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A Compendium of Marine Related Carbon Stores, Sequestrations and Emissions

Scottish Marine and Freshwater Science Vol 11 No 1

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This report presents the results of marine and freshwater scientific work carried out by Marine Scotland Science.

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A Compendium of Marine Related Carbon Stores, Sequestrations and Emissions

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1. Introduction

This report assembles quantitative estimates of marine carbon stores, sequestration rates and emission rates relevant to Scotland. Where specific Scottish data is not available (e.g. fishing fleet emissions) UK values have been used. For comparative purposes UK, European and global values have also been presented.

Information Sources

Values have been obtained from a range of peer-reviewed publications, government reports and web sites.

The information sources used were those available in 2019. Where values relate to specific time periods/years, these are given.

All information sources are cited, and to clarify the citations for some values exact location and/or quotes from reports and papers have been used in order to avoid any doubt.

Some non-carbon data are also presented. For example, the protein output of the fishing sector is estimated in order to allow carbon efficiency estimates to be compared between marine and non-marine food sources.

Units

All carbon-related values have been converted to common units, i.e. tonnes of carbon dioxide equivalents for stores, and tonnes of carbon dioxide equivalents per year for emission rates and sequestration rates.

To convert from organic and/or inorganic carbon stored, or emitted, to carbon dioxide equivalent we multiply masses or fluxes by the ratio of the molecular masses of carbon dioxide (CO_2) and carbon (C), i.e. 44/12 , or 3.67.

Hence, for example, if one tonne of organic carbon stored in marine sediment was converted to carbon dioxide and released to the atmosphere, it would create 3.67 tonnes of carbon dioxide. Hence this store is said to represent 3.67 tonnes of carbon dioxide equivalent (i.e. 3.67 t CO_2-eq.). In this way the size of stores of carbon can be compared to, for example, the emissions of carbon dioxide by a sector of Scottish industry.

Carbon dioxide equivalents can also be used to compare the greenhouse effect of different gases. For example, releasing 1 kg of methane (CH_4) into the atmosphere is about equivalent to releasing 25 kg of carbon dioxide (CO_2). In this report, the emissions of the UK fishing fleet (Section 2), xxx include all greenhouse gases emitted, converted to carbon dioxide equivalents.

The following unit symbols have been used in this report:

t	Metric tonne or 1000 kg
Mt	A megatonne 1,000,000 metric tonnes 1,000,000,000 kg
Mt C	A megatonne of carbon
kg CO_2-eq.	A kilogramme of carbon dioxide equivalent
Mt CO2-eq.	A megatonne of carbon dioxide equivalent

Changing Baselines

In some sections (e.g. fishing emissions) the total sectoral emissions are related to national total emissions, in terms of percentages. Similarly blue carbon stores and sequestration rates are compared to emission sizes. It is important to note that these comparisons need to be dated.

For example, using the latest values available in 2019 (i.e. Burrows et al., 2014), the total carbon sequestered into kelp beds in Scotland per year is 6.3 Mt CO_2-eq./year (Section 7). This is the equivalent of 16% of the annual CO_2 emissions by Scotland in 2017 (i.e. 39 Mt CO_2-eq./year).

However, as Scotland moves towards zero net emissions by 2045, the total emissions will fall year on year, and hence the ratio between kelp sequestration, which for this example we will assume will remain constant, and national emissions will increase. Hence, when we quote ratios and percentages, we must also state the time period that the associated calculations were made for.

Of course, the amount sequestered by kelp will change, as will the estimate of the sequestered value. In fact, the current marine carbon figures must be viewed as entirely preliminary, and much work remains to validate them, determine their variability and determine the uncertainty associated with the quoted values.

Aim of Report

In summary, the aim of this report is to provide a quick and comprehensive reference source for those working in marine management, policy or science to facts and figures concerning marine carbon stores, sequestrations and emissions as available in 2019.

2. CO_2-eq. Emission Calculations for UK Fishing Fleet 2017

Introduction

This section provides summaries of the GHG emissions, values and food production of the UK fishing fleet, broken down into different fleet segments. It brings together values from a diverse set of sources, and converts them into relevant units.

Summary UK fishing fleet data, by fishing segment, was extracted from Seafish (2018) and the associated on-line database accessed on 24/05/2019 as file:

March_2018_Seafish_Fleet_Economic_Performance_Dataset_2007-17.xls

A fishing fleet segment is part of the overall fleet that uses a specific type of fishing method, or fishing gear. The 32 UK fishing fleet segments in the Seafish (2018) dataset are given in Table 1.

Table 1

Description of the 32 UK fishing fleet segments used in Seafish (2018).

N	Code	Data Sheet Name	Description
1	DT1	Area VIIA demersal trawl	Area VIIA demersal trawl over 10m
2	NT1	Area VIIA nephrops over 250kW	Area VIIA nephrops over 250kW
3	NT2	Area VIIA nephrops under 250kW	Area VIIA nephrops under 250kW
4	DT2	Area VIIBCDEFGHK 24-40m	Area VIIb-k trawlers 10-24m (Not Nephrops)
5	DT3	Area VIIBCDEFGHK trawlers 10-24m	Area VIIb-k trawlers 24-40m (Not Nephrops)
6	GN1	Gill netters	UK Gill netters over 10m (Not Nephrops)
7		Inactive	Not used
8	LL1	Longliners	UK Longliners over 10m (Not Nephrops)
9	LA1	Low activity over 10m	Low activity vessels over 10m
10	LA2	Low activity under 10m	Low activity vessels under 10m
11	BT1	North Sea beam trawl over 300kW	North Sea beam trawl over 300kW (Not Nephrops)
12	BT2	North Sea beam trawl under 300kW	North Sea beam trawl under 300kW (Not Nephrops)
13	NT3	North Sea nephrops over 300kW	North Sea nephrops trawl over 300kW
14	NT4	North Sea nephrops under 300kW	North Sea nephrops trawl under 300kW
15	DT3	NSWOS demersal over 24m	North Sea and West of Scotland demersal trawl over 24m (Not Nephrops)
16	DS1	NSWOS demersal pair trawl seine	North Sea and West of Scotland demersal pair trawls and seines (Not Nephrops)
17	DS2	NSWOS demersal seiners	North Sea and West of Scotland demersal seiners (Not Nephrops)
18	DT4	NSWOS demersal under 24m over 300kW	North Sea and West of Scotland demersal trawl under 24m, over 300kW (Not Nephrops)
19	DT5	NSWOS demersal under 24m under 300kW	North Sea and West of Scotland demersal trawl under 24m, under 300kW (Not Nephrops)
20	PT1	Pots and traps 10-12m	UK pots and traps 10m-12m
21	PT2	Pots and traps over 12m	UK Pots and traps over 12m
22	BT3	South West beamers over 250kW	South West beam trawl under 250kW
23	BT4	South West beamers under 250kW	South West beam trawl over 250kW
24	SD1	UK scallop dredge over 15m	UK scallop dredge over 15m (Scallops, queen scallops, cockles)
25	SD2	UK scallop dredge under 15m	UK scallop dredge under 15m (Scallops, queen scallops, cockles)
26	UT1	Under 10m demersal trawl/seine	UK demersal trawls and seines under 10m
27	UT2	Under 10m drift and/or fixed nets	UK drift and fixed nets under 10m
28	UT3	Under 10m pots and traps	UK pots and traps under 10m
29	UT4	Under 10m using hooks	UK hooks under 10m
30	NT5	WOS nephrops over 250kW	West of Scotland nephrops trawl over 250kW
31	NT6	WOS nephrops under 250kW	West of Scotland nephrops trawl under 250kW
32	PL1	Pelagic	UK pelagic trawl over 40m (mackerel)

Seafish (2018) does not list the same level of detail for the pelagic segment as for the other 31 UK fishing segments, hence the pelagic sector calculations needed additional work.

The following section describes the calculations for the 31 non-pelagic segments:

Non-Pelagic Segment Emissions

The average annual cost of fuel for a single vessel in a fleet segment in 2017 is $V_{FuelCost}$ (£). The average cost of a litre of fuel in 2017 was L_{Cost} (£/litre). Thus the average fuel usage by a single vessel in a fleet segment, V_{Fuel} (litres), in 2017 is given by:

$$V_{Fuel} = V_{FuelCost} / L_{Cost} \qquad (1)$$

And the total average annual fuel usage of the entire fleet segment, S_{Fuel} (litres), consisting of S_N vessels is given by:

$$S_{Fuel} = S_N \,.\, V_{Fuel} \qquad (2)$$

The CO_2 equivalent for the segment, S_{CO2} (kg CO_2-eq.), is then given by:

$$S_{CO2} = S_{Fuel} \,.\, L_{CO2} \qquad (3)$$

Where L_{CO2} is the CO_2 equivalent emission (kg CO_2-eq.) from one litre of fuel. This estimate includes all greenhouse gases emitted by the burning of diesel fuel. Table 2 has the values for the constants used in this study.

Segment Protein

If the total landings of the segment is S_{Land} (tonnes), then the total amount of protein derived from this landed product, S_{Prot} (tonnes) is given by:

$$S_{Prot} = S_{Land} \,.\, C_{Prot} \qquad (4)$$

Where C_{Prot} is a ratio expressing how much protein there is per unit weight of landed product. This value was taken as 0.2 from Hilborn et al. (2018) who estimated that 200 g of landed wild caught fish or shellfish contained approximately 40 g of protein, i.e. 20% of landed fish or shellfish is protein.

Segment GHG Emission Efficiency

The efficiency of a segment, in terms of the total GHG emission per unit weight of protein produced is now calculated. In order to be comparable to Hilborn et al. (2018), the unit weight of protein is taken as 40 g, equivalent to a 200 g portion of fish or shellfish.

The average CO_2-equivalent emission for a segment of the UK fishing fleet, $S_{Efficiency}$ (kg CO_2-eq. per 40 g protein), is given by:

$$S_{Efficiency} = 40 \, . \, (S_{CO2}.1000) \, / \, (S_{Prot}.1000.1000) \qquad (5)$$

The average CO_2-equivalent emission for a segment of the UK fishing fleet, $S_{Efficiency}$ (kg CO_2-eq. per 40 g protein), is given by:

$$S_{Efficiency} = 40 \, . \, S_{CO2} \, / \, (S_{Prot}.1000.1000) \qquad (6)$$

Segment Value (GVA)

Seafish (2018) gives the value of a segment of the UK fishing fleet in terms of average Gross Value Added (GVA) income per vessel, V_{GVA} (£'000). The value of the segment, expressed as GVA, S_{GVA}, is, therefore:

$$S_{GVA} = S_N \, . \, V_{GVA}$$

Table 2 gives the values of the constants used in the calculations and where these were derived from and Table 3 summarises the terms used in the calculations which were extracted from Seafish (2018).

Table 2

Constants used in the CO_2-equivalent calculations.

Symbol	Value	Description	Source	Units
L_{Cost}	£0.42	Average cost of fuel per litre in 2017	Seafish (2018)	£ per litre
L_{CO2}	2.73	CO_2 equivalent emission from one litre of fuel – all GHG gases included – standard diesel	ICBE (2019)	kg CO_2-eq.
C_{Prot}	0.2	Ratio expressing how much protein there is per unit weight of landed product	Hilborn et al. (2018)	-

Table 3
Data extracted from the Seafish (2018) data set and used in the CO_2-eq. calculations.

Symbol	Seafish (2018) Description	Comments	Units
S_N	Active vessels (#)	Number of active vessels in the fleet segment	
S_{Land}	Landings (tonnes)	Total annual landings of fish / shellfish from the fleet segment	tonnes
$V_{FuelCost}$	Fuel (£'000)	Average annual cost of fuel for a single vessel in a fleet segment	£ (GBP)
VGVA	Gross Value Added (£'000)	Average Gross Value Added (GVA) income per vessel	£ (GBP)

Pelagic Segment Calculations

Seafish (2018) does not include the data needed for the above calculations for the UK pelagic sector. For this segment, alternative estimates were made.

The 2017 landings for the segment, S_{Land}, were obtained from SG (2018a; Table 1) and were 305,352 tonnes. Using Equation 4 above allows the calculation of the amount of protein produced by the sector, S_{Prot}.

Once having calculated S_{Prot}, we can use Equation 6 above to calculate S_{CO2} if we know $S_{Efficiency}$ for the segment. From S_{CO2} we can calculate S_{Fuel} using Equation 3, and hence V_{Fuel} using Equation 2.

This is where a sense check was used in order to estimate $S_{Efficiency}$ for the segment. Hilborn et al. (2018) estimated an $S_{Efficiency}$ for small pelagic fisheries of 0.3 kg CO_2-eq. per 40 g of protein. Using this value resulted in a completely unrealistic value of fuel usage, i.e. over 6 million litres of fuel per year per vessel. It should be noted that the Hilborn et al. (2018) figure was for a full-life cycle (LCA) estimate for such a fishery, whereas we are estimating annual emissions from fuel usage only.

A report completed for the Scottish Fishermen's Organisation (SFO) reported that modern UK pelagic vessels burn 550 litres/hour at half speed and 800 litres/hour at full throttle, based on survey responses from skippers (SFO, 2017). A median value of 650 litres/hour was selected for the calculations here. This allowed estimates of V_{Fuel} to be converted into an average steaming time in days per vessel. When a value of $S_{Efficiency}$ of 0.05 kg CO_2-eq. per 40 g of protein landed was selected, the average steaming time for a vessel was estimated as 68 days, based on the fuel burnt. This was considered possible for a three month fishing season.

As an additional check, using a value of $S_{Efficiency}$ of 0.05 kg CO_2-eq. per 40 g of protein gave a S_{CO2} value of 75.3M kg CO_2-eq. for the whole pelagic segment, which in turn gave a total CO_2-eq. emission value for the entire UK fishing sector of 0.68M kg CO_2-eq. This was comparable to the estimate by BEIS (2019A) of 0.6M kg CO_2-eq. Therefore, we can have some confidence in the $S_{Efficiency}$ estimate as it gives sensible values in at least two other, checkable parameters.

Finally, Seafish (2018) gives the total GVA for the UK fishing fleet as £497 M. The sum of the 31 non-pelagic fishing segments GVA is £307.198M (Table 4). Therefore, we can assume that the GVA for the pelagic sector was approximately £189,802,000 in 2017. This is not dissimilar to the value of landings of the pelagic sector reported by SG (2018a), i.e. £197,088,000.

The complete set of final values estimated for the pelagic sector are included in Table 4.

Table 4

Summary of results of the calculations for GHG emissions, protein production and GVA value, 31 non-pelagic segments of the UK fishing fleet, 2017, based principally on Seafish (2018), and estimates for the pelagic segment. Fleet segments are: DT - Demersal trawl; NT - Nephrops trawl; GN - Gill netters; LL – Long liners; LA - Low activity; BT - Beam trawl; DS - Demersal seiners; PT - Pots and traps; SD - Scallop dredge; UT - Under 10m; PL - Pelagic. Explanation of segment codes given in Table 1.

