5}$ concentration due to vegetation. Whilst vegetation captures pollutants with a higher efficiency than bare soil, it also results in some additional biogenic emissions. In EMEP4UK, certain types of vegetation emit biogenic volatile organic compounds (BVOCs), which act as a further precursor for particulate matter, and result in increased emissions of NO from soils, in particular in forests. This is the reason for the substantial decline in NO_2 removal over time. With anthropogenic NO_X emissions decreasing over time, the soil NO emissions due to vegetation starts to outweigh the capture in anthropogenic NO_x, leading to a small net increase in NO_2 concentrations overall.

In 2015, UK vegetation removed 1,262 ktonnes of $PM_{2.5}$, SO_2, NO_2 and O_3 (1,325 ktonnes including combined PM_{10} & $PM_{2.5}$ and NH_3). This fell from a total of 1,285 ktonnes of pollutants in 2007, and projected to fall to 1,230 ktonnes in 2030. By far the largest component in terms of weight was O_3.

The physical quantities of pollutants removed differ by vegetation type. The habitat which removes the most pollution varies. Woodland removes the most PM_{10} and $PM_{2.5}$. However, for the other pollutants, the greatest removal occurs in enclosed farmland, which incorporates both arable & horticulture, and improved grassland. This partly reflects the spatial pattern of highest pollutant concentrations in relation to the spatial pattern of vegetation types, but is also a function of how different pollutants deposit to vegetation. For example, $PM_{2.5}$ deposition is primarily governed by surface roughness and turbulence, whereas NH_3 deposition is governed to a large extent by surface wetness and leaf-surface chemistry. The EMEP4UK model accounts for the time periods when cropland is not in production. The open water, wetland and floodplain category reported here only includes pollutant removal by vegetated wetlands (fen marsh & swamp; bog), and not that removed by open water, which is small in comparison.

For the majority of pollutants, the absolute amount of pollution removed by vegetation, and the corresponding reduction in concentration, all get smaller over time i.e. the flow of service declines. This occurs primarily because pollutant concentrations have declined over this period, with the exception of O_3. In other words, there is less pollution for the vegetation to remove, so it provides less service. The pollutant concentrations are the major driver of change in the quantity of service provided, followed to a lesser extent by changes in meteorology (rainfall, temperature, windspeed) and chemical interactions among pollutants. Changes in extent (Table 7) are not a factor in this analysis as land cover was held constant over time.

Table 8. Average concentrations from EMEP4UK model in the two scenarios, and absolute change in concentration and relative difference (%) which represents the effect of vegetation in the national account. Negative values show a reduction in pollutant concentration due to vegetation (Units: µg m^{-3}).

Pollutant	Habitat	2007	2011	2015	2030
PM10	Current vegetation	11.55	10.74	9.9	8.01
	No vegetation	12.53	11.6	10.55	8.38
	Change in concentration	-0.98	-0.86	-0.65	-0.37
	Difference (%)	-7.8%	-7.4%	-6.2%	-4.4%
PM2.5	Current vegetation	6.36	6.08	4.85	3.31
	No vegetation	7.2	6.83	5.4	3.61
	Change in concentration	-0.84	-0.75	-0.55	-0.3
	Difference (%)	-11.7%	-11.0%	-10.2%	-8.3%
SO2	Current vegetation	1.46	1.07	0.85	0.5
	No vegetation	2.07	1.55	1.21	0.72
	Change in concentration	-0.61	-0.48	-0.36	-0.22
	Difference (%)	-29.5%	-31.0%	-29.8%	-30.6%
NH3	Current vegetation	1.32	1.49	1.33	1.18
	No vegetation	1.78	1.95	1.74	1.55
	Change in concentration	-0.46	-0.46	-0.41	-0.37
	Difference (%)	-25.8%	-23.6%	-23.6%	-23.9%
NO2	Current vegetation	9.33	7.62	5.8	3.16
	No vegetation	9.55	7.69	5.8	3.07
	Change in concentration	-0.22	-0.07	0	0.09
	Difference (%)	-2.3%	-0.9%	0.0%	2.9%
O3	Current vegetation	64.8	63.7	67.2	68.2
	No vegetation	75.3	74.3	77.5	78.7
	Change in concentration	-10.5	-10.6	-10.3	-10.5
	Difference (%)	-13.9%	-14.3%	-13.3%	-13.3%

Table 9. Pollutant capture by UKNEA broad habitat in the national account, as dry deposition of pollutants (ktonnes per year).

Pollutant	Habitat	2007	2011	2015	2030
PM10	Woodland	42.7	39.3	34.4	26.7
	Enclosed farmland	4.3	3.7	3.4	2.5
	Semi-natural grassland	1.8	1.7	1.5	1.2
	Mountain moor & heath	1.3	1.1	1.1	0.9
	Open water, wetland & floodplain[1]	0.7	0.6	0.6	0.5
	Coastal margins	0.04	0.04	0.03	0.02
	Total vegetation	50.8	46.4	41.1	31.8
PM2.5	Woodland	24.9	23.1	17.5	10.9
	Enclosed farmland	3.3	2.8	2.3	1.5
	Semi-natural grassland	1.3	1.2	1.0	0.7
	Mountain moor & heath	0.8	0.8	0.6	0.4
	Open water, wetland & floodplain[1]	0.4	0.4	0.3	0.2
	Coastal margins	0.03	0.03	0.02	0.01
	Total vegetation	30.8	28.3	21.8	13.8
SO2	Woodland	16.9	13.8	11.0	6.5
	Enclosed farmland	34.2	24.8	20.3	11.1
	Semi-natural grassland	5.7	4.7	3.9	2.3
	Mountain moor & heath	2.2	2.1	1.9	1.3
	Open water, wetland & floodplain[1]	1.0	1.0	0.8	0.6
	Coastal margins	0.16	0.12	0.10	0.06
	Total vegetation	60.1	46.6	37.9	21.8
NH3	Woodland	13.2	12.9	12.0	10.3
	Enclosed farmland	24.6	24.0	24.0	20.4
	Semi-natural grassland	4.9	5.0	4.8	4.2
	Mountain moor & heath	1.7	1.9	1.7	1.5
	Open water, wetland & floodplain[1]	0.8	0.9	0.8	0.7
	Coastal margins	0.10	0.10	0.10	0.08
	Total vegetation	45.3	44.8	43.5	37.2