	Fuel Cost per vessel (£'000)	**Litres per vessel (litres)**	**N Vessels in Sector**	**Litres per sector (litres)**	**kg CO_2 of sector (kg CO_2-eq.)**	**Landings of sector (tonnes)**	**Protein of sector (tonnes)**	**kg CO_2 per 40g protein**	**Average GVA per vessel (£'000)**	**Value of Sector (£'000)**
	$V_{FuelCost}$	V_{Fuel}	S_N	S_{Fuel}	S_{CO2}	S_{Land}	S_{Prot}	$S_{Efficency}$	V_{GVA}	S_{GVA}
BT1	517.0	1,230,952	9	11,078,571	30,244,500	7,210	1,442	0.84	184.0	1,656
BT2	47.0	111,905	20	2,238,095	6,110,000	472	94	2.59	-1.4	-28
BT3	246.1	585,952	26	15,234,762	41,590,900	7,743	1,549	1.07	427.0	11,102
BT4	110.1	262,143	22	5,767,143	15,744,300	4,538	908	0.69	370.4	8,149
DS1	136.6	325,238	25	8,130,952	22,197,500	27,524	5,505	0.16	982.2	24,555
DS2	102.7	244,524	17	4,156,905	11,348,350	13,706	2,741	0.17	664.4	11,295
DT1	45.9	109,286	13	1,420,714	3,878,550	1,992	398	0.39	142.7	1,855
DT2	234.3	557,857	12	6,694,286	18,275,400	5,834	1,167	0.63	418.5	5,022
DT3	30.3	72,143	61	4,400,714	12,013,950	8,381	1,676	0.29	142.9	8,717
DT3	331.7	789,762	43	33,959,762	92,710,150	46,620	9,324	0.40	866.8	37,272
DT4	161.6	384,762	37	14,236,190	38,864,800	18,033	3,607	0.43	462.8	17,124
DT5	25.0	59,524	18	1,071,429	2,925,000	1,569	314	0.37	99.8	1,796
GN1	32.8	78,095	30	2,342,857	6,396,000	7,636	1,527	0.17	232.8	6,984
LA1	3.4	8,095	44	356,190	972,400	107	21	1.81	-2.7	-119
LA2	0.5	1,190	1660	1,976,190	5,395,000	1,921	384	0.56	1.8	2,988
LL1	93.8	223,333	29	6,476,667	17,681,300	8,140	1,628	0.43	217.1	6,296
NT1	46.2	110,000	30	3,300,000	9,009,000	3,901	780	0.46	173.9	5,217
NT2	17.9	42,619	37	1,576,905	4,304,950	2,753	551	0.31	79.7	2,949

NT3	145.8	347,143	55	19,092,857	52,123,500	14,493	2,899	0.72	253.1	13,921
NT4	38.3	91,190	68	6,200,952	16,928,600	4,631	926	0.73	69.7	4,740
NT5	57.0	135,714	42	5,700,000	15,561,000	6,142	1,228	0.51	151.6	6,367
NT6	24.1	57,381	77	4,418,333	12,062,050	4,850	970	0.50	83.2	6,406
PT1	9.4	22,381	175	3,916,667	10,692,500	10,601	2,120	0.20	83.0	14,525
PT2	51.1	121,667	92	11,193,333	30,557,800	24,380	4,876	0.25	252.3	23,212
SD1	77.2	183,810	89	16,359,048	44,660,200	20,033	4,007	0.45	197.1	17,542
SD2	20.6	49,048	205	10,054,762	27,449,500	15,551	3,110	0.35	57.6	11,808
UT1	7.6	18,095	175	3,166,667	8,645,000	5,018	1,004	0.34	38.7	6,773
UT2	3.5	8,333	180	1,500,000	4,095,000	2,795	559	0.29	25.7	4,626
UT3	5.5	13,095	1095	14,339,286	39,146,250	24,927	4,985	0.31	36.5	39,968
UT4	1.9	4,524	231	1,045,000	2,852,850	2,648	530	0.22	19.4	4,481
Non-PL Total				**221,405,238**	**604,436,300**	**304,148**	**60,830**			**307,198**
PL1	445.8	1,061,398	26	27,596,337	75,338,000	301,352	60,270	0.05	7,300.1	189,802
Total UK Industry				**249,001,575**	**679,774,300**	**605,500**	**121,100**			**497,000**

UK Fishing Emissions - Overall Summary

As a percentage of the total national emissions, fishing represents a small component: 0.8% for Scotland and 0.1% for the UK as a whole (Table 5).

Table 5

Summary of UK and Scottish fishing fleet contribution (2017) to total national emissions (2017).

Country	National Fishing Fleet Emissions	Country Total Emissions	Fishing Emissions as Percentage of Country Total
	Mt CO_2-eq. / year	Mt CO_2-eq. / year	%
Scotland	0.3	39	0.8
UK	0.7	503	0.1

Table 6

Summary of UK fishing fleet emissions, landings and carbon efficiency (2017) by fleet segment.

	Segment	Annual Emissions (t CO_2-eq.)	Annual Landings (tonnes)	Annual Protein (tonnes)	Annual Value (GVA) (£'000)	Carbon Efficiency (kg CO_2 per 40g protein)
DT	Demersal Trawl	168,668	82,427	16,485	11,964	0.42
NT	Nephrops Trawl	109,989	36,770	7,354	6,600	0.54
BT	Beam Trawl	93,690	19,964	3,993	20,879	1.15
PL	Pelagic	75,338	301,352	60,270	189,802	0.05
SD	Scallop Dredge	72,110	35,583	7,117	14,675	0.40
UT	Under 10m	54,739	35,389	7,078	13,962	0.29
PT	Pots and Traps	41,250	34,981	6,996	18,868	0.23
DS	Demersal Seine	33,546	41,230	8,246	17,925	0.16
LL	Long Line	17,681	8,140	1,628	6,296	0.43
GN	Gill Net	6,396	7,636	1,527	6,984	0.17
LA	Low Usage	6,367	2,029	406	1,435	1.19
	TOTAL	**679,774**	**605,501**	**121,100**	**309,390**	**0.22**

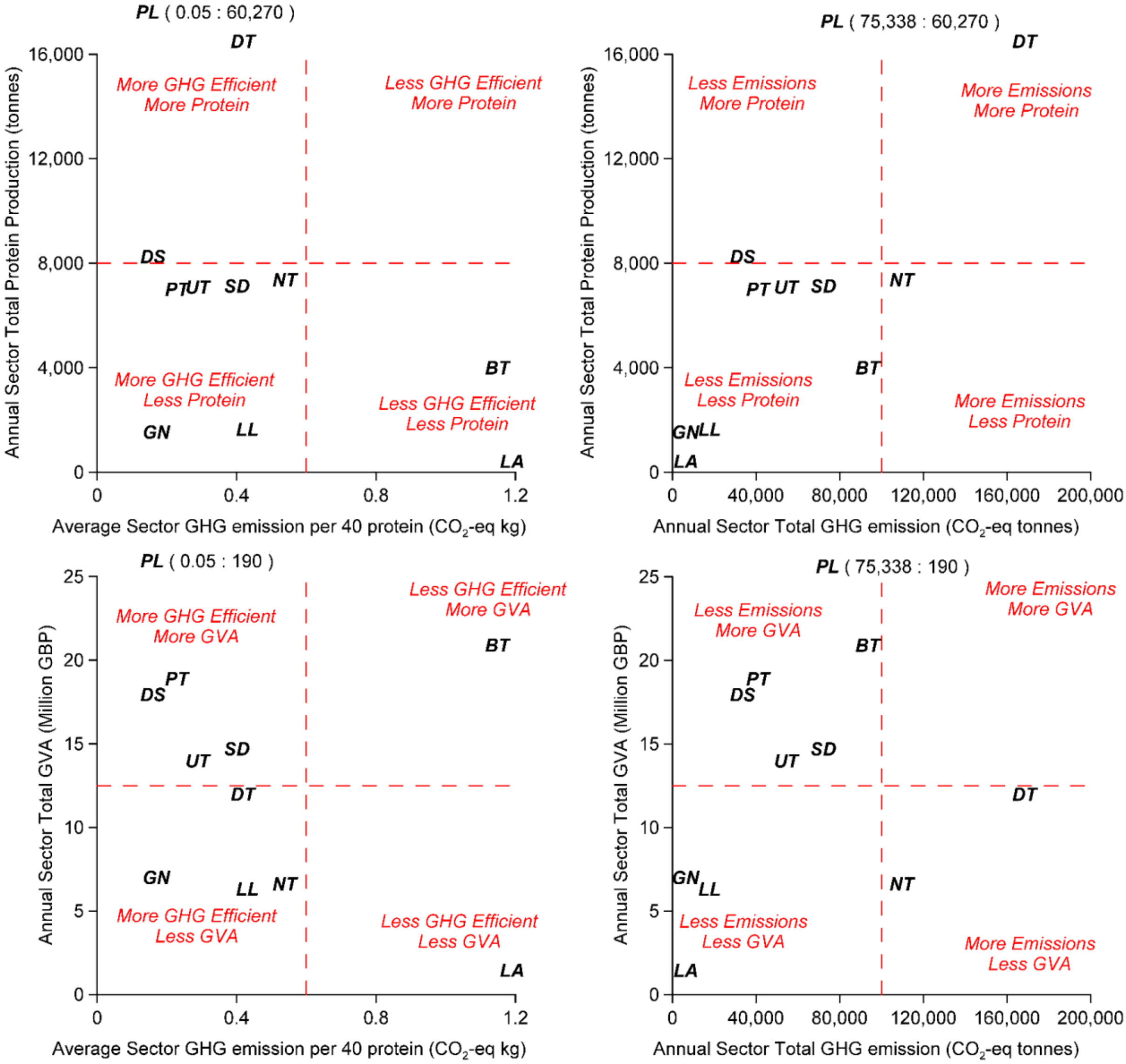


Figure 1: Summary of UK fishing fleet emissions, landings, values and carbon efficiency (2017) by fleet segment. Segment details are given in Table 6. Pelagic Sector pairs of data are indicated by their coordinates in order to avoid large axis scales, as this sector has extremely high landings, value and carbon efficiencies.

3. CO_2-eq. Emission Calculations for EU Fishing Fleet 2016 and Global Estimates

Introduction

This section provides some brief summaries of emissions from European and global fishery fleets to facilitate comparison with UK fisheries.

European Fishing Emissions

From STECF (2018), we learn that in 2016 the EU fleet had 65,400 active vessels which spent 4.85 million days at sea and burnt 2.25 billion litres of fuel to land 4.9 million tonnes of seafood worth 7.7 billion euros. Using the methodology presented in Section 1, we can make the following estimates:

Table 7

Summary of European fishing fleet emissions, landings and carbon efficiency (2016).

N Vessels	65,400	
Total fuel annual fuel use	2,250,000,000	litres
Total annual emissions	6,142,500,000	kg CO_2-eq.
Total annual landings	4,900,000	tonnes
Total annual protein	980,000	tonnes
Average annual carbon efficiency	0.25	kg CO_2 per 40g protein

Global Fishing Emissions

Tyedmers et al. (2005) state:

"By integrating data representing more than 250 fisheries from around the world with spatially resolved catch statistics for 2000, we calculate that globally, fisheries burned almost 50 billion litres of fuel in the process of landing just over 80 million t of marine fish and invertebrates for an average rate of 620 L t^{-1}. Consequently, fisheries account for about 1.2% of global oil consumption, an amount equivalent to that burned by the Netherlands, the 18th-ranked oil consuming country globally, and directly emit more than 130 million t of CO_2 into the atmosphere."

Using figures presented above, we would estimate that 50 billion (i.e. 50 x 10^9) litres of fuel would emit 136.5 x 10^9 kg CO_2-eq. per year, or 136.5 Mt CO_2 eq./year. This is very close to the authors estimate of 130 Mt CO_2-eq.

Summary Comparisons

In terms of total emissions, in Mt-CO_2-eq. / year we have the following:

Table 8

Summary of Scottish (2017), UK (2017), EU (2016) and global (2000) fishing fleet emissions.

Fleet	Source	Annual Emissions (Mt CO_2-eq. / year)
Scotland	Table 5	0.3
UK	Table 5	0.7
Europe	STECF (2018)	6
Global	Tyedmers et al. (2005)	130

4. Carbon Footprint of Marine and Non-Marine Food

Introduction

This section presents figures related to the “carbon footprint” of different types of marine and non-marine foodstuffs. Data has been extracted from two sources: Hilborn et al. (2018) and Poore and Nemecek (2018). Data has been drawn from both tables, and by digitising aspects of figures.

The “carbon footprint” of food is here defined as the total greenhouse gas emissions from life cycle analyses, LCA, expressed as kg CO_2 equivalents (kg CO_2-eq.) for a typical single meal for one person, which is assumed to be 40 g of protein (Hilborn et al., 2018) of different foodstuffs.

Emission estimates are to the farm gate / quayside (i.e. does not include onward transport and processing), and are derived from meta analyses of global LCA studies (Hilborn et al., 2018; Poore and Nemecek, 2018). Estimates for aquaculture include emissions associated with feed where relevant.

Values from Hilborn et al. (2018) were extracted as follows:

- Minimum and maximum from their Figure 1 (main text)
- Mean from their Table S2 (Supplementary Material)

Values from Poore and Nemecek (2018) were extracted as follows:

- Minimum, maximum and mean from their Figure 1 (main text)

Table below give extracted values.

Table 9

Extracted values of carbon footprint for marine and non-marine foodstuffs (minimum, mean, maximum), expressed as kg CO2 equivalents for a typical single meal for one person assumed to be 40 g of protein. Label Prefixes: AQ – Aquaculture production; FA – Farm production; FS – fishing production; VG – non-animal based production; H – from Hilborn et al., 2018. P – from Poore and Nemecek, 2018. Label Suffixes (where shortened): Inverts. – Invertebrates including squid and octopus; LPelagic – Large pelagic (e.g. tuna); SPelagic – Small pelagic (e.g. mackerel and herring); GNuts – Ground nuts.