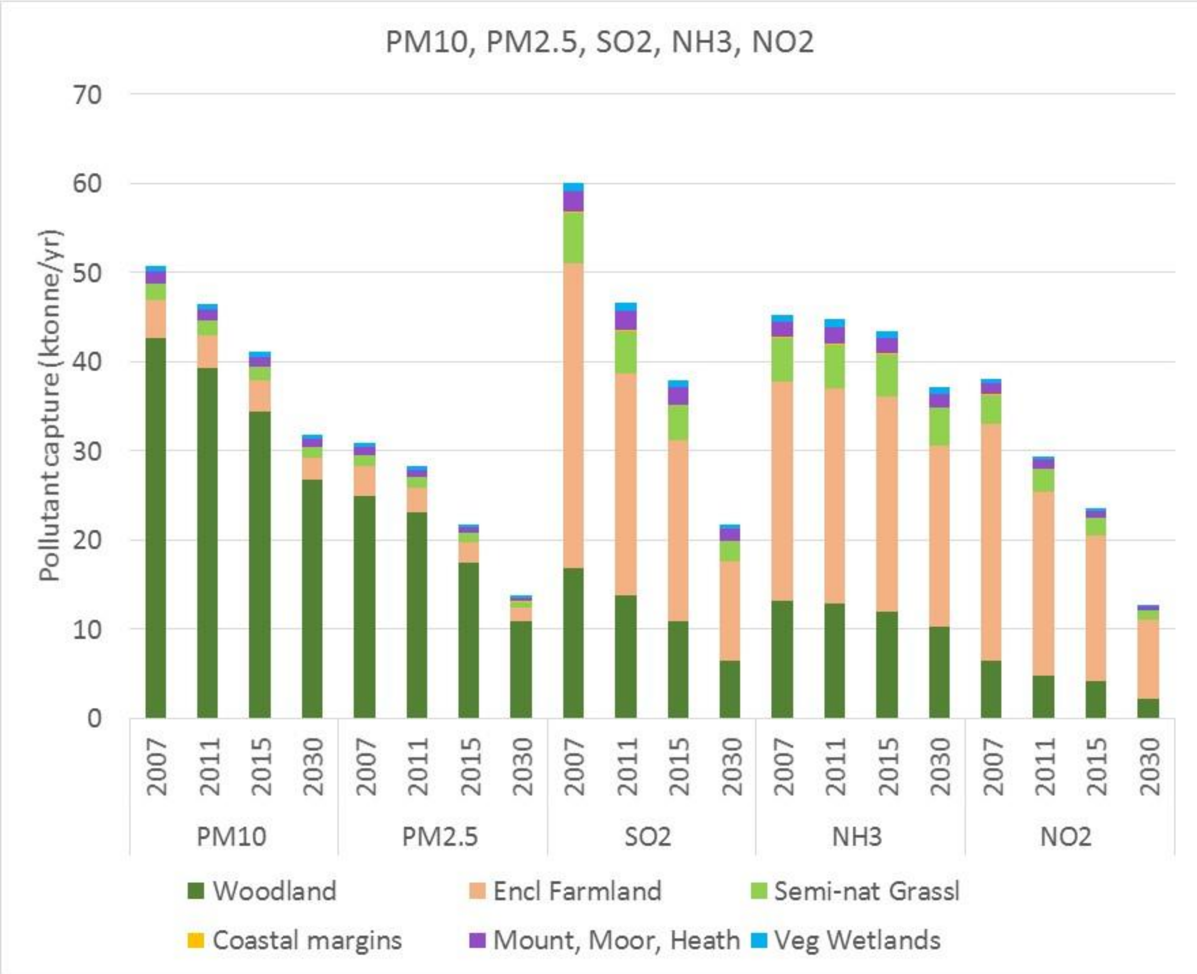
NO2	Woodland	6.4	4.9	4.1	2.3
	Enclosed farmland	26.7	20.5	16.3	8.7
	Semi-natural grassland	3.2	2.6	2.0	1.1
	Mountain moor & heath	1.2	1.0	0.8	0.4
	Open water, wetland & floodplain[1]	0.4	0.4	0.3	0.2
	Coastal margins	0.08	0.07	0.05	0.03
	Total vegetation	38.0	29.4	23.6	12.7
O3	Woodland	211.7	203.4	213.4	213.1
	Enclosed farmland	630.3	612.7	657.1	662.5
	Semi-natural grassland	144.0	137.9	141.4	140.7
	Mountain moor & heath	119.6	112.9	117.0	116.1
	Open water, wetland & floodplain[1]	49.1	46.7	48.3	48.0
	Coastal margins	1.78	1.71	1.81	1.83
	Total vegetation	1156.5	1115.2	1179.0	1182.3
All pollutants	Woodland	290.9	274.2	275.0	258.9
	Enclosed farmland	720.1	685.8	721.1	705.2
	Semi-natural grassland	159.6	151.9	153.6	149.4
	Mountain moor & heath	126.0	119.1	122.4	120.2
	Open water, wetland & floodplain[1]	52.0	49.5	50.8	49.9
	Coastal margins	2.16	2.04	2.09	2.02
	Total vegetation	1350.7	1282.6	1325.0	1285.8

1 Only vegetated wetlands (fen marsh & swamp; bog) included here. Open freshwater is not included.

Table 10 shows the average deposition velocity to each vegetation type. Note separate deposition velocities are provided for coniferous and deciduous woodland. The deposition velocity summarises the average efficiency of each vegetation type per unit land area in removing air pollution as implied by the detailed model calculations. There are various ways to average the deposition velocities, which in the model are calculated for each land cover class and grid cell at an hourly resolution. Here the averages were calculated as the spatial average over those cells that contain a given vegetation type, of the ratio of the annual deposition to that land cover divided by the average annual concentration. These are the values needed for the accounts calculations via the Tier 1 approach, but they can be quite different to a straight time-average of the hourly deposition velocities used by the model.

Woodlands are the most efficient at removing air pollution for all pollutants. However, the differential with the other habitats varies by pollutant. The differential is greatest for $PM_{2.5}$ and least for O_3. Note the deposition velocity is not constant over time, but varies due to changes in pollutant concentrations, meteorology and interactions among the two. The *average* deposition velocity presented here also responds to the degree of (anti-)correlation between the concentration and time-resolved deposition velocity, which can differ between compounds and between years.

a)



b)

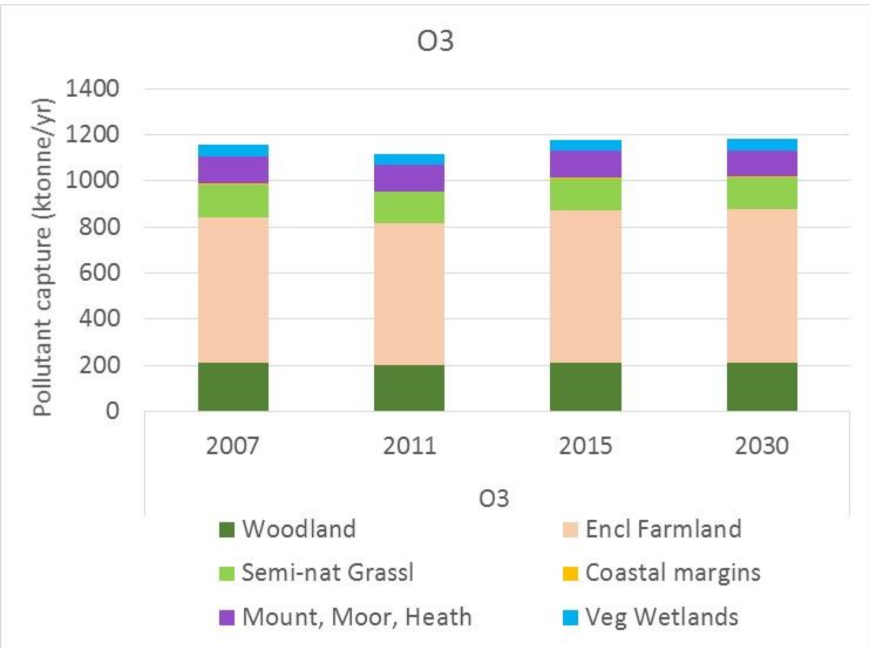


Figure 3. Pollutants captured by vegetation (ktonne yr^{-1}) showing a) PM_{10}, $PM_{2.5}$, NH_3, NO_2, and b) O_3

Table 10. Summary of deposition velocities per unit ground surface (mm s^{-1}) extracted from model outputs as a spatial and temporal average over the year, for the national account. Reported by EMEP4UK vegetation type not for UKNEA broad habitats, for each pollutant.