Food Type	Per 100g			Per 40g		
	Min	Mean	Max	Min	Mean	Max
AQ-H-Catfish	10.3	20.7	34.0	4.1	8.3	13.6
AQ-H-Shrimp	7.6	10.4	16.9	3.0	4.2	6.8
AQ-P-Shellfish	5.4	18.0	15.0	2.2	7.2	6.0
AQ-H-Tilapia	2.0	7.5	12.8	0.8	3.0	5.1
AQ-P-Fish	2.4	6.0	11.6	1.0	2.4	4.6
AQ-H-Carp	0.6	6.3	8.2	0.2	2.5	3.3
AQ-H-Salmon	0.9	1.5	1.5	0.3	0.6	0.6
AQ-H-Mollusks	0.2	0.9	1.1	0.1	0.4	0.4
FA-P-Beef	20.5	50.0	75.0	8.2	20.0	30.0
FA-P-Lamb	12.8	20.0	27.3	5.1	8.0	10.9
FA-H-Beef	10.9	14.4	18.6	4.4	5.7	7.5
FA-P-Cheese	5.0	11.0	15.0	2.0	4.4	6.0
FA-P-Pork	4.5	7.6	13.7	1.8	3.0	5.5
FA-P-Poultry	2.3	5.7	11.6	0.9	2.3	4.6
FA-P-Eggs	2.5	4.2	7.5	1.0	1.7	3.0
FA-H-Pork	2.9	4.4	5.9	1.2	1.8	2.4
FA-H-Chicken	1.3	2.5	3.0	0.5	1.0	1.2
FS-H-Invert	5.1	17.1	25.5	2.0	6.8	10.2
FS-H-Shrimp	3.7	10.6	12.8	1.5	4.2	5.1
FS-H-Whitefish	0.3	1.8	3.1	0.1	0.7	1.2
FS-H-LPelagic	1.0	1.6	1.6	0.4	0.6	0.7
FS-H-SPelagic	0.3	0.7	0.7	0.1	0.3	0.3
VG-P-Grains	0.9	2.7	4.5	0.4	1.1	1.8
VG-P-Tofu	0.8	2.0	3.4	0.3	0.8	1.3
VG-P-Nuts	0.2	0.3	2.3	0.1	0.1	0.9
VG-P-GNuts	0.6	1.2	2.1	0.2	0.5	0.8
VG-P-Pulses	0.7	0.8	1.5	0.3	0.3	0.6
VG-P-Peas	0.3	0.4	0.5	0.1	0.2	0.2

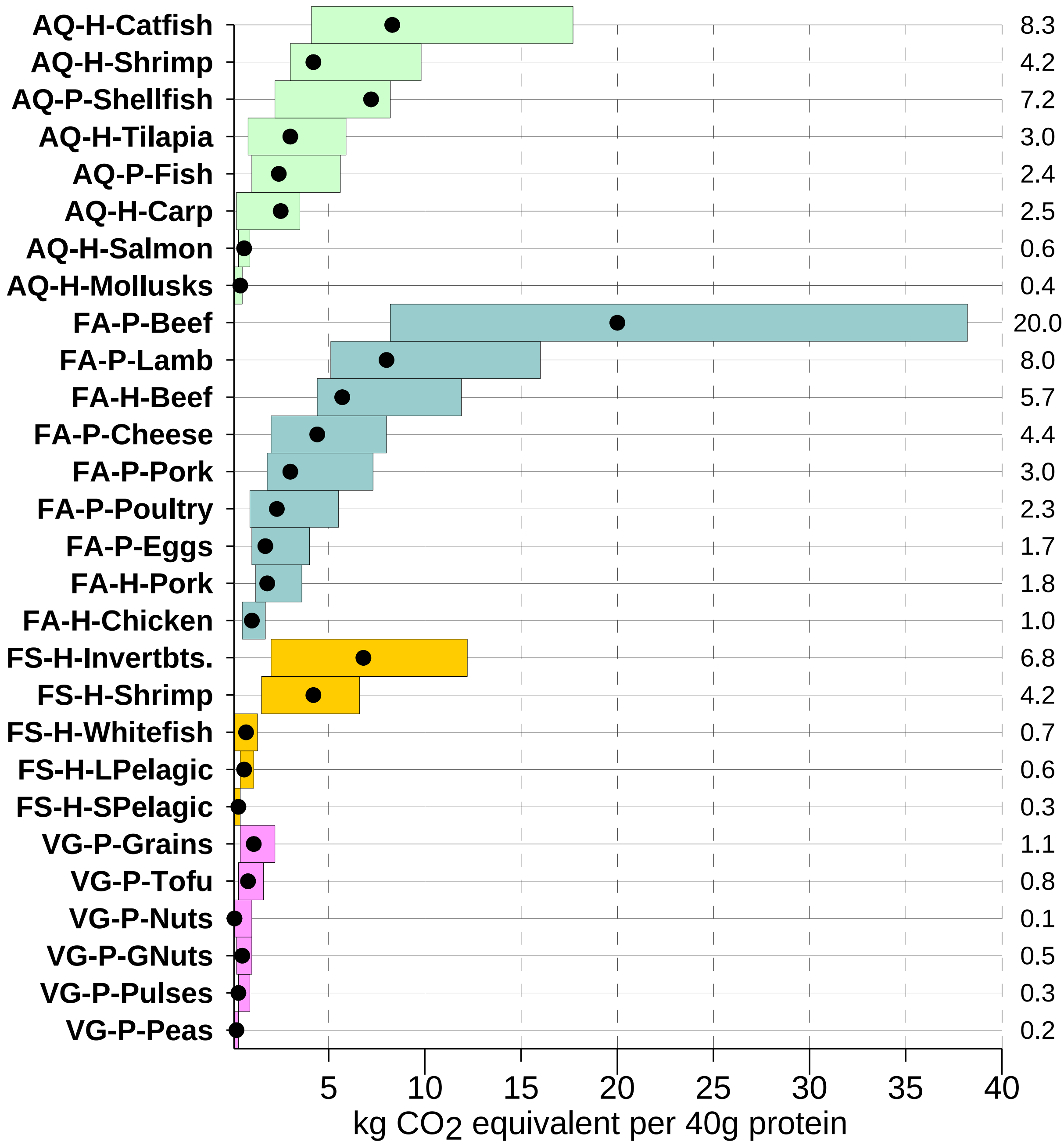


Figure 2: A comparison of the carbon footprint (i.e. total greenhouse gas emissions from life cycle analyses, LCA, expressed as kg CO_2 equivalents, kg CO_2-eq, for a typical single meal for one person assumed to be 40 g of protein, Hilborn et al., 2018) of different foodstuffs. Emission estimates are to the farm gate/quayside (i.e. does not include onward transport and processing), and are derived from meta analyses of global LCA studies. Symbol and value on right side is mean value. Estimates for aquaculture include emissions associated with feed where relevant. Label Prefixes: AQ – Aquaculture production (green bars); FA – Farm production (blue bars); FS – fishing production (yellow bars); VG – non-animal based production (pink bars); H – from Hilborn et al., 2018 (minimum and maximum from their Figure 1, mean from their Table S2); P – from Poore and Nemecek, 2018 (min, max and mean from their Figure 1). Label Suffixes (where shortened): Inverts. – Invertebrates including squid and octopus; LPelagic – Large pelagic (e.g. tuna); SPelagic – Small pelagic (e.g. mackerel and herring); GNuts – Ground nuts.

5. UK Sectoral Greenhouse Gas Emissions

Introduction

The aim of this section is to provide a table (Table 9) of GHG emissions from different sources and sectors within the UK and within Scotland, so that easy comparisons can be made.

Data sources are given in the table. BEIS (2019a) figures are from on-line data set, Table 3: Estimated emissions of Greenhouse Gases by source category, type of fuel and end-user category, UK 1990-2017.

Although the tables reproduce material published elsewhere, here different sources are brought together in one place, and in the same format and units to permit ready comparison.

Table 10a Total UK GHG emissions by sector. Units - Mt CO_2-eq. per year. Data source – BEIS (2019a), Table 3. n/a – not available at time of writing.

Sector	2010	2011	2012	2013	2014	2015	2016	2017	2018
Energy supply	207.4	192.7	203.3	190.1	165.2	145.3	121.8	112.6	n/a
Business	94.1	85.8	87.8	88.6	86.6	85.1	81.4	80.1	n/a
Transport (including Intntnl. Aviation and Shipping)	165.3	165.7	162.4	161.4	163.4	165.1	168.2	168.7	n/a
Public Buildings	9.5	8.0	8.9	9.1	7.8	8.0	8.2	7.8	n/a
Residential	87.5	70.1	76.6	77.5	64.8	67.4	69.8	66.9	n/a
Agriculture	44.6	44.8	44.5	44.2	45.6	45.1	45.2	45.6	n/a
Industrial processes	12.6	11.3	10.7	12.9	13.0	12.7	10.6	10.8	n/a
Land use, land use change and forestry	-9.1	-9.6	-9.0	-9.4	-9.6	-9.7	-9.8	-9.9	n/a
Waste management	29.7	27.7	26.1	23.1	20.9	20.6	20.0	20.3	n/a
Total greenhouse gas emissions	641.7	596.5	611.3	597.6	557.6	539.5	515.4	503.0	n/a

Table 10b Total Scottish GHG emissions by sector. Units - Mt CO_2-eq. per year. Data source – SG (2017), Table B2. n/a – not available at time of writing.

Source Sector	2010	2011	2012	2013	2014	2015	2016	2017	2018
Energy Supply	20.9	17.0	17.4	16.0	13.9	12.2	7.2	n/a	n/a
Transport (including Intntnl. Aviation and Shipping)	14.3	13.9	13.7	13.6	13.8	14.1	14.4	n/a	n/a
Transport (excluding IA&S)	12.9	12.4	12.2	12.0	12.2	12.4	12.6	n/a	n/a
International Aviation and Shipping (IA&S)	1.4	1.5	1.5	1.5	1.6	1.7	1.8	n/a	n/a
Agriculture and Related Land Use	11.1	10.7	10.5	10.4	10.4	10.2	10.0	n/a	n/a
Business and Industrial process	9.4	9.1	9.0	9.2	8.7	8.7	8.6	n/a	n/a
Residential	8.0	6.5	7.0	7.1	5.9	6.1	6.3	n/a	n/a
Waste Management	2.5	2.4	2.1	1.5	1.5	1.7	1.6	n/a	n/a
Other sources	3.2	3.0	3.1	3.1	2.9	2.9	3.1	n/a	n/a
Development	1.9	1.9	1.9	1.9	1.9	1.9	2.0	n/a	n/a
Public Sector Buildings	1.3	1.1	1.2	1.2	1.0	1.1	1.1	n/a	n/a
Forestry	-13.7	-13.5	-11.3	-12.4	-12.7	-12.9	-12.7	n/a	n/a
Total greenhouse gas emissions	**55.8**	**49.2**	**51.5**	**48.4**	**44.4**	**43.0**	**38.6**	n/a	n/a

Table 10c Details of UK GHG emissions by sector. Units - Mt CO_2-eq. per year. Data source – BEIS (2019a), Table 3, and Table 8 for international aviation and shipping. Data for 2018 not available at time of writing report in 2019.

	2010	2011	2012	2013	2014	2015	2016	2017	2018
TOTAL Energy supply	207.4	192.7	203.3	190.1	165.2	145.3	121.8	112.6	
Power stations	158.1	145.4	159.4	148.4	125.2	105.0	83.0	73.1	
Refineries	17.0	17.4	15.8	14.7	13.5	13.5	13.6	13.6	
Manufacture of solid fuels and other energy industries	18.4	16.6	15.4	15.1	14.8	15.4	15.1	15.7	
Solid fuel transformation	0.3	0.4	0.2	0.3	0.4	0.5	0.4	0.4	
Coal mining and handling	2.5	2.4	2.5	1.7	1.7	1.4	0.5	0.5	
Exploration, production and transport of oils	0.5	0.5	0.2	0.2	0.3	0.3	0.3	0.3	
Power station flue-gas desulphurisation	0.4	0.4	0.5	0.5	0.4	0.3	0.1	0.1	
Exploration, production and transport of gas	5.2	4.9	4.8	4.7	4.5	4.2	4.2	4.0	
Offshore oil and gas - Flaring	4.3	4.0	3.6	3.8	3.7	4.1	4.0	4.2	
Offshore oil and gas - Venting	0.7	0.7	0.9	0.7	0.7	0.7	0.6	0.7	
TOTAL Business	94.1	85.8	87.8	88.6	86.6	85.1	81.4	80.1	
Incidental lubricant combustion in engines	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	
Refrigeration and air conditioning	13.7	12.2	12.8	13.1	13.3	13.3	12.6	11.6	
Foams	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	
Firefighting	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	
Solvents	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
One component foams	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Iron and steel - combustion and electricity	11.9	11.0	12.0	14.6	14.9	13.4	10.0	9.3	
Other industrial combustion and electricity	54.3	50.3	49.3	46.7	45.6	45.1	44.9	45.6	
Miscellaneous industrial and commercial combustion and electricity	11.5	10.0	11.5	11.9	10.3	11.3	11.7	11.4	
Electronics, electrical insulation, scientific research, military applications and sporting goods	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	
Non energy use of fuels	0.7	0.4	0.4	0.3	0.5	0.0	0.2	0.2	
Accidental fires - business	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
N2O use as an anaesthetic	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	
TOTAL Transport	165.3	165.7	162.4	161.4	163.4	165.1	168.2	168.7	
International aviation	31.8	33.3	32.4	32.7	32.9	33.5	33.7	35.0	