Pollutant	Habitat	2007	2011	2015	2030
PM10	Coniferous woodland	7.74	7.6	7.88	8.04
	Deciduous woodland	5.23	5.15	5.31	5.46
	Crops	2.15	2.1	2.35	2.64
	Moorland/ grassland	2.34	2.3	2.54	2.82
	Water	2.12	2.05	2.37	2.67
	Bare soil/ desert	2.15	2.08	2.34	2.64
PM2.5	Coniferous woodland	6.35	6.22	5.94	5.48
	Deciduous woodland	4.02	3.82	3.71	3.37
	Crops	0.71	0.59	0.66	0.61
	Moorland/ grassland	0.96	0.94	0.91	0.84
	Water	0.6	0.54	0.58	0.55
	Bare soil/ desert	0.6	0.59	0.57	0.53
SO2	Coniferous woodland	16.06	18.24	17.77	17.85
	Deciduous woodland	15.89	18.1	17.68	17.78
	Crops	5.05	5.51	5.45	5.41
	Moorland/ grassland	6.92	7.65	7.55	7.48
	Water	6.41	6.47	6.75	6.8
	Bare soil/ desert	1.15	1.26	1.17	1.15
NH3	Coniferous woodland	15	12.99	12.81	12.21
	Deciduous woodland	14.63	12.63	12.52	11.9
	Crops	3.53	3.34	3.33	3.27
	Moorland/ grassland	6.79	6.2	6.32	6.14
	Water	6.5	6.27	6.6	6.56
	Bare soil/ desert	1.2	1.27	1.25	1.24
NO2	Coniferous woodland	0.97	0.93	1	1.02
	Deciduous woodland	0.72	0.67	0.77	0.8
	Crops	0.54	0.51	0.54	0.54
	Moorland/ grassland	0.53	0.52	0.53	0.53
	Water	0.05	0.05	0.05	0.05
	Bare soil/ desert	0.05	0.05	0.05	0.05
O3	Coniferous woodland	4.44	4.34	4.32	4.28
	Deciduous woodland	3.91	3.82	3.83	3.77
	Crops	3.5	3.39	3.51	3.48
	Moorland/ grassland	2.78	2.74	2.67	2.63
	Water	0.49	0.49	0.5	0.5
	Bare soil/ desert	0.5	0.5	0.5	0.5

4.3. Health account of annual provision of environmental benefit, national account

Table 11 shows the avoided mortality and morbidity due to air pollution removal by UK vegetation. In 2015 the avoided burden on mortality is estimated at 1900 fewer deaths from short term exposure to O_3 (noting that these are, for the most part, likely to involve only a short reduction in life expectancy and are valued accordingly), 27,800 avoided life years lost from exposure to $PM_{2.5}$ and NO_2 combined, 5,800 fewer respiratory hospital admissions and 1,300 fewer cardiovascular hospital admissions from exposure to $PM_{2.5}$, SO_2, NO_2 and O_3.

Table 11. Change in mortality and morbidity of UK population as a result of air pollution removal by vegetation, for the national account.

		Change in no. of hospital admissions/life years lost/deaths attributable to presence of UK vegetation			
		2007	**2011**	**2015**	**2030**
		no./yr	no./yr	no./yr	no./yr
PM2.5	Respiratory hospital admissions	-814	-693	-533	-318
	Cardiovascular hospital admissions	-715	-609	-469	-279
	Life years lost	-42,736	-34,759	-26,009	-14,385
SO2	Respiratory hospital admissions	-308	-240	-181	-110
NO2	Respiratory hospital admissions	-346	-188	-125	-3
	Cardiovascular hospital admissions	-294	-160	-106	-3
	Life years lost	-5,618	-2,913	-1,843	-16
O3	Respiratory hospital admissions	-4,679	-4,889	-5,017	-5,861
	Cardiovascular hospital admissions	-722	-755	-775	-905
	Deaths	-1,798	-1,743	-1,899	-2,110
All pollutants combined	Respiratory hospital admissions	-6,146	-6,011	-5,856	-6,291
	Cardiovascular hospital admissions	-1,731	-1,524	-1,349	-1,186
	Life years lost	-48,354	-37,672	-27,851	-14,400
	Deaths	-1,798	-1,743	-1,899	-2,110

4.4. Monetary account of annual provision of environmental benefit, national account

The account in Table 12 captures the annual economic value (£) of various health impacts as a result of the reductions in air pollutant concentrations that have been quantified in the physical flow account. It shows that the total estimated value of air quality regulating benefits from UK vegetation is £1.75bn/year in 2007 and £1bn/year in 2015 (in 2012 prices).

Table 12. Annual value of air quality regulation from UK natural capital, for the national account.

		Annual value (2012 prices)			
		2007 £m/yr	**2011** £m/yr	**2015** £m/yr	**2030** £m/yr
PM2.5	Respiratory hospital admissions	£5.4	£4.6	£3.5	£2.1
	Cardiovascular hospital admissions	£4.6	£3.9	£3.0	£1.8
	Life years lost	£1,495.8	£1,216.6	£910.3	£503.5
SO2	Respiratory hospital admissions	£2.1	£1.6	£1.2	£0.7
NO2	Respiratory hospital admissions	£2.3	£1.3	£0.8	£0.02
	Cardiovascular hospital admissions	£1.9	£1.0	£0.7	£0.02
	Life years lost	£196.6	£101.9	£64.5	£0.5
O3	Respiratory hospital admissions	£31.1	£32.5	£33.4	£39.0
	Cardiovascular hospital admissions	£4.7	£4.9	£5.0	£5.8
	Deaths	£10.8	£10.5	£11.4	£12.7
Total		**£1,755.2**	**£1,378.8**	**£1,033.8**	**£566.2**

Table 13. Annual value of air quality regulation from UK natural capital, for the national account, broken down by UKNEA broad habitat.