International shipping	9.0	10.0	8.5	8.7	9.1	8.1	8.6	7.8
Civil aviation (domestic, cruise)	1.3	1.3	1.2	1.2	1.1	1.2	1.1	1.1
Civil aviation (domestic, landing and take off)	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
Passenger cars	70.3	69.5	69.2	68.1	68.3	68.8	69.8	69.6
Light duty vehicles	16.1	16.2	16.4	16.6	17.3	18.1	19.3	19.4
Buses	4.3	4.0	3.8	3.8	3.8	3.7	3.5	3.4
HGVs	18.5	18.1	18.2	18.3	18.8	19.8	20.5	20.8
Mopeds & motorcycles	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Road vehicle LPG and biofuel use (all vehicles)	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3
Incidental lubricant combustion in road engines	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Urea use in abatement technology	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Railways	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Railways - stationary combustion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
National navigation	6.2	5.9	5.4	5.0	5.1	5.5	5.4	5.3
Incidental lubricant combustion in marine engines	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fishing vessels	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Military aircraft and shipping	2.9	2.8	2.6	2.3	2.0	1.7	1.6	1.6
Aircraft support vehicles	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6
TOTAL Public Buildings	9.5	8.0	8.9	9.1	7.8	8.0	8.2	7.8
TOTAL Residential	87.5	70.1	76.6	77.5	64.8	67.4	69.8	66.9
Residential combustion	85.4	68.1	74.6	75.5	62.9	65.5	68.0	65.2
Use of non aerosol consumer products	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Accidental fires - residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aerosols and metered dose inhalers	2.0	1.9	1.9	1.8	1.8	1.8	1.7	1.6
Composting - household	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
TOTAL Agriculture	44.6	44.8	44.5	44.2	45.6	45.1	45.2	45.6
Stationary and mobile combustion	4.0	4.1	4.1	4.1	4.1	4.3	4.3	4.3
Incidental lubricant combustion in engines	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cattle - enteric fermentation	16.9	16.7	16.5	16.5	16.7	16.8	16.8	16.8
Sheep - enteric fermentation	3.6	3.7	3.8	3.8	4.0	4.0	3.9	4.0
Goats - enteric fermentation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Horses - enteric fermentation	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
Pigs - enteric fermentation	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Deer - enteric fermentation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cattle - wastes	5.3	5.2	5.2	5.2	5.3	5.3	5.3	5.3
Sheep - wastes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Goats - wastes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Horses - wastes	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Pigs - wastes	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0
Poultry	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Deer - wastes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Liming	1.2	1.3	1.1	0.9	1.2	0.9	0.9	0.9
Direct soil emission	9.0	9.1	9.0	9.1	9.4	9.0	9.0	9.2
Field burning of agricultural wastes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Urea application	0.3	0.3	0.3	0.2	0.3	0.4	0.4	0.3
Indirect soil emission	2.1	2.2	2.2	2.1	2.3	2.2	2.2	2.2
TOTAL Industrial processes	12.6	11.3	10.7	12.9	13.0	12.7	10.6	10.8
Sinter production	1.8	1.6	2.0	2.7	2.8	2.3	1.4	1.3
Cement production	3.8	4.1	3.7	4.0	4.2	4.5	4.6	4.4
Lime production	1.1	1.2	1.2	1.2	1.3	1.2	1.0	1.1
Soda ash production	0.3	0.3	0.3	0.3	0.2	0.1	0.1	0.1
Glass production	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Fletton brick production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonia production	1.0	0.6	1.0	0.9	0.9	1.0	0.9	1.1
Aluminium production	0.4	0.5	0.1	0.1	0.1	0.1	0.1	0.1
Nitric acid production	1.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Adipic acid production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other - chemical industry	0.3	0.4	0.4	0.3	0.3	0.2	0.3	0.3
Halocarbon production	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.2
Magnesium cover gas	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Iron and steel production	1.5	1.2	0.9	2.2	2.0	2.1	1.0	1.2
Titanium dioxide production	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2

Bricks production	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Non ferrous metal processes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Use of N2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL Land use, land use change and forestry	-9.1	-9.6	-9.0	-9.4	-9.6	-9.7	-9.8	-9.9
Forest land remaining forest land	-19.2	-18.9	-16.8	-17.9	-18.1	-18.0	-18.1	-18.0
Biomass burning	0.0	0.1	0.3	0.1	0.1	0.0	0.0	0.0
Land converted to forest land	-0.3	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
Drainage of organic soils	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Direct N2O emissions from N mineralization/immobilisation	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Biomass burning	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland remaining cropland	5.7	5.7	5.8	5.7	5.7	5.8	5.8	5.8
Land converted to cropland	6.3	6.1	5.9	5.7	5.6	5.4	5.2	5.1
Direct N2O emissions from N mineralization/immobilisation	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Biomass burning	0.3	0.2	0.3	0.2	0.3	0.2	0.3	0.2
Grassland remaining grassland	-4.6	-4.6	-4.7	-4.8	-4.9	-4.9	-5.0	-5.1
Land converted to grassland	-3.8	-3.9	-4.0	-4.0	-4.0	-4.1	-4.0	-4.1
Direct N2O emissions from N mineralization/immobilisation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Drainage of organic soils	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Wetlands remaining wetland	0.3	0.3	0.2	0.4	0.3	0.3	0.3	0.3
Drainage of organic soils	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Land converted to wetland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements remaining settlements	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Biomass burning	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1
Land converted to settlements	4.0	4.0	4.0	4.0	3.9	4.0	4.1	4.1
Direct N2O emissions from N mineralization/immobilisation	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Harvested wood	-2.1	-2.4	-3.8	-2.6	-2.3	-2.2	-2.2	-2.0
Indirect N2O emissions	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
TOTAL Waste management	29.7	27.7	26.1	23.1	20.9	20.6	20.0	20.3
Landfill	24.3	22.0	20.6	17.5	15.0	14.6	13.9	14.1
Waste-water handling	4.0	4.0	3.9	3.9	4.0	4.1	4.0	4.1
Waste Incineration	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Composting - non-household	0.9	1.0	1.0	1.0	1.0	1.0	1.1	1.1
Anaerobic digestion	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2
Mechanical biological treatment	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6

Table 10d Details of Scottish GHG emissions by sector. Units - Mt CO_2-eq. per year Data source – SG (2017) and associated on-line data set.

	2010	2011	2012	2013	2014	2015	2016
Agriculture and Related Land Use	11.12	10.71	10.51	10.43	10.45	10.16	10.05
1A4ci_Agriculture/Forestry/Fishing:Stationary	0.05	0.05	0.04	0.04	0.05	0.03	0.03
1A4cii_Agriculture/Forestry/Fishing:Off-road	0.74	0.75	0.77	0.77	0.77	0.80	0.81
2D1_Lubricant_Use	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3A1_Enteric_Fermentation_dairy_cattle	0.49	0.49	0.49	0.49	0.51	0.52	0.52
3A1_Enteric_Fermentation_non-dairy_cattle	2.49	2.46	2.42	2.37	2.35	2.35	2.34
3A2_Enteric_Fermentation_sheep	0.88	0.92	0.91	0.85	0.88	0.90	0.89
3A3_Enteric_Fermentation_swine	0.02	0.01	0.01	0.01	0.01	0.01	0.01
3A4_Enteric_Fermentation_other:deer	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3A4_Enteric_Fermentation_other:goats	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3A4_Enteric_Fermentation_other:horses	0.04	0.04	0.03	0.03	0.03	0.03	0.03
3B1_Manure_Management_dairy_cattle	0.22	0.22	0.23	0.23	0.24	0.24	0.24
3B1_Manure_Management_non-dairy_cattle	0.73	0.72	0.71	0.70	0.69	0.69	0.68
3B1_Manure_Management_other_cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3B2_Manure_Management_sheep	0.03	0.03	0.03	0.03	0.03	0.03	0.03
3B3_Manure_Management_swine	0.08	0.08	0.07	0.06	0.06	0.06	0.07
3B4_Manure_Management_other:deer	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3B4_Manure_Management_other:goats	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3B4_Manure_Management_other:horses	0.02	0.02	0.02	0.02	0.02	0.02	0.02
3B4_Manure_Management_other:poultry	0.03	0.03	0.03	0.03	0.03	0.02	0.03
3B4_Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3D_Agricultural_Soils	1.63	1.59	1.60	1.65	1.66	1.61	1.58
3D1_Agricultural_soils-Mineralization/Immobilization	0.22	0.23	0.23	0.23	0.23	0.23	0.24
3F_Field_burning	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3G1_Liming - limestone	0.14	0.17	0.13	0.18	0.23	0.09	0.12
3G2_Liming - dolomite	0.09	0.06	0.08	0.06	0.10	0.09	0.09
3H_Urea application	0.02	0.03	0.02	0.02	0.03	0.03	0.04
4_Indirect_N2O_Emissions	0.11	0.11	0.10	0.10	0.10	0.10	0.10

4B1_Cropland Remaining Cropland	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4B1_Cropland_Remaining_Cropland	2.17	2.20	2.23	2.23	2.25	2.26	2.27
4B2_1_Forest Land converted to Cropland	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4B2_2_Grassland converted to Cropland	3.32	3.19	3.06	2.95	2.84	2.74	2.64
4B2_4_Settlements converted to Cropland	-0.01	-0.01	-0.01	-0.01	0.00	0.00	0.00
4C_Grassland_Emissions_from_Drainage	0.05	0.05	0.05	0.05	0.05	0.05	0.05
4C1_Grassland Remaining Grassland	-1.86	-1.89	-1.90	-1.95	-1.98	-2.01	-2.04
4C2_1_Forest Land converted to Grassland	0.59	0.40	0.43	0.49	0.50	0.51	0.55
4C2_2_Cropland converted to Grassland	-1.10	-1.11	-1.12	-1.12	-1.12	-1.13	-1.13
4C2_3_Wetlands converted to Grassland	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4C2_4_Settlements converted to Grassland	-0.19	-0.20	-0.21	-0.22	-0.23	-0.24	-0.25
4D_Wetlands_Emissions_from_Drainage	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4D1_Wetlands remaining wetlands	0.13	0.09	0.03	0.14	0.11	0.10	0.10
4D2_Land converted to wetlands	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Business and Industrial Process	9.42	9.11	9.00	9.19	8.67	8.67	8.57
1A1ai_Public_Electricity&Heat_Production	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1A2a_Iron_and_steel	0.05	0.05	0.05	0.05	0.05	0.03	0.00
1A2b_Non-Ferrous_Metals	0.06	0.05	0.03	0.02	0.01	0.01	0.01
1A2c_Chemicals	1.01	0.91	0.74	1.01	0.98	1.02	0.77
1A2d_Pulp_Paper_Print	0.37	0.35	0.32	0.32	0.21	0.17	0.14
1A2e_food_processing_beverages_and_tobacco	0.60	0.57	0.58	0.54	0.53	0.48	0.50
1A2f_Non-metallic_minerals	0.15	0.17	0.16	0.17	0.17	0.14	0.18
1A2gvii_Off-road_vehicles_and_other_machinery	0.56	0.48	0.57	0.46	0.49	0.57	0.52
1A2gviii_Other_manufacturing_industries_and_construction	1.97	2.21	1.96	1.88	1.95	1.92	1.90
1A4ai_Commercial/Institutional	1.26	1.10	1.27	1.32	1.14	1.24	1.29
2A1_Cement_Production	0.28	0.34	0.31	0.34	0.36	0.29	0.37
2A2_Lime_Production	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2A3_Glass_production	0.05	0.05	0.06	0.05	0.05	0.04	0.05
2A4a_Other_process_uses_of_carbonates:ceramics	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2B1_Ammonia_Production	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2B1_Chemical_Industry:Ammonia_production	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2B10_Chemical_Industry:Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2B2_Nitric_Acid_Production	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2B3_Adipic_Acid_Production	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2B6_Titanium_dioxide_production	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2B7_Soda_Ash_Production	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2B8a_Methanol_production	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2B8b_Ethylene_Production	0.01	0.01	0.02	0.02	0.02	0.00	0.00
2B8c_Ethylene_Dichloride_and_Vinyl_Chloride_Monomer	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2B8d_Ethylene_Oxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2B8e_Acrylonitrile	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2B8f_Carbon_black_production	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2B8g_Petrochemical_and_carbon_black_production:Other	1.61	1.51	1.59	1.60	1.24	1.32	1.43
2B9a1_Fluorchemical_production:By-product_emissions	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2B9b3_Fluorchemical_production:Fugitive_emissions	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2C1a_Steel	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2C1b_Pig_iron	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2C1d_Sinter	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2C3_Aluminium_Production	0.04	0.05	0.06	0.08	0.11	0.08	0.09
2C4_Magnesium_production	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2C6_Zinc_Production	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2D1_Lubricant_Use	0.01	0.01	0.00	0.00	0.00	0.00	0.00
2D4_Other_NEU	0.05	0.03	0.03	0.02	0.04	0.00	0.00
2E1_Integrated_circuit_or_semiconductor	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2F1a_Commercial_refrigeration	0.44	0.33	0.33	0.34	0.33	0.31	0.26
2F1b_Domestic_refrigeration	0.02	0.02	0.02	0.01	0.01	0.01	0.01
2F1c_Industrial_refrigeration	0.15	0.14	0.14	0.15	0.16	0.16	0.15
2F1d_Transport_refrigeration	0.05	0.05	0.05	0.05	0.05	0.06	0.06
2F1e_Mobile_air_conditioning	0.26	0.26	0.27	0.27	0.27	0.27	0.27
2F1f_Stationary_air_conditioning	0.18	0.19	0.21	0.22	0.24	0.25	0.26
2F2a_Closed_foam_blowing_agents	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2F2b_Open_foam_blowing_agents	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2F3_Fire_Protection	0.02	0.02	0.02	0.02	0.03	0.03	0.03
2F5_Solvents	0.00	0.01	0.01	0.01	0.01	0.01	0.01
2F6b_Other_Applications:Contained-Refrigerant_containers	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2G1_Electrical_equipment	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2G2_Military_applications	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2G2_Particle_accelerators	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2G2e_Electronics_and_shoes	0.08	0.08	0.09	0.10	0.10	0.11	0.12
2G2e_Tracer_gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2G3a_Medical aplications	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2G3b_N2O_from_product_uses:_Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2G4_Other_product_manufacture_and_use	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5C2.2b_Non-biogenic:Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Development	1.93	1.91	1.89	1.93	1.88	1.87	2.02
4E1_Settlements remaining settlements	0.66	0.66	0.66	0.66	0.66	0.65	0.65
4E2_1_Forest Land converted to Settlements	0.31	0.30	0.29	0.33	0.30	0.30	0.46
4E2_2_Cropland converted to Settlements	0.08	0.08	0.08	0.09	0.09	0.09	0.09
4E2_3_Grassland converted to Settlements	0.89	0.88	0.86	0.85	0.84	0.83	0.82
Energy Supply	20.89	17.02	17.42	15.97	13.86	12.22	7.16
1A1ai_Public_Electricity&Heat_Production	15.85	12.13	12.82	11.43	9.80	7.73	2.49
1A1b_Petroleum_Refining	2.13	2.25	2.25	2.04	1.77	2.02	2.17
1A1ci_Manufacture_of_solid_fuels	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1A1cii_Oil_and_gas_extraction	1.43	1.32	1.18	1.20	1.15	1.19	1.38
1A1ciii_Other_energy_industries	0.52	0.29	0.32	0.39	0.28	0.35	0.40
1B1ai_Underground_mines:Abandoned	0.07	0.07	0.07	0.07	0.07	0.07	0.07
1B1ai_Underground_mines:Mining_activities	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1B1ai_Underground_mines:Post-mining_activities	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1B1aii_Surface_mines:Mining_activities	0.06	0.06	0.05	0.03	0.03	0.01	0.01
1B1b_Solid_Fuel_Transformation	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1B2a1_Oil_exploration	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1B2a2_Oil_Production	0.01	0.01	0.00	0.00	0.00	0.00	0.00
1B2a3_Oil_transport	0.01	0.01	0.00	0.00	0.00	0.00	0.00