Pollutant	Habitat	2007	2011	2015	2030
PM2.5 all health effects	Woodland	£1,217,696,000	£999,512,000	£737,952,000	£401,672,000
	Enclosed farmland	£161,255,000	£119,909,000	£97,885,000	£56,396,000
	Semi-natural grassland	£64,182,000	£53,685,000	£41,114,000	£24,348,000
	Mountain moor & heath	£41,458,000	£34,353,000	£26,343,000	£16,499,000
	Open water, wetland & floodplain	£19,750,000	£16,439,000	£12,665,000	£7,947,000
	Coastal margins	£1,449,000	£1,199,000	£914,000	£514,000
	Total vegetation	£1,505,789,000	£1,225,097,000	£916,876,000	£507,376,000
SO2 all health effects	Woodland	£576,000	£473,000	£349,000	£218,000
	Enclosed farmland	£1,168,000	£850,000	£643,000	£370,000
	Semi-natural grassland	£193,000	£162,000	£122,000	£77,000
	Mountain moor & heath	£74,000	£73,000	£60,000	£43,000
	Open water, wetland & floodplain	£34,000	£34,000	£27,000	£19,000
	Coastal margins	£5,000	£4,000	£3,000	£2,000
	Total vegetation	£2,050,000	£1,595,000	£1,204,000	£729,000
NO2 all health effects	Woodland	£33,995,000	£17,198,000	£11,594,000	£104,000
	Enclosed farmland	£140,781,000	£72,686,000	£45,732,000	£400,000
	Semi-natural grassland	£16,938,000	£9,168,000	£5,541,000	£49,000
	Mountain moor & heath	£6,443,000	£3,682,000	£2,218,000	£20,000
	Open water, wetland & floodplain	£2,240,000	£1,263,000	£775,000	£7,000
	Coastal margins	£422,000	£233,000	£142,000	£1,000
	Total vegetation	£200,819,000	£104,230,000	£66,002,000	£582,000
O3 all health effects	Woodland	£8,522,000	£8,725,000	£9,006,000	£10,359,000
	Enclosed farmland	£25,374,000	£26,284,000	£27,731,000	£32,201,000
	Semi-natural grassland	£5,799,000	£5,915,000	£5,969,000	£6,841,000
	Mountain moor & heath	£4,815,000	£4,843,000	£4,936,000	£5,643,000
	Open water, wetland & floodplain	£1,977,000	£2,003,000	£2,039,000	£2,334,000
	Coastal margins	£72,000	£74,000	£76,000	£89,000
	Total vegetation	£46,558,000	£47,844,000	£49,757,000	£57,467,000
Total pollutants	Woodland	£1,260,788,000	£1,025,907,000	£758,901,000	£412,353,000
	Enclosed farmland	£328,578,000	£219,729,000	£171,992,000	£89,368,000
	Semi-natural grassland	£87,112,000	£68,931,000	£52,746,000	£31,315,000
	Mountain moor & heath	£52,790,000	£42,951,000	£33,557,000	£22,205,000
	Open water, wetland & floodplain	£24,001,000	£19,738,000	£15,505,000	£10,307,000
	Coastal margins	£1,948,000	£1,510,000	£1,136,000	£606,000
	Total vegetation	£1,755,217,000	£1,378,766,000	£1,033,838,000	£566,155,000

4.5. Monetary account of future provision of environmental benefit, national account

The following tables capture the **asset value of natural capital for its air quality regulating benefits** as measured by the present value of the stream of (annual) ecosystem services that the asset(s) will provide over the 100 year period selected for the analysis (in line with Defra/ONS principles paper). Table 14 shows the asset value not including uplift, while Table 15 shows the asset value including uplift.

Table 14. Asset value of air quality regulation from UK natural capital, for the national account with no income uplift, as measured by the present value of the stream of (annual) ecosystem services that the asset(s) will provide over the 100 year period selected for the analysis.

		Asset value (2012 prices)			
		2007 £m/yr	2011 £m/yr	2015 £m/yr	2030 £m/yr
PM2.5	Respiratory hospital admissions	£88.9	£79.6	£72.8	£62.9
	Cardiovascular hospital admissions	£75.7	£67.8	£62.1	£53.7
	Life years lost	£22,509.4	£19,730.5	£17,802.8	£15,009.6
SO2	Respiratory hospital admissions	£31.0	£27.3	£25.0	£21.7
NO2	Respiratory hospital admissions	£15.6	£9.5	£6.2	£0.6
	Cardiovascular hospital admissions	£12.9	£7.9	£5.1	£0.5
	Life years lost	£1,254.7	£732.4	£455.2	£16.2
O3	Respiratory hospital admissions	£1,084.3	£1,105.0	£1,123.4	£1,161.9
	Cardiovascular hospital admissions	£162.4	£165.5	£168.2	£174.0
	Deaths	£357.1	£362.8	£368.7	£377.4
Total		**£25,591.9**	**£22,288.3**	**£20,089.5**	**£16,878.5**

Table 15. Asset value of air quality regulation from UK natural capital, for the national account with income uplift, as measured by the present value of the stream of (annual) ecosystem services that the asset(s) will provide over the 100 year period selected for the analysis.

		Asset value (2012 prices)			
		2007 £m/yr	2011 £m/yr	2015 £m/yr	2030 £m/yr
PM2.5	Respiratory hospital admissions	£135.3	£135.6	£138.5	£171.4
	Cardiovascular hospital admissions	£115.3	£115.6	£118.1	£146.1
	Life years lost	£33,585.2	£33,152.4	£33,535.3	£40,866.2
SO2	Respiratory hospital admissions	£47.0	£46.7	£47.7	£59.2
NO2	Respiratory hospital admissions	£16.2	£10.8	£7.5	£1.7
	Cardiovascular hospital admissions	£13.4	£8.9	£6.2	£1.4
	Life years lost	£1,274.9	£800.6	£531.2	£44.2
O3	Respiratory hospital admissions	£1,932.2	£2,112.6	£2,306.8	£3,163.5
	Cardiovascular hospital admissions	£289.4	£316.4	£345.4	£473.7
	Deaths	£632.7	£690.5	£753.6	£1,027.4
Total		**£38,041.5**	**£37,390.0**	**£37,790.4**	**£45,954.7**

5. RESULTS FOR THE CROSS-CUTTING URBAN ACCOUNT

5.1. Physical account of natural capital extent, cross-cutting urban account

Table 16 reports the total urban extent in GB as defined within this study is 1,765,700 ha. The majority of this is urban fabric and mixed surfaces, an OS MasterMap category which includes gardens. Of the green and blue space categorised, 412,400 ha is grassland including open parkland and 97,600 ha is woodland. Blue space occupies a smaller area of 19,474 ha.

Table 16. Quantity of urban natural capital. Left-hand columns show extent calculated direct from OS MasterMap, as reported in the urban cross-cutting accounts scoping study **(eftec, 2017), right-hand columns show extent calculated after converting to 25m raster format, used as input to modelling in this study.**

Indicator		Broad habitat	Amount	Unit	Source	Amount	Unit	Source
Extent	GB urban extent		1,765,700	Ha	eftec (2017) report	1,765,700	Ha	Hybrid LCM/ OSMM
	Area of 'broad' UKNEA habitats (GB only)	Woodland	99,400	Ha	OS MasterMap (GB only)	97,600	Ha	OS MasterMap (GB only)
		Grassland	420,400			412,400		
		Freshwater/ saltwater	22,700			19,474		
		Urban and mixed surfaces	1,223,200			1,236,226		

5.2. Physical account of environmental benefit provision, cross-cutting urban account

The change in pollutant concentrations is shown in Table 17, and the quantity of pollutants removed by each urban natural capital category is shown in Table 18. The urban accounts were only calculated for 2015 and 2030.

In 2015, urban green and blue space removed 26.6 ktonnes of $PM_{2.5}$, SO_2, NO_2 and O_3 (28.7 ktonnes including combined PM_{10} & $PM_{2.5}$ and NH_3). The change in concentration due to pollution removal by urban natural capital is much smaller than in the national account, up to a maximum of 1.8% reduction for SO_2, and only 0.44% reduction in concentration for $PM_{2.5}$. Nevertheless, there are still health and monetary benefits.

Table 17. Average concentrations from EMEP4UK model in the two scenarios (Current vegetation, No vegetation), and absolute change in concentration and relative difference (%) which represents the effect of urban green/blue space. Negative values show a reduction in pollutant concentration due to urban green/blue space (Units: µg m^{-3}).

Pollutant	Habitat	2015
PM10	Current vegetation	13.62
	No vegetation	13.66
	Absolute difference	-0.04
	Difference (%)	-0.29
PM2.5	Current vegetation	6.21
	No vegetation	6.24
	Absolute difference	-0.03
	Difference (%)	-0.44
SO2	Current vegetation	0.77
	No vegetation	0.78
	Absolute difference	-0.01
	Difference (%)	-1.83
NH3	Current vegetation	1.41
	No vegetation	1.42
	Absolute difference	-0.01
	Difference (%)	-0.90
NO2	Current vegetation	4.66
	No vegetation	4.69
	Absolute difference	-0.03
	Difference (%)	-0.61
O3	Current vegetation	66.6
	No vegetation	66.7
	Absolute difference	-0.2
	Difference (%)	-0.25

Table 18. Pollutant capture by urban green and blue space in the urban cross-cutting account, as dry deposition of pollutants (ktonnes per year).
* excludes $PM_{2.5}$ as a subset of PM_{10}

Pollutant	Habitat	2015
PM10	Urban trees/woodland	1.23
	Urban grassland	0.45
	Urban water	-0.004
	Total urban natural capital	1.68
PM2.5	Urban trees/woodland	0.70
	Urban grassland	0.31
	Urban water	-0.003
	Total urban natural capital	1.01
SO2	Urban trees/woodland	0.59
	Urban grassland	1.00
	Urban water	0.049
	Total urban natural capital	1.65
NH3	Urban trees/woodland	0.44
	Urban grassland	0.95
	Urban water	0.045
	Total urban natural capital	1.43
NO2	Urban trees/woodland	0.41
	Urban grassland	1.61
	Urban water	0.000
	Total urban natural capital	2.02
O3	Urban trees/woodland	4.97
	Urban grassland	16.94
	Urban water	-0.003
	Total urban natural capital	21.91
All pollutants*	Urban trees/woodland	7.65
	Urban grassland	20.95
	Urban water	0.087
	Total urban natural capital	28.68

5.3. Health account of annual provision of environmental benefit, cross-cutting urban account

Table 19 shows the avoided mortality and morbidity due to air pollution removal by UK urban green and blue space. In 2015 there were 239 avoided deaths, 3,600 avoided life years lost, 899 fewer respiratory hospital admissions and 220 fewer cardiovascular hospital admissions.

Table 19. Change in mortality and morbidity of UK population as a result of air pollution removal by urban green/blue space, for the urban cross-cutting account.

		2015
		no./yr
PM2.5	Respiratory hospital admissions	-58
	Cardiovascular hospital admissions	-51
	Life years lost	-2,733
SO2	Respiratory hospital admissions	-30
NO2	Respiratory hospital admissions	-63
	Cardiovascular hospital admissions	-53
	Life years lost	-908
O3	Respiratory hospital admissions	-749
	Cardiovascular hospital admissions	-116
	Deaths	-239
All pollutants combined	Respiratory hospital admissions	-899
	Cardiovascular hospital admissions	-220
	Life years lost	-3,641
	Deaths	-239

5.4. Monetary account of annual provision of environmental benefit, cross-cutting urban account

The economic value arising from these avoided health costs was substantial, £136m in 2015 (Table 20). This is broken down by habitat in Table 21, calculated at the GB level based on their relative contribution to the pollutant removal within each grid cell. A full analysis by habitat was not conducted as it would require separate model runs for each habitat. This shows that the majority of benefit from urban pollution removal is attributed to urban woodland and urban grassland, with slightly greater value attributable to urban woodland.

Table 20. Annual value of air quality regulation from urban green/blue space, for the cross-cutting urban account

		2015
		no./yr
PM2.5	Respiratory hospital admissions	£390,000
	Cardiovascular hospital admissions	£330,000
	Life years lost	£95,660,000
SO2	Respiratory hospital admissions	£200,000
NO2	Respiratory hospital admissions	£420,000
	Cardiovascular hospital admissions	£340,000
	Life years lost	£31,780,000
O3	Respiratory hospital admissions	£4,980,000
	Cardiovascular hospital admissions	£750,000
	Deaths	£1,430,000
All pollutants combined	**Total**	**£136,280,000**

Table 21. Annual value of air quality regulation from urban green/blue space, for the cross-cutting urban account, broken down by urban green/blue habitat type.

Pollutant	Habitat	2015
PM2.5 all health effects	Urban woodland	£67,011,184
	Urban grassland	£29,650,906
	Urban fresh/saltwater	-£285,668
	Total urban natural capital	£96,376,422
SO2 all health effects	Urban woodland	£70,936
	Urban grassland	£119,903
	Urban fresh/saltwater	£5,861
	Total urban natural capital	£196,701
NO2 all health effects	Urban woodland	£6,586,339
	Urban grassland	£25,964,428
	Urban fresh/saltwater	-£5,337
	Total urban natural capital	£32,545,430
O3 all health effects	Urban woodland	£1,625,505
	Urban grassland	£5,535,672
	Urban fresh/saltwater	-£1,002
	Total urban natural capital	£7,160,174
Total pollutants	Urban woodland	£75,293,964
	Urban grassland	£61,270,909
	Urban fresh/saltwater	-£286,146
	Total urban natural capital	£136,278,727

5.5. Monetary account of future provision of environmental benefit, cross-cutting urban account

The following tables capture the **asset value of natural capital for its air quality regulating benefits** as measured by the present value of the stream of (annual) ecosystem services that the asset(s) will provide over the 100 year period selected for the analysis (in line with Defra/ONS principles paper). Table 22 shows the asset value not including uplift, while Table 23 shows the asset value including uplift.

Table 22. Asset value of air quality regulation from urban green/blue space, for the cross-cutting urban account with no income uplift, as measured by the present value of the stream of (annual) ecosystem services that the asset(s) will provide over the 100 year period selected for the analysis.

		2015
		no./yr
PM2.5	Respiratory hospital admissions	£8,450,000
	Cardiovascular hospital admissions	£7,210,000
	Life years lost	£1,995,080,000
SO2	Respiratory hospital admissions	£3,980,000
NO2	Respiratory hospital admissions	£5,970,000
	Cardiovascular hospital admissions	£4,920,000
	Life years lost	£436,360,000
O3	Respiratory hospital admissions	£177,430,000
	Cardiovascular hospital admissions	£26,570,000
	Deaths	£48,560,000
All pollutants combined	**Total**	**£2,714,530,000**

Table 23. Asset value of air quality regulation from urban green/blue space, for the cross-cutting urban account with income uplift, as measured by the present value of the stream of (annual) ecosystem services that the asset(s) will provide over the 100 year period selected for the analysis.

		2015
		no./yr
PM2.5	Respiratory hospital admissions	£16,290,000
	Cardiovascular hospital admissions	£13,880,000
	Life years lost	£3,808,450,000
SO2	Respiratory hospital admissions	£7,550,000
NO2	Respiratory hospital admissions	£10,350,000
	Cardiovascular hospital admissions	£8,540,000
	Life years lost	£746,960,000
O3	Respiratory hospital admissions	£366,630,000
	Cardiovascular hospital admissions	£54,900,000
	Deaths	£99,780,000
All pollutants combined	**Total**	**£5,133,330,000**

6. DISCUSSION

6.1. Scope and Interpretation

Baseline

The Defra/ONS principles paper does not explicitly reference the relevant baseline to use when estimating the provision of environmental benefits. However, it implies that it is the total amount of benefit produced - "valuation considers the value of goods and services produced during an accounting period" (Defra, ONS, 2017). Using this principle this analysis has adopted a baseline which assumes that no natural capital exists (i.e. "bare soil"). Providing an explicit baseline such as 'bare soil' is important for services such as air quality regulation, because some level of pollutant removal will be provided by all surfaces, including structurally complex urban fabric such as buildings. In other words, the benefit to be quantified is the additional pollutant capture provided by vegetation over and above the pollutant deposition that would occur on bare soil or other surfaces.