1B2a4_Oil_refining/storage	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1B2b1_Gas_exploration	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1B2b3_Gas_processing	0.10	0.11	0.08	0.08	0.06	0.04	0.02
1B2b4_Gas_transmission_and_storage	0.01	0.01	0.01	0.00	0.00	0.00	0.00
1B2b5_Gas_distribution	0.33	0.31	0.31	0.30	0.27	0.27	0.25
1B2c_Flaring_Gas	0.05	0.06	0.04	0.03	0.03	0.03	0.02
1B2c_Flaring_Oil	0.31	0.36	0.24	0.34	0.36	0.45	0.32
1B2c_Venting_Gas	0.01	0.02	0.04	0.03	0.04	0.03	0.03
1B2c_Venting_Oil	0.00	0.02	0.01	0.00	0.00	0.00	0.00
2A4d_Other_process_uses_of_carbonates:other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Forestry	-13.69	-13.47	-11.32	-12.39	-12.70	-12.89	-12.66
4A_Forest Land_Emissions_from_Drainage	0.03	0.03	0.03	0.03	0.03	0.03	0.03
4A1_ Forest Land remaining Forest Land	-11.88	-11.57	-10.03	-11.38	-11.87	-12.02	-11.97
4A2_1_Cropland converted to Forest Land	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
4A2_2_Grassland converted to Forest Land	-0.17	-0.12	-0.10	-0.10	-0.08	-0.09	-0.11
4A2_4_Settlements converted to Forest Land	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
4A2_5_Other land converted to Forest Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4A2_Cropland converted to Forest Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4A2_Grassland converted to Forest Land	0.05	0.05	0.05	0.05	0.05	0.05	0.05
4A2_Land converted to Forest Land_Emissions_from_Fertilisation	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4A2_Other Land converted to Forest Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4A2_Settlements converted to Forest Land	0.00	0.00	0.00	0.01	0.01	0.01	0.01
4G_Harvested Wood Products	-1.71	-1.85	-1.27	-0.99	-0.82	-0.85	-0.65
International Aviation and Shipping	1.43	1.55	1.46	1.53	1.61	1.70	1.82
Aviation_Bunkers	1.01	1.10	1.09	1.15	1.21	1.32	1.43
Marine_Bunkers	0.42	0.45	0.37	0.38	0.41	0.38	0.39
Public Sector Buildings	1.28	1.06	1.19	1.20	1.02	1.06	1.08
1A4ai_Commercial/Institutional	1.28	1.06	1.19	1.20	1.02	1.06	1.08
Residential	8.01	6.49	7.03	7.07	5.94	6.11	6.32
1A4bi_Residential_stationary	7.81	6.29	6.83	6.87	5.75	5.93	6.13
1A4bii_Residential:Off-road	0.03	0.03	0.03	0.03	0.03	0.03	0.03

2D2 Non-energy_products_from_fuels_and_solvent_use:Paraffin_wax_use	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2F4a_Metered_dose_inhalers	0.07	0.08	0.08	0.08	0.08	0.08	0.08
2F4b_Aerosols:Other	0.09	0.08	0.08	0.08	0.07	0.07	0.06
5B1a_composting_municipal_solid_waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5C2.2b_Non-biogenic:Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5C2.2b_Non-biogenic:Other_Accidental fires (vehicles)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Transport (excluding international aviation and shipping)	12.91	12.38	12.22	12.03	12.15	12.38	12.58
1A3a_Domestic_aviation	0.54	0.53	0.52	0.53	0.51	0.51	0.48
1A3bi_Cars	5.76	5.68	5.71	5.62	5.63	5.65	5.78
1A3bii_Light_duty_trucks	1.43	1.44	1.46	1.48	1.55	1.63	1.73
1A3biii_Heavy_duty_trucks_and_buses	2.21	2.13	2.15	2.17	2.17	2.21	2.22
1A3biv_Motorcycles	0.03	0.03	0.03	0.03	0.03	0.03	0.03
1A3bv_Other_road_transport	0.03	0.03	0.03	0.03	0.02	0.02	0.02
1A3c_Railways	0.17	0.17	0.17	0.17	0.17	0.17	0.17
1A3d_Domestic_navigation	2.01	1.73	1.52	1.40	1.41	1.58	1.58
1A3eii_Other_Transportation	0.08	0.08	0.08	0.09	0.09	0.10	0.10
1A4ai_Commercial/Institutional	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1A4ciii_Fishing	0.39	0.32	0.33	0.31	0.38	0.32	0.33
1A5b_Other:Mobile	0.23	0.22	0.20	0.18	0.16	0.13	0.12
2D1_Lubricant_Use	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2D3_Non-energy_products_from_fuels_and_solvent_use:Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste Management	2.54	2.40	2.06	1.45	1.47	1.73	1.64
5A1a_Managed_Waste_Disposal_sites_anaerobic	2.15	1.99	1.69	1.09	1.10	1.34	1.25
5B1a_composting_municipal_solid_waste	0.10	0.11	0.11	0.11	0.12	0.12	0.13
5B2a_Anaerobic_digestion_municipal_solid_waste	0.00	0.00	0.00	0.01	0.01	0.01	0.01
5C1.1b_Biogenic:Sewage_sludge	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5C1.2a_Non-biogenic:municipal_solid_waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5C1.2b_Non-biogenic:Clinical_waste	0.01	0.01	0.01	0.01	0.01	0.01	0.01
5C1.2b_Non-biogenic:Other_Chemical_waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5D1_Domestic_wastewater_treatment	0.12	0.12	0.11	0.10	0.11	0.10	0.11
5D2_Industrial_wastewater_treatment	0.16	0.17	0.13	0.13	0.13	0.14	0.14

Grand Total	55.82	49.16	51.46	48.39	44.36	43.01	38.57

6. UK Renewable Energy Generation and Emission Savings

Introduction

This section presents figures describing energy generation in the UK and in Scotland, and the proportion supplied by renewable energy including marine renewables. Energy generation, summarised in giga watt hours (GWh, or 1,000,000,000 watts of electrical energy generated per hour) is converted into the equivalent GHG emissions, expressed in carbon dioxide equivalents.

Source data is BEIS (2019a) for UK GHG emission data, and BEIS (2019b) for UK renewable energy statistics. Additional data on Scottish GHG emissions were obtained from SG (2017), and on Scottish renewable energy generation from Scottish Renewables (2019).

Displacement of GHG emissions using renewable energy

From Scottish Renewables (2019), Chart 7: Emissions Reduced by Scotland's Renewables Electricity Output, coupled with the BEIS (2019b) estimates of Scottish renewable energy generation, we get the following estimates of GHG emission displacement by renewable energy:

Table 11

GHG emissions displaced by renewable energy generation, and associated displacement ratios (tonnes CO_2-eq. / GWh).

Year	GHG Displacement ('000 tonnes CO_2-eq.)	Renewable Energy Generation (GWh)	Displacement Ratio (tonnes CO_2-eq. per GWh)
2010	5,611	9419	600
2011	8,364	13,869	600
2012	10,377	14,667	710
2013	11,900	16,990	700
2014	12,300	19,045	650
2015	13,400	21,744	620
2016	9,400	19,782	480
		Average	620

Hence, for every 1 GWh of electricity generation using renewable energy, 620 tonnes CO_2-eq. of GHG emissions are displaced.

SG (2019) on-line emissions calculator also gives relevant figures. The conversion factors for different fuel types are given as follows:

Table 12

GHG emissions displacement ratios (tonnes CO_2-eq. / GWh) for different fuel types.

Electricity Source	**2015**	**2016**	**2017**
Coal	909	931	918
Gas	302	378	357
All fossil fuels	625	497	460
All fuels (incl. nuclear and renewables)	335	265	225
Grid Mix	462	412	352

The conversion factor for all fossil fuels for 2015 in the table above (i.e. 625 t CO_2-eq./GWh) agrees well with the first estimate of 620 t CO_2-eq./GWh, also for 2015. Estimation of the GHG emissions displaced by renewable energy depends on which fuel type it replaces. For this study we will use the figure of 460 t CO_2-eq./GWh, the value for all fossil fuels for 2017.

Table 13a

Electricity generation in the UK by source type. Units – GWh. Source BEIS (2019a), Annual Page, Table 6.1. Renewable electricity capacity and generation. Nuclear and Fossil fuel split from SG (2018).

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Onshore wind	7,226	10,814	12,244	16,925	18,555	22,852	20,857	29,088	30,432
Offshore wind	3,060	5,149	7,603	11,472	13,405	17,423	16,406	20,916	26,683
Shoreline wave / tidal	2	1	4	5	2	2	0	4	8
Solar photovoltaics	40	244	1,354	2,010	4,054	7,533	10,411	11,525	12,922
Hydro	3,591	5,692	5,310	4,701	5,888	6,297	5,617	5,928	5,464
Bioenergy	12,260	13,313	14,735	18,100	22,619	29,256	30,064	31,869	35,579
Nuclear	62,140	68,980	70,405	70,607	63,748	70,345	71,726	95,243[1]	89,929[1]
Fossil Fuels (Coal and Gas)	285,896	257,890	246,362	228,971	204,494	179,703	178,679	142,020[1]	134,096[1]
All Electricity	374,214	362,084	358,017	352,791	332,765	333,411	333,760	336,593	335,113
Renewables	26,179	35,213	41,250	53,213	64,523	83,363	83,355	99,330	111,088

1 – these values estimated using 2016 nuclear / fossil fuel ratio and difference of total electricity production and renewables total.

Table 13b

Electricity generation in Scotland by source type. Units – GWh. Source BEIS (2019a), SCOTLAND – Quarter Page, Table 6.1c Renewable electricity capacity and generation: Scotland. Nuclear and Fossil fuel split from SG (2018).

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Onshore wind	4,431	6,653	7,752	10,563	11,130	13,340	11,954	16,448	17,809
Offshore wind	442	603	541	587	569	539	502	616	1,370
Shoreline wave / tidal	0	0	0	1	2	1	0	3	8
Solar photovoltaics	1	8	70	96	142	185	275	289	329
Hydro	3,258	5,330	4,847	4,370	5,484	5,814	5,149	5,356	4,983
Bioenergy	1,288	1,273	1,460	380	1,717	1,864	1,899	2,453	2,210
Nuclear	15,293	16,892	17,050	18,498	16,633	17,763	19,630	17,000[1]	17,000[1]
Fossil Fuels (coal and gas)	23,118	19,048	17,367	16,277	13,038	10,427	5,368	4,835[1]	3,291[1]
All Electricity	47,831	49,807	49,087	50,772	48,715	49,932	44,777	47,000[1]	47,000[1]
Renewables		13,867	14,670	15,997	19,044	21,743	19,779	25,165	26,709

1 – estimated using Chart 6 from SG (2019)

Table 13c

Emissions displaced by renewable energy generation in the UK by source type. Units – Mt CO_2-eq. Source – Table 13a converted using 460 t CO_2-eq. / GWh.

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Onshore wind	3.3	5.0	5.6	7.8	8.5	10.5	9.6	13.4	14.0
Offshore wind	1.4	2.4	3.5	5.3	6.2	8.0	7.5	9.6	12.3
Shoreline wave / tidal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar photovoltaics	0.0	0.1	0.6	0.9	1.9	3.5	4.8	5.3	5.9
Hydro	1.7	2.6	2.4	2.2	2.7	2.9	2.6	2.7	2.5
Bioenergy	5.6	6.1	6.8	8.3	10.4	13.5	13.8	14.7	16.4
Total	12.0	16.2	19.0	24.5	29.7	38.3	38.3	45.7	51.1
Total Marine	1.4	2.4	3.5	5.3	6.2	8.0	7.5	9.6	12.3
Total Terrestrial	10.6	13.8	15.5	19.2	23.5	30.3	30.8	36.1	38.8

Table 13d

Emissions displaced by renewable energy generation in Scotland by source type. Units – Mt CO_2-eq. Source – Table 13b converted using 460 t CO_2-eq./GWh.

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Onshore wind	2.0	3.1	3.6	4.9	5.1	6.1	5.5	7.6	8.2
Offshore wind	0.2	0.3	0.2	0.3	0.3	0.2	0.2	0.3	0.6
Shoreline wave / tidal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar photovoltaics	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2
Hydro	1.5	2.5	2.2	2.0	2.5	2.7	2.4	2.5	2.3
Bioenergy	0.6	0.6	0.7	0.2	0.8	0.9	0.9	1.1	1.0
Total	4.3	6.4	6.7	7.4	8.8	10.0	9.1[1]	11.6	12.3
Total Marine	0.2	0.3	0.2	0.3	0.3	0.2	0.2	0.3	0.6
Total Terrestrial	4.1	6.1	6.5	7.1	8.5	9.8	8.9	11.3	11.7

1 – Scottish Renewables (2019; Chart 7) quotes a value of 9.4 Mt CO_2-eq. For the emissions displaced by all Scottish renewables in 2016. This gives some confidence to the calculations performed in this study.

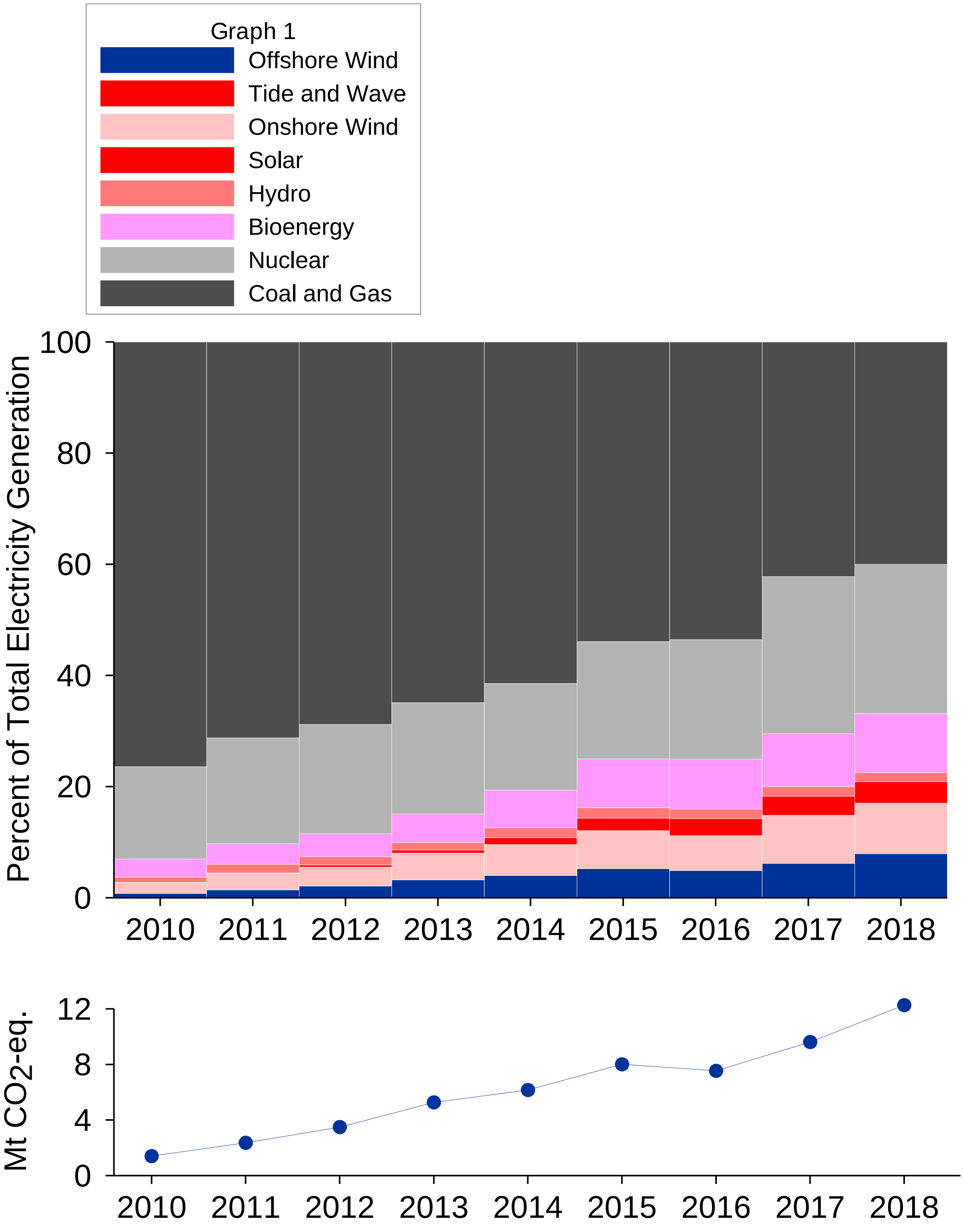


Figure 3: The growth of offshore wind renewable energy in the UK. Upper figure – percentage of the total Scottish electricity generation each year, 2010 to 2018, generated by different technologies (see Legend). Lower figure – the total amount of GHG emissions displaced by offshore wind electricity generation.