Causes of variation in the accounts

The main factor governing temporal trends in the accounts is changes in the pollutant concentrations associated with changes in emissions. Changes in the concentrations of the various pollutants interact, affecting transformations, PM formation and also each other's deposition velocity. Meteorology also plays a role, but when looking at changes over several years, this is smaller than the primary driver of pollutant concentrations. A different picture is likely to emerge when looking at adjacent years between which emission changes are less pronounced. The importance of emission changes can be illustrated by comparing the 2015 and 2030 projections, since both land cover and meteorology were kept constant due to the difficulty of projecting these forward in time. Any difference between those two years in pollution removal or concentrations is purely down to atmospheric chemistry effects. Land cover was held constant throughout this analysis although, even if included, its effects are likely to be small. The Phase 1 report (Jones et al. 2016) highlighted a maximum of 2% change in land cover nationally over a 10-year period.

Note that calculations are based on a change in concentration (i.e. a change in exposure to the pollutants), so the average value per unit change in concentration goes up. However, if expressed as average value per unit change in pollutant deposited, it appears to go down over time (Table 24).

Table 24. Example calculations of average value per unit change in pollutant, for $PM_{2.5}$ in the national account

	Value per tonne pollutant captured		Value per µg/m^3 change in concentration	
	2007	2015	2007	2015
$PM_{2.5}$	£48,833	£42,145	£1,771,517,002	£1,667,046,387

This occurs because the relationship between pollutant emissions/deposition and changes in concentration is non-linear, and is concentration dependent. The ktonnes of pollutant captured has decreased over time, but so has the efficiency of capture i.e. the change in concentration per kt captured (blue line), see Figure 4 below. There is both greater pollution removal and greater efficiency at higher pollutant concentrations, because steeper concentration gradients increase the rate of pollutant deposition to a surface. Values also change, but to a lesser extent, due to an increase in the beneficiary population, and due to the economic adjustments in value over time.

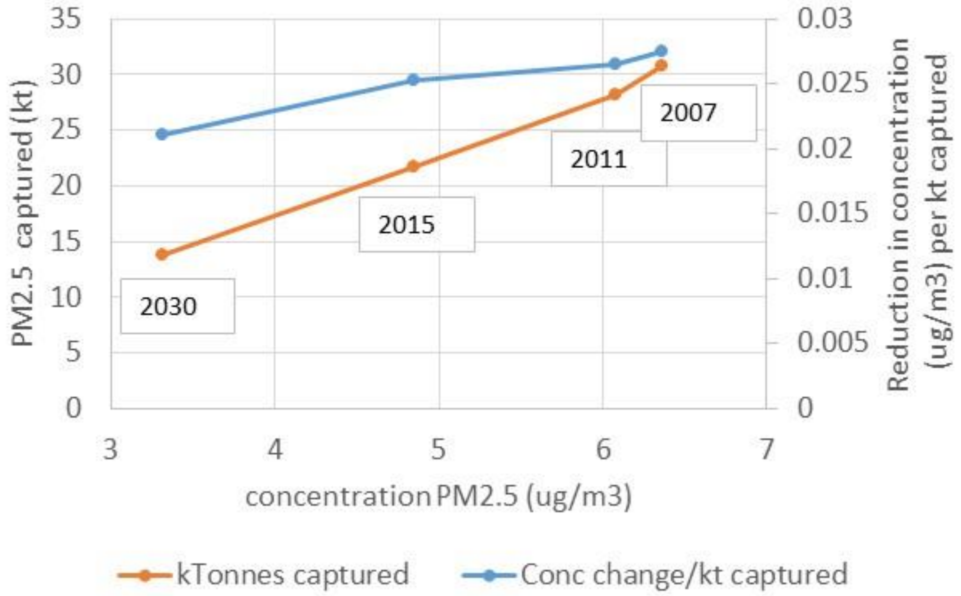


Figure 4. Change in capture efficiency of $PM_{2.5}$ with change in concentration.

Comparison with other studies

The values produced in this study are broadly comparable with other studies. Comparison with outputs from the draft air pollution accounts is only possible for tonnes of PM_{10} and SO_2 removed by vegetation. This study estimates 34.4 kt of PM_{10} removed by woodland in 2015, compared with a much higher figure of 151.8 kt in the draft accounts. The estimate for SO_2 for woodland in this study was 11.0 kt, compared with 1.5 kt in the draft accounts[16]. The values for enclosed farmland also differ considerably in this study (3.4 kt PM_{10}, 20.3 kt SO_2) compared with the draft accounts (54.9 kt PM_{10}, 1.2 kt SO_2). The likely reasons for this are discussed in detail in the Phase 1 report (Jones et al. 2016), and include an incorrect additional scaling for surface area applied in the earlier study, the use of static deposition velocities based on old literature values, with relatively simplistic adjustments for climate at a regional level compared with the more realistic EMEP4UK modelling approach which incorporates pollutant chemistry and meteorology interactions and atmospheric transport.

Comparing the 2015 results of this study with the i-tree Eco London study (Rogers et al. 2015), for trees only, and for the pollutants (PM_{10} (including $PM_{2.5}$), SO_2, NO_2 and O_3), this study estimates 275 kt pollutants removed. If the 2.2 kt pollutant removal in i-tree London was scaled to the UK based on land area, it would equate to 345 kt, and is therefore broadly similar to our results. This study estimates a value of £758m for pollutant removal by UK trees, for four pollutants only ($PM_{2.5}$, SO_2, NO_2 and O_3). If the i-tree £126m estimate of pollutant removal by trees in London for those four pollutants and PM_{10} is scaled to the UK based on population, this equates to £952m, approximately 30% higher than our estimate. These figures are not widely different, but possible reasons for the differences may be that i-tree did an inventory of individual trees and therefore likely included a greater estimate of tree cover than our study. Meanwhile, the valuation approach also differs. In this study we value the health benefit arising from a change in air pollutant concentrations, while the i-tree study used damage costs per tonne of pollutant emitted.

16 https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/annex1backgroundandmethodsforexperimentalpollutionremovalestimates

In comparison to international studies, Nowak et al. (2014) calculated air pollution removed for four pollutants ($PM_{2.5}$, SO_2, NO_2 and O_3) by trees across the USA. They estimated 9-23 million tonnes of pollution removed, scaling to the UK land area would give an estimate of 0.27 – 0.77 million tonnes, with our UK 2015 value just at the low end of that range (0.26 million tonnes). However, this quick comparison ignores considerations of differences in tree cover and pollutant concentrations between the studies. Nowak et al. (2014) showed only a small reduction in pollutant concentrations (< 1 %), compared with our larger ranges (0-30% reduction). In terms of health impacts, the UK accounts show an order of magnitude greater avoided mortality (adjusting for population) compared with the USA, but proportionally much lower values for avoided respiratory symptoms. It should be noted that the comparison between UK and USA is further complicated by difference in the pollution levels of the individual compounds and also in the degree of segregation between emission regions, forests and receptor regions (urban areas).

It is noted that there is interest in the use of green infrastructure as a means of reducing pollutant exposures in cities. For this reason it is important to understand precisely what the results provided here represent: the benefit of all vegetation in the UK. Given the long range dispersion of pollutants, the results for any local authority do not solely represent the benefits of vegetation within the boundaries of that local authority, but the benefit arising from vegetation over a much larger area. This means that static approaches such as that used by i-tree are likely to under-estimate the benefit provided by trees outside of the urban area but which are experienced by the population in urban areas, and also the benefits provided by urban trees which extend to populations living beyond that urban extent.