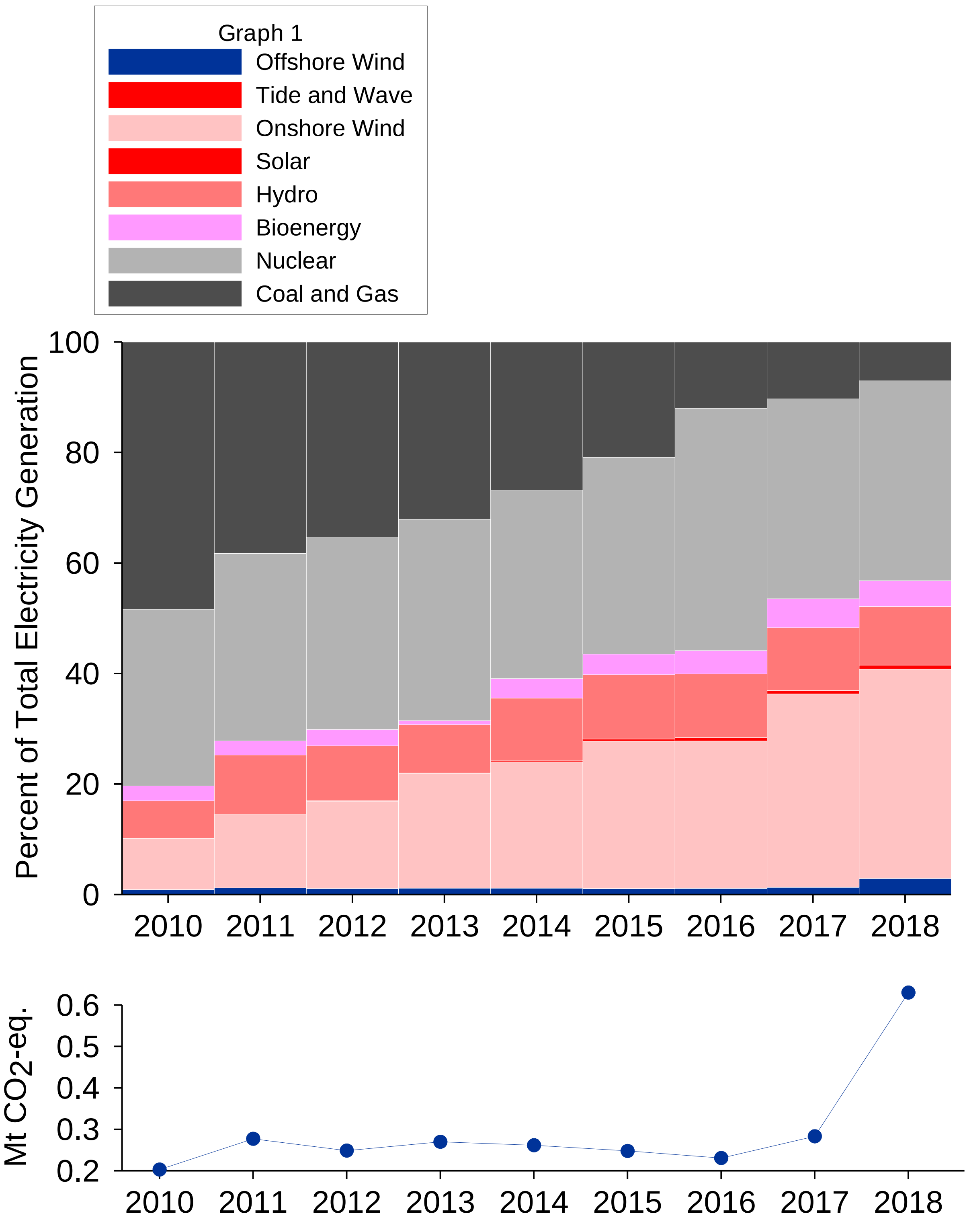


Figure 4: The growth of offshore wind renewable energy in Scotland. Upper figure – percentage of the total Scottish electricity generation each year, 2010 to 2018, generated by different technologies (see Legend). Lower figure – the total amount of GHG emissions displaced by offshore wind electricity generation.

7. Blue Carbon – Sequestration Rates and Storage Estimates for Scotland

Introduction

This section uses three main sources of information to present figures relating to Scottish marine carbon stores and sequestration rates. Two of the sources were reports commissioned by Scottish Natural Heritage (SNH), one an audit of all Scottish marine carbon (Burrows et al. 2014), and one an audit of Scottish marine carbon located within Marine Protected Areas (as of 2017; Burrows et al., 2017). The third source consists of two papers by a research team at Heriott-Watt University (Smeaton et al., 2016; 2017).

Carbon to CO_2-Equivalent Conversion

All three data sources used in this section use carbon masses and fluxes predominantly. All of these have been converted to carbon dioxide equivalents in order to allow inter-comparison with other figures in this report.

To convert from organic and/or inorganic carbon stored to carbon dioxide equivalent we multiply by the ratio of the molecular masses of CO_2 and C, i.e. 44/12, or 3.67.

e.g. Burrows et al. (2014) state that the deposition rate of organic carbon in Scotland's marine sediments amounts to 7.2 MtC/yr and inorganic carbon 0.5 MtC/yr, i.e. a total of 7.7 MtC/yr which converts to 28.2 Mt CO_2 / year.

Table 14

Marine carbon sequestration rates from Burrows et al. (2014), updated by figures published in Burrows et al. (2017).

Page	Report Quote	Parameter	Mt C per Year	Mt CO_2 – eq. per Year
i	Deposition of organic carbon amounts to **7.2 MtC/yr** and inorganic carbon **0.5 MtC/yr** in Scotland's marine sediments.	C fixed and locked into sediment - TOTAL	**7.7**	28.2
49	The primary source of organic carbon in sediments is phytoplankton, estimated as **3.9MtC/yr**,	C fixed and locked into sediment - PHYTOPLANKTON	**3.9**	14.3
11	this gives estimated production from kelp in Scottish waters as **1 732 000 tC/yr** (or 1.73 MtC/yr).	C fixed and locked into sediment - COASTAL PLANTS (KELP)	**1.732**	6.35
13	Scottish saltmarshes may have an average sequestration potential of **14200 t C/yr** (0.014 Mt C yr^{-1}).	C fixed and locked into sediment - COASTAL PLANTS (SALTMARSH)	**0.014**	0.051
14	an estimate of sequestration capacity for seagrasses in Scotland of **1321 t C/yr.**	C fixed and locked into sediment - COASTAL PLANTS (SEAGRASS)	**0.001321**	0.005
38	standing stock of organic carbon in the top 10cm of sea loch sediment of 338 000 tC or 0.34 MtC, and a sequestration capacity of sea lochs of **0.18 MtC/yr**.	C fixed and locked into sediment - SEA LOCHS	**0.18**	0.660
18	We have thus used a blanket average of 50% live generating an annual carbon sequestration added to the standing stock of between 33.5-**607**- **tC/yr** for all Scottish beds.	C fixed and locked into sediment - MAERL BEDS	**0.000607**	0.002
A	Total carbon sequestration rate in the inshore MPA network was estimated as 511 000 t y-1, of which 127 000 t y-1 (24.8%) was organic, and 384 000 t y-1 (75.2%) inorganic carbon.	C fixed by Scottish inshore MPAs	**0.51**	1.9

A – Page 43 of Burrows et al. (2017).

Table 15

Marine carbon stores from Burrows et al. (2014), updated by figures published in Burrows et al. (2017).

Page	Report Quote	Parameter	Mt C	Mt CO_2-eq.
i	An estimated 18 million tonnes (MtC) of organic carbon are stored in the top 10cm of sediments across the 470 000km^2 area of Scotland's seas.	Organic Carbon in top 10 cm of sediment	18	66
A	592 Mt organic carbon (revised Burrows et al., (2014) value)	Organic Carbon in top 10 cm of sediment	592	2,170
i	An estimated 1738 million tonnes (MtC) of inorganic carbon are similarly stored as nonliving shell material.	Inorganic Carbon in top 10 cm of sediment	1,738	6,373
Total of Burrows et al. (2014) organic + inorganic		Total Carbon in top 10 cm of sediment	1,756	6,439
Burrows et al. (2017) organic + Burrows et al. (2014) inorganic		Total Carbon in top 10 cm of sediment	2,330	8,543
10	this produces total estimates of standing stock of kelp around Scotland of 202 000t and 404 000t C, over a total area of 2155km^2.	Organic Carbon in Live Kelp	0.404	1.48
38	standing stock of organic carbon in the top 10cm of sea loch sediment of 338 000 tC or 0.34 MtC, and a sequestration capacity of sea lochs of 0.18 MtC/yr.	Organic Carbon in top 10 cm sea lochs	0.338	1.24
17	we estimate 440561 t C are locked within maerl deposits. (4.23 km^3 × 0.8667 Tons m^{-3} ×	Inorganic Carbon in maerl beds	0.440561	1.62

A – this is from Page i of Burrows et al. (2017).

Table 16

Marine carbon stores from Burrows et al. (2017).

Page	Report Quote	Parameter	Mt C	Mt CO_2-eq.
i	Stocks of carbon within the habitats and surface sediments of inshore MPAs are estimated at 9.4 million tonnes (Mt) organic carbon and 47.8 Mt inorganic carbon;	Organic carbon in Scotland's MPAs	9.4	34
		Inorganic carbon in Scotland's MPAs	47.8	175
		Total carbon in Scotland's MPAs	57.2	210
iv	When compared to terrestrial stocks such as Scottish peatlands which hold 1620 Mt carbon (Chapman et al., 2013)[A] and forestry stores (biomass) which hold an estimated 85.15 Mt carbon (Forestry Commission, 2016a)	Total carbon (all organic) in Scotland's peatlands	1,620	5,940
		Total carbon (all organic) in Scotland's forests	85.2	312

A – Although Chapman et al. (2013) is given as the reference for the carbon stock in Scottish peat, the value actually comes from Chapman et al. (2009). It assumes the average depth of peat in Scotland is 2 m.

Table 17

Marine carbon store from Smeaton et al. (2016, 2017).

Report Quote	Parameter	Mt C	Mt CO_2
Burrows et al. (2014) - C fixed and locked into sediment - SEA LOCHS Organic Carbon in top 10 cm sea lochs	Organic Carbon	0.338	1.24
Total carbon in Scotland's 111 lochs	Total Carbon	640	2,350
Total organic carbon in Scotland's 111 lochs	Organic Carbon	295	1,080
Total inorganic carbon in Scotland's 111 lochs	Inorganic Carbon	345	1,270

Table 18

Marine carbon sequestration rates from Smeaton et al. (2016, 2017).

Source	Parameter	Mt C per Year	Mt CO_2 per Year
Burrows et al. (2014) - C fixed and locked into sediment - SEA LOCHS	Total Carbon	**0.18**	0.660
Carbon burial per year – MIN (31,139 t/year)	Total Carbon	**0.031**	0.11
Carbon burial per year – MAX (40,615 t/year)	Total Carbon	**0.041**	0.15

2019 Update – Seabed Sediment

Smeaton et al. (2019) updated the estimates of the stored carbon in Scottish seabed sediments. They estimated that in the upper 10cm of the seabed sediment covering the "mapped extended Exclusive Economic Zone (i.e. 554,755 km^2)" there is 1,515 ± 252 Mt C. Of this, 1,294 ± 161 Mt are inorganic carbon and 221 ± 92 Mt are organic carbon.

In summary, in terms of carbon loads:

		Organic Carbon		Inorganic Carbon		Total Carbon	
		Mt	s.d.	Mt	s.d.	Mt	s.d.
OLD	Burrows et al. 2014	592		1,738		2,330	
NEW	Smeaton et al 2019	221	92	1,294	161	1,515	252

In summary, in terms of CO_2-eq. loads:

		OC		IC		Total Carbon	
		Mt-CO_2 eq.	s.d.	Mt-CO_2 eq.	s.d.	Mt-CO_2 eq.	s.d.
OLD	Burrows et al. 2014	2,171		6,373		8,543	
NEW	Smeaton et al 2019	810	337	4,745	590	5,555	924

2019 Update - Scottish Soil Carbon Content

The following estimates have been proposed for total carbon stocks in all Scottish soils, to a depth of 1m (Aitkenhead and Coull, 2016):

Value		Source
Mt Carbon	Mt CO_2-eq.	
2,187	8,026	Bradley et al., 2005
2,055	7,542	Chapman et al., 2013
3,000	11,010	Campbell et al. 2012
2,954	10,841	Aitkenhead and Coull, 2016

The values presented by Aitkenhead and Coull (2016) are used here as being the most recent and complete estimates, and which include information on the vertical structure of Carbon in Scottish soils.