7. CONCLUSIONS AND NEXT STEPS

7.1. Summary

This UK natural capital account shows the significant value of air pollution removal provided by vegetation in the UK, in terms of the quantities of pollutants removed, the health benefits arising from the resulting change in pollutant concentrations, and the economic value of that avoided mortality and morbidity.

7.2. Maintaining ecosystem accounts

With respect to maintaining the air pollution removal account over time and the frequency with which this should be done (i.e. whether this should be a 1 year, 2 year or 5 year, etc. basis), the following main factors should be considered:

i) The period over which the underlying datasets that are used to populate the accounts are updated needs to be determined. Pollutant emissions are reported every year, and meteorology data are provided every year, although with a one-to-two year lag in reporting. Population estimates are updated every few years. There is no current approach to regularly update landcover in a reporting manner consistent with previous classifications. The CEH Landcover Map 2015 has just been released, and new satellite products will also be developed. However, land cover change is very small in comparison to other variables driving changes in this service. It is therefore a relatively low priority to update.

ii) The purpose of the accounts needs to be addressed. If the purpose is for a comparison with the System of National Accounts (SNA), then a longer time period may be justified (e.g. 5 years) as the accounts are more of an administrative tool to attribute economic value to the environment. However, if the purpose is to assess the sustainability of an ecosystem stock and the economic value that flows from it then a shorter time period (e.g. 2 years) might be selected. The purpose of this would be to establish a practice of regularly measuring (changes in) the extent and condition of the stock so that this can be tracked and the potential impacts on future environmental benefit flows captured. For this tracking to be possible, there must be sufficient confidence in the underlying data and its ability to accurately detect changes in the condition of the stock over time at the spatial scale of interest.

7.3. Future refinement of air quality natural capital account

Table 25 shows the physical and monetary value estimated for the environmental benefit and the certainty associated with those estimates. The ratings for the monetary aspects do not relate to the total value shown but rather the methodology applied. In the case of air pollution removal, while the science is fairly robust, different models and different approaches may produce varying estimates, by up to a factor of 2 difference. There is a trade-off inherent in the accuracy of incorporating atmospheric transport and pollutant interactions at national scale, and the fine detail required to populate information about the type and location of vegetation on the ground. The approach taken here is robust, but emphasises pollutant transport and chemistry over fine-scale granularity.

Table 25. Overview of certainty associated with physical and monetary value estimates

Environmental benefit	Scale	Physical estimate	RAG	Monetary, 2015 (2012 prices)	RAG
National account: Air quality regulation, 2015, $PM_{2.5}$, SO_2, NO_2, O_3 (& including PM_{10} and NH_3)	UK	1,262 ktonnes pollutants removed (1,325 ktonnes including combined PM_{10} & $PM_{2.5}$ and NH_3)	(amber)	£1,033m	(green)
Cross-cutting urban account: Air quality regulation, 2015, $PM_{2.5}$, SO_2, NO_2, O_3 (& including PM_{10} and NH_3)	Urban extent, GB	26.6 ktonnes pollutants removed (28.7 ktonnes including combined PM_{10} & $PM_{2.5}$ and NH_3)	(amber)	£136m	(green)

RAG	Description
(red)	Evidence is partial and significant assumptions are made that require further research
(amber)	Evidence is based on assumptions grounded in science and using published data but with some uncertainty regarding the combination of assumptions
(green)	Evidence is peer reviewed or based on published guidance

In conclusion, a number of recommendations are outlined with respect to the development of UK natural capital accounts for air pollution removal.

- The current accounts are based on a model comparison of ‘current vegetation’ and ‘no vegetation’ scenarios. This allows extraction of the pollutant removal by each vegetation type, but does not allow spatial attribution of those benefits to each vegetation type. In other words, the change in pollutant concentration at any location is an outcome of all the vegetation and meteorology-pollutant interactions that have occurred in the parcel of air before reaching that location. In order to quantify the change in concentration due to a particular vegetation type, separate scenario comparisons are required for each vegetation type, creating a new ‘no vegetation’ scenario for each.

- The EMEP4UK model only incorporates seven land cover classes relevant for the UK. Inclusion of additional classes would provide greater thematic resolution to the modelling, and may allow for inclusion of condition variables in the land cover.

- The EMEP4UK model version to produce these accounts was run at 5x5 km resolution for pollutant interactions. It would be possible to run the model at a finer resolution of ~2x2 km, although the time taken to process and the storage required for the results of each run would be far greater.

- Consideration could be given to inclusion of land cover change over time, although this is likely to be small influence on the outputs.

- The damage costs used to produce the accounts are based on the latest COMEAP guidance. However, the science of quantification of health impacts of air pollution is a fast evolving field. The need to factor in additional impacts, or revise the response functions and data used for quantification here, should be kept under review.

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ANNEX 1.

Table A1. Lookup table showing UK area of each LCM2007 class and cross-matching to EMEP4UK vegetation classes and UKNEA broad habitat reporting classes.

			EMEP4UK landcover class		
LCM 2007 code	LCM class UK area (km2)	LCM class	Reference scenario	No-vegetation scenario	UKNEA Broad habitat reporting category
1	13,785	broadleaved woodland	Deciduous forest	Bare soil/Desert	Woodland
2	15,090	coniferous woodland	Conifer forest	Bare soil/Desert	Woodland
3	63,058	arable & horticulture	Crops	Bare soil/Desert	Enclosed farmland
4	62,442	improved grassland	Semi-natural	Bare soil/Desert	Enclosed farmland
5	14,438	rough grassland	Semi-natural	Bare soil/Desert	semi-natural grassland
6	1,508	neutral grassland	Semi-natural	Bare soil/Desert	semi-natural grassland
7	372	calcareous grassland	Semi-natural	Bare soil/Desert	semi-natural grassland
8	16,492	acid grassland	Semi-natural	Bare soil/Desert	semi-natural grassland
9	102	fen marsh swamp	Semi-natural	Bare soil/Desert	Open water, wetland and floodplain
10	7,673	heather	Semi-natural	Bare soil/Desert	Mountain moor & heath
11	13,506	heather grassland	Semi-natural	Bare soil/Desert	Mountain moor & heath
12	11,006	bog	Semi-natural	Bare soil/Desert	Open water, wetland and floodplain
13	4,918	montane	Semi-natural	Bare soil/Desert	Mountain moor & heath
14	1,324	inland rock	Bare soil/Desert	Bare soil/Desert	Not reported
15	1,664	saltwater	Water	Water	Not reported
16	3,263	freshwater	Water	Bare soil/Desert	Open water, wetland and floodplain
17	80	supralittoral rock	Bare soil/Desert	Bare soil/Desert	Not reported
18	484	supralittoral sediment	Bare soil/Desert	Bare soil/Desert	Not reported
19	504	littoral rock	Bare soil/Desert	Bare soil/Desert	Not reported
20	2,148	littoral sediment	Bare soil/Desert	Bare soil/Desert	Not reported
21	445	saltmarsh	Semi-natural	Bare soil/Desert	Coastal margins
22	3,343	urban	Urban	Urban	Urban
23	11,389	suburban	Urban	Urban	Urban

ANNEX 2.