Aitkenhead and Coull (2016) present the total Carbon content for the following soil types:

Soil Type	Total Carbon	
	Mt	Mt CO_2-eq.
Alluvial	41	150
Alpine	146	535
Bare ground	51	185
Brown earth	590	2,166
Gley	645	2,369
Peat	814	2,987
Podzol	537	1,969
Ranker	83	303
Regosol	19	70
Other	29	107
Total	2,954	10,841

In order to correct to the upper 10cm, two methods can be used.

Uniform Vertical Profile

The first assumes a uniform average Carbon content profile in the vertical for Scottish soils. This method results in a value of 1,084 Mt CO_2-eq. (295 Mt Carbon) for the upper 10cm of Scottish soils, and 299 Mt CO_2-eq. (81 Mt Carbon) for peat.

Average Scottish Soil Vertical Profile

A second method uses the vertical profile of average soil carbon content per cm presented in Figure 4 of Aitkenhead and Coull (2016). Digitising this curve gives the following values:

Depth (cm)		Peat Total Carbon		All Soil Total Carbon	
Top	Bot	Mt C	Mt CO_2-eq.	Mt C	Mt CO_2-eq.
0	**10**	**139**	**509**	**561**	**2,059**
10	20	124	456	484	1,776
20	30	111	406	427	1,567
30	40	97	355	351	1,289
40	50	83	305	291	1,069
50	60	71	260	240	880
60	70	60	222	197	723
70	80	51	187	162	594
80	90	43	157	133	489
90	100	36	131	108	396
	Total	**814**	**2,987**	**2,954**	**10,841**

Hence, using the depth resolved estimation method, Scottish marine and terrestrial carbon stores become:

Total Carbon in top 10cm of Scotland's peatlands	509 million tonnes of CO_2-eq.
Total Carbon in top 10cm of Scotland's soils excluding peat	1,550 million tonnes of CO_2-eq.
Total Carbon in Scottish living trees	312 million tonnes of CO_2-eq.
Total Carbon in top 10cm of Scotland's seabed sediment	5,555 million tonnes of CO_2-eq.

Table 19

Overall summary of carbon sequestration rates and stores from Burrows et al. (2014, 2017), Smeaton et al. (2016, 2017) and Smeaton et al. (2019). Store times are estimated using the ratio of store size to sequestration rate, and indicates the length of time that is needed to sequester the indicated store at the indicated sequestration rate.

Ecosystem Component	Annual Carbon Sequestration Rate (Mt CO_2-eq. per year)	Carbon Store		
		Description	Size (Mt CO_2-eq.)	Store Time (Years)
Sediment Total	28	Total Carbon in upper 10 cm of seabed	5,555	198
Phytoplankton	14.3	Organic Carbon in upper 10 cm of seabed	221	15
Kelp	6.3	Organic Carbon in live kelp	1.5	0.2
Sea lochs	0.15	Organic Carbon in upper 10 cm of seabed	1.2	1.9
		Total Carbon in all sediment	2,350	16,000
Saltmarsh	0.051	Organic Carbon	Unknown	
Seagrass	0.005	Organic Carbon		
Maerl Beds	0.002	Inorganic Carbon	1.6	726
Scotland's Inshore MPAs				
MPAs	1.9	Total Carbon	210	110
Scottish Terrestrial Comparisons				
Peatlands (top 10 cm)	-0.1 [A]	Organic Carbon	509	-
Forests (living trees)	12.7 [B]	Organic Carbon	312	24

A – Table 16 above. Peat currently emits GHG (methane) as it requires restoration. B – Table 16 above.

UK Equivalent Estimates

We can scale some of the Scottish figures to that of the whole UK using the ratio of the area of Scottish waters (approx. 469,000 km^2. 555,000 km^2 used for seabed carbon, from Smeaton et al., 2019) to the area of all UK waters (i.e. approximately 751,000 km^2).

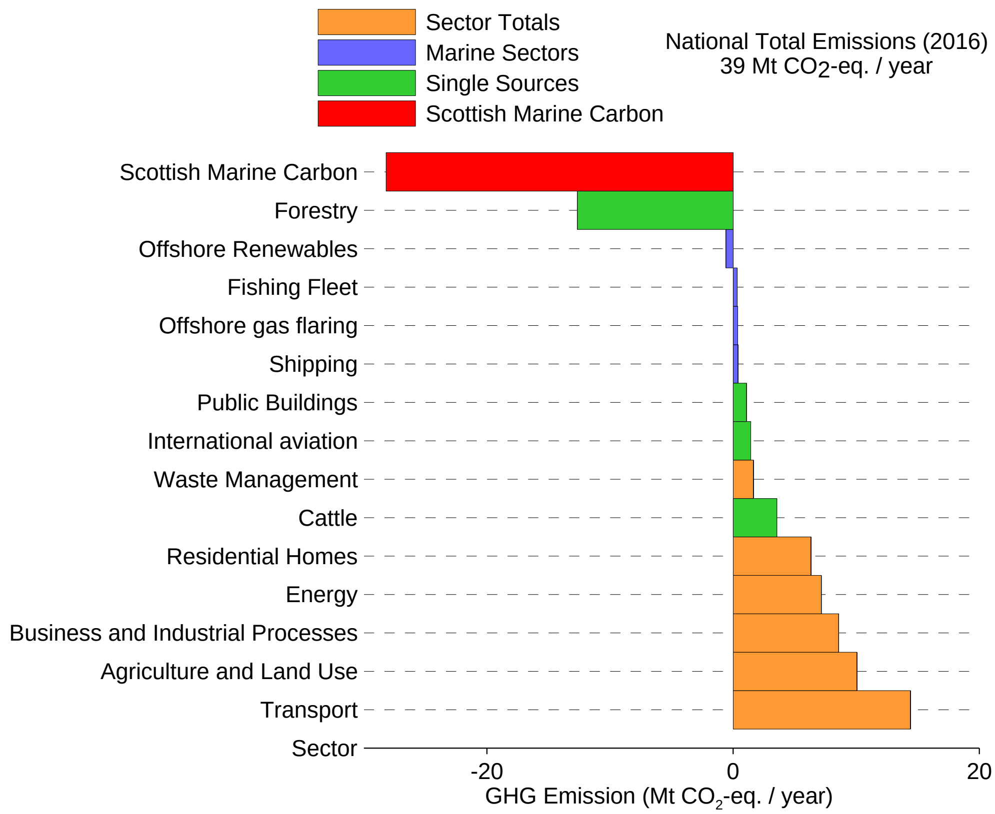
Using this ratio we get:

Table 20

Estimated UK marine carbon stores and sequestrations rates using Scottish values.

Description	Value Scotland	Area Scotland ('000 km^2)	Area UK ('000 km^2)	Value UK	Units
Total carbon sequestration	28	469	751	45	Mt CO_2-eq. / year
Carbon store in seabed upper 10 cm (organic + inorganic)	5,555	555	752	7,527	Mt CO_2-eq.
Phytoplankton production	14	469	753	22	Mt CO_2-eq. / year

However, this is a very approximate estimate as many of the assumptions made to reach the Scottish figure concerning the nature of Scottish waters and seabed habitats may well not apply to all UK waters on a straight *pro rata* basis.



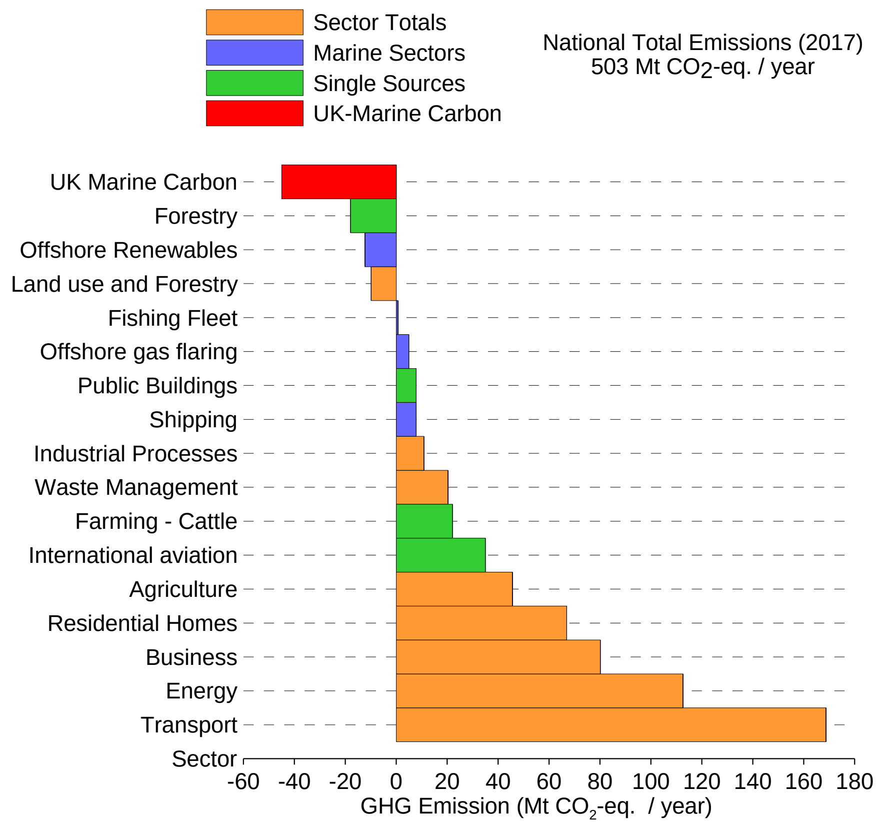


Figure 5: Comparison of various marine and non-marine related emissions/sequestrations – Scotland (upper figure) and UK (lower figure). Single emission sources (green), marine emission sectors and sources (blue) and emission sector totals (orange) from Tables 10c and 10d. Marine carbon values from Tables 19 and 20.

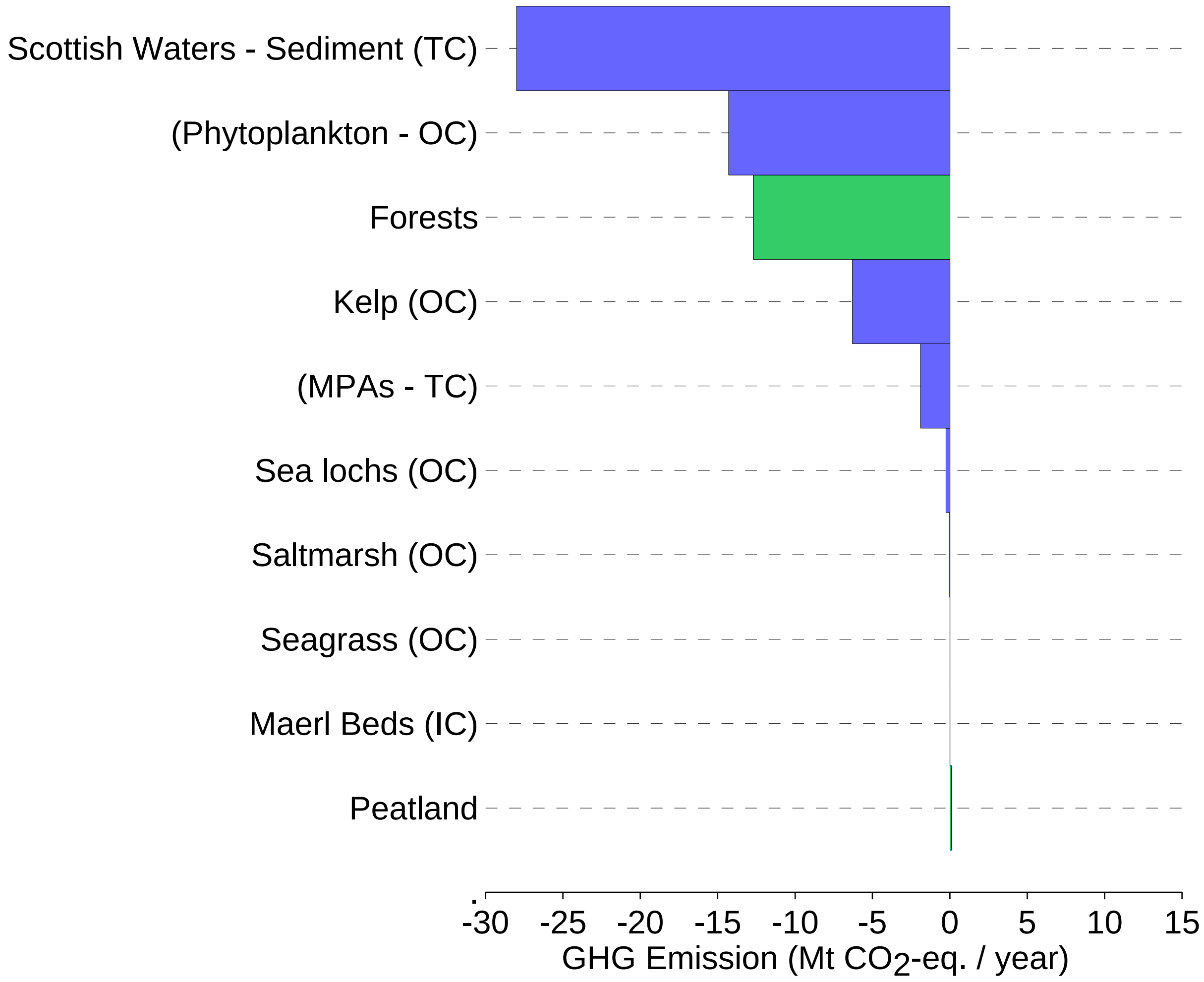


Figure 6: Detail of Scottish marine carbon sequestration rates (Table 19).