The following Tables contain additional data for the urban analysis. They contain scaled values for 2030 based on a previous model run with different settings. These data should only be used at UK level to understand projections of change over time in the physical and monetary flows provided by urban vegetation.

Table A2. Pollutant capture by urban green and blue space in the urban cross-cutting account, as dry deposition of pollutants (ktonnes per year). Note 2030 values are scaled based on a previous model run.

Pollutant	Habitat	2015	Scaled 2030
PM10	Urban trees/woodland	1.23	0.85
	Urban grassland	0.45	0.32
	Urban water	-0.004	-0.003
	Total urban natural capital	1.68	1.16
PM2.5	Urban trees/woodland	0.70	0.40
	Urban grassland	0.31	0.18
	Urban water	-0.003	-0.002
	Total urban natural capital	1.01	0.58
SO2	Urban trees/woodland	0.59	0.32
	Urban grassland	1.00	0.52
	Urban water	0.049	0.025
	Total urban natural capital	1.65	0.89
NH3	Urban trees/woodland	0.44	0.36
	Urban grassland	0.95	0.80
	Urban water	0.045	0.039
	Total urban natural capital	1.43	1.18
NO2	Urban trees/woodland	0.41	0.21
	Urban grassland	1.61	0.82
	Urban water	0.000	0.000
	Total urban natural capital	2.02	1.04
O3	Urban trees/woodland	4.97	5.13
	Urban grassland	16.94	17.53
	Urban water	-0.003	-0.003
	Total urban natural capital	21.91	22.62
All pollutants*	Urban trees/woodland	7.65	7.01
	Urban grassland	20.95	20.20
	Urban water	0.087	0.058
	Total urban natural capital	28.68	26.43

* excludes $PM_{2.5}$ as a subset of PM_{10}

Table A3. Change in mortality and morbidity of UK population as a result of air pollution removal by urban green/blue space, for the urban cross-cutting account. Note 2030 values are scaled based on a previous model run. Ozone related health impacts go up because average ozone concentrations are increasing over time.

		2015	Scaled 2030
		no./yr	no./yr
PM2.5	Respiratory hospital admissions	-58	-38
	Cardiovascular hospital admissions	-51	-33
	Life years lost	-2,733	-1,666
SO2	Respiratory hospital admissions	-30	-17
NO2	Respiratory hospital admissions	-63	-20
	Cardiovascular hospital admissions	-53	-17
	Life years lost	-908	-272
O3	Respiratory hospital admissions	-749	-939
	Cardiovascular hospital admissions	-116	-145
	Deaths	-239	-281
All pollutants combined	Respiratory hospital admissions	-899	-1,014
	Cardiovascular hospital admissions	-220	-196
	Life years lost	-3,641	-1,938
	Deaths	-239	-281

Table A4. Annual value of air quality regulation from urban green/blue space, for the cross-cutting urban account. Note 2030 values are scaled based on a previous model run. Ozone related health impacts go up because average ozone concentrations are increasing over time.

		Annual value	
		2015	**2030**
		£/yr	£/yr
PM2.5	Respiratory hospital admissions	£390,000	£250,000
	Cardiovascular hospital admissions	£330,000	£220,000
	Life years lost	£95,660,000	£58,320,000
SO2	Respiratory hospital admissions	£200,000	£110,000
NO2	Respiratory hospital admissions	£420,000	£140,000
	Cardiovascular hospital admissions	£340,000	£110,000
	Life years lost	£31,780,000	£9,510,000
O3	Respiratory hospital admissions	£4,980,000	£6,240,000
	Cardiovascular hospital admissions	£750,000	£930,000
	Deaths	£1,430,000	£1,690,000
	Total	**£136,280,000**	**£77,520,000**

Table A5. Annual value of air quality regulation from urban green/blue space, for the cross-cutting urban account, broken down by urban green/blue habitat type. Note 2030 values are scaled based on a previous model run. Ozone related health impacts go up because average ozone concentrations are increasing over time.

Pollutant	Habitat	2015	Scaled 2030
PM2.5 all health effects	Urban woodland	£67,011,184	£40,668,183
	Urban grassland	£29,650,906	£18,321,574
	Urban fresh/saltwater	-£285,668	-£199,696
	Total urban natural capital	£96,376,422	£58,790,061
SO2 all health effects	Urban woodland	£70,936	£42,342
	Urban grassland	£119,903	£69,002
	Urban fresh/saltwater	£5,861	£3,297
	Total urban natural capital	£196,701	£114,641
NO2 all health effects	Urban woodland	£6,586,339	£1,980,808
	Urban grassland	£25,964,428	£7,772,426
	Urban fresh/saltwater	-£5,337	-£520
	Total urban natural capital	£32,545,430	£9,752,713
O3 all health effects	Urban woodland	£1,625,505	£2,007,788
	Urban grassland	£5,535,672	£6,857,407
	Urban fresh/saltwater	-£1,002	-£1,199
	Total urban natural capital	£7,160,174	£8,863,996
Total pollutants	Urban woodland	£75,293,964	£44,699,121
	Urban grassland	£61,270,909	£33,020,409
	Urban fresh/saltwater	-£286,146	-£198,118
	Total urban natural capital	£136,278,727	£77,521,411

Table A6. Asset value of air quality regulation from urban green/blue space, for the cross-cutting urban account with no income uplift, as measured by the present value of the stream of (annual) ecosystem services that the asset(s) will provide over the 100 year period selected for the analysis. Note 2030 values are scaled based on a previous model run. Ozone related health impacts go up because average ozone concentrations are increasing over time.

		Asset value, no income uplift	
		2015	**Scaled 2030**
		£/yr	£/yr
PM2.5	Respiratory hospital admissions	£8,450,000	£7,540,000
	Cardiovascular hospital admissions	£7,210,000	£6,420,000
	Life years lost	£1,995,080,000	£1,738,720,000
SO2	Respiratory hospital admissions	£3,980,000	£3,420,000
NO2	Respiratory hospital admissions	£5,970,000	£4,030,000
	Cardiovascular hospital admissions	£4,920,000	£3,320,000
	Life years lost	£436,360,000	£283,400,000
O3	Respiratory hospital admissions	£177,430,000	£186,090,000
	Cardiovascular hospital admissions	£26,570,000	£27,870,000
	Deaths	£48,560,000	£50,300,000
	Total	**£2,714,530,000**	**£2,311,110,000**

Table A7. Asset value of air quality regulation from urban green/blue space, for the cross-cutting urban account with income uplift, as measured by the present value of the stream of (annual) ecosystem services that the asset(s) will provide over the 100 year period selected for the analysis. Note 2030 values are scaled based on a previous model run. Ozone related health impacts go up because average ozone concentrations are increasing over time.

		Asset value, with income uplift	
		2015	**Scaled 2030**
		£/yr	£/yr
PM2.5	Respiratory hospital admissions	£16,290,000	£20,520,000
	Cardiovascular hospital admissions	£13,880,000	£17,490,000
	Life years lost	£3,808,450,000	£4,733,980,000
SO2	Respiratory hospital admissions	£7,550,000	£9,310,000
NO2	Respiratory hospital admissions	£10,350,000	£10,980,000
	Cardiovascular hospital admissions	£8,540,000	£9,050,000
	Life years lost	£746,960,000	£771,600,000
O3	Respiratory hospital admissions	£366,630,000	£506,660,000
	Cardiovascular hospital admissions	£54,900,000	£75,870,000
	Deaths	£99,780,000	£136,950,000
	Total	**£5,133,330,000**	**£6,292,410,000**