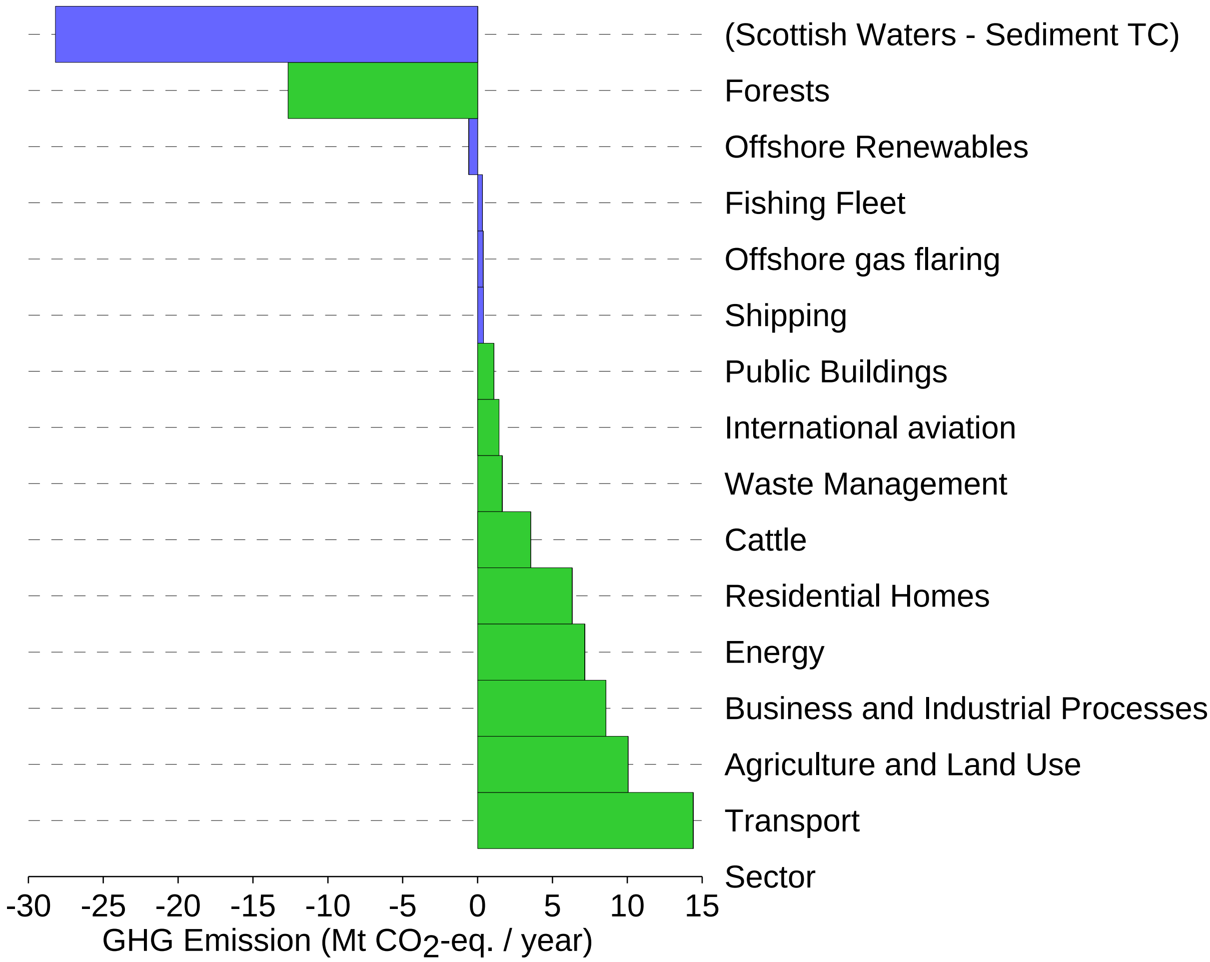


Figure 7: Scottish marine carbon sequestration rates compared to non-marine emissions.

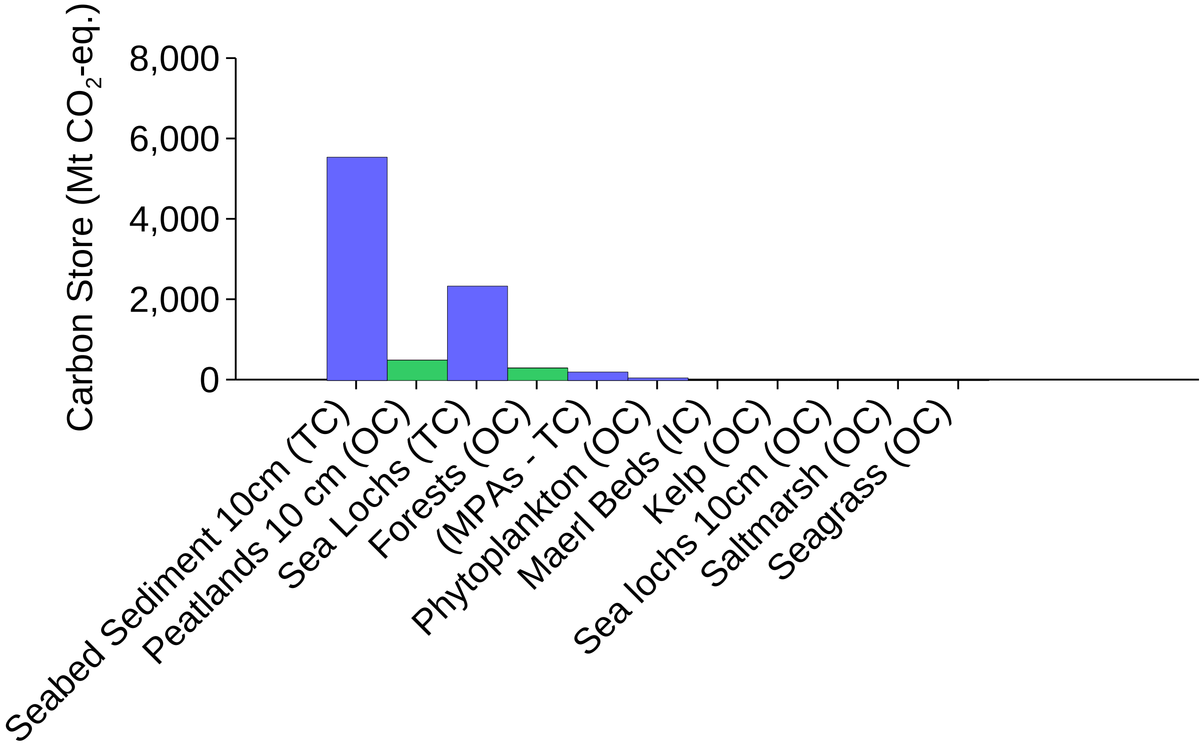


Figure 8: Detail of Scottish marine carbon stores (Table 19).

8. Blue Carbon – Regional and Global Emission Estimates

From literature, the following tables summarise some recent estimates of global GHG emissions and stores related to blue carbon, compared to other key emission sources:

Table 21

Summary of some global values relating to carbon emissions and sequestration rates.

Source	Annual Emission ($Mt\ CO_2$-eq. / year)	Reference
Fossil fuel use	23,500	Shepherd et al., 2009
Terrestrial land use change (deforestation)	5,900	Shepherd et al., 2009
Degrading coastal blue carbon systems (mangroves, saltmarsh, seagrass)	550 to 3,740	Wylie et al., 2016
Carbon burial in coastal zone	-880	Smeaton et al., 2016

Table 22

Summary of some global values relating to carbon stores.

Source	Carbon Store ($Mt\ CO_2$-eq.)	Reference
TOTAL Intermediate and deep ocean	129,000,000	Shepherd et al., (2009)
TOTAL Global fossil fuel reserves	12,700,000	Shepherd et al., (2009)
TOTAL Terrestrial vegetation and soil	8,430,000	Shepherd et al., (2009)
TOTAL Surface Ocean	3,400,000	Shepherd et al., (2009)
TOTAL Atmosphere	2,800,000	Shepherd et al., (2009)
TOTAL Seabed sediment	550,000	Shepherd et al., (2009)
Mangroves	29,300	IPCC (2014)
TOTAL Marine Biota	11,000	Shepherd et al., (2009)
Seagrass Meadows (Max)	8,400	IPCC (2014)
Seagrass Meadows (Min)	4,200	IPCC (2014)
Tidal Marshes	2,900	IPCC (2014)

Note that the specific items (no TOTAL prefix) will be included in the TOTAL figures.

Kröger et al. (2018) made the following estimates for the NW European Continental Shelf:

Table 23

Blue carbon estimates by Kröger et al. (2018) for the NW European Continental Shelf: Sequestration Rates

Source	Annual Sequestration (Mt CO_2-eq. / year)
Ocean CO_2 Uptake - Min	59
Ocean CO_2 Uptake - Max	147
Coastal Habitats CO_2 Uptake - Min	1
Coastal Habitats CO_2 Uptake - Max	2
Carbon input to sea from rivers - Min	100
Carbon input to sea from rivers - Max	220

Table 24

Blue carbon estimates by Kröger et al. (2018) for the NW European Continental Shelf: Stores.

Source	Annual Sequestration (Mt CO_2-eq. / year)
Coastal Habitats - Min	29
Coastal Habitats - Max	147
Offshore Sediment (upper 10 cm) - Min	23,100
Offshore Sediment (upper 10 cm) - Max	69,700
Offshore Water Column - Min	9,200
Offshore Water Column - Max	10,300

9. Some Emissions Statistics Relevant to Marine Science Travel

Table 25

From BEIS (2019c). 1- Average passenger class, radiative forcing included. 2- Upper medium class car, average petrol/diesel. 3 – BEIS (2019c). 4 - Ferreboeuf, 2019 - Table 8: Digital Environmental Repository (DER), Utilization phase – Digital actions. Average EU/USA. 5 – World Bank (2019). Emissions are for 2014, from the burning of fossil fuels and the manufacture of cement, including consumption of solid, liquid, and gas fuels and gas flaring. 6 - Least Developed Countries, UN Definition – 33 African countries, 9 Asian countries, 4 in Oceania and 1 in the Americas.

<table>
<tr><th>Theme</th><th>Description</th><th>kg CO_2-eq.</th><th>Unit</th></tr>
<tr><td rowspan="3">Air Travel[1]</td><td>UK Domestic Flight</td><td>0.25</td><td rowspan="6">per passenger km</td></tr>
<tr><td>Short Haul International Flight</td><td>0.16</td></tr>
<tr><td>Long Haul International Flight</td><td>0.20</td></tr>
<tr><td rowspan="3">Land Travel</td><td>Car[2]</td><td>0.18</td></tr>
<tr><td>Train - UK</td><td>0.04</td></tr>
<tr><td>Train - International</td><td>0.01</td></tr>
<tr><td>Hotel[3]</td><td>Average Northern Europe</td><td>23.5</td><td>per traveller night</td></tr>
<tr><td>Video Streaming[4]</td><td>Average EU/USA</td><td>0.24</td><td>per hour</td></tr>
<tr><td rowspan="3">Citizens[5]</td><td>North America</td><td>44.8</td><td rowspan="3">per person per day</td></tr>
<tr><td>European Union</td><td>17.7</td></tr>
<tr><td>Least Developed Countries[6]</td><td>0.87</td></tr>
</table>

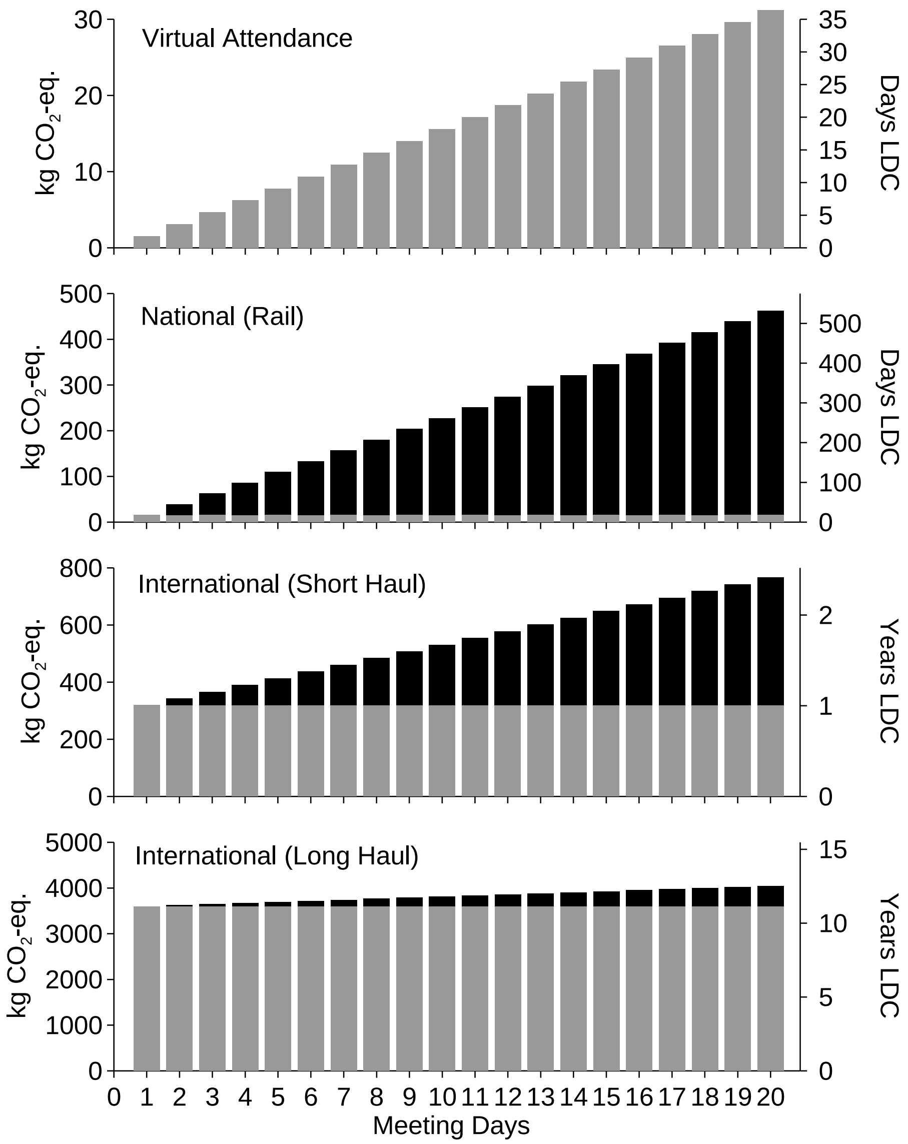


Figure 9: Greenhouse gas emissions (left axis) created by one person attending meetings of 1 to 20 days duration using different methods of attendance. Meeting emissions also compared to emissions of one person in a Least Developed Country (LDC: right axis). Light grey bars – video streaming or travel. Black bars – hotel stays. Virtual attendance assumes 6.5 hours video streaming per day. Journeys: National (rail) 200 km; International (short haul) 1000 km; International (long haul) 9000 km. Travel emissions: Rail travel (UK train), short haul international flight, long haul international flight 0.04, 0.16, 0.20 kg CO_2-eq./passenger km respectively (flights assume average passenger class, radiative forcing included). Hotel emissions (average northern Europe) 23.5 kg CO_2-eq./traveller night. Virtual meeting emissions: 0.24 kg CO_2-eq./per person hour (video streaming, average EU/USA). LDC (Least Developed Country, UN definition) emissions: 0.87 kg CO_2-eq. per person per day.

Virtual attendance:

Start	End	Hours
09:00	11:00	2
11:30	13:30	2
14:00	15:00	1
15:30	17:00	1.5
		6.5

10. Emissions from Marine Scotland Research Vessels

In these estimates, one tonne of vessel fuel is assumed to produce 3.044 tonnes of CO_2-eq. emissions. The density of fuel is assumed to be 0.85.

Table 26

Annual fuel use and emissions from the two Marine Scotland research vessels, MRV Alba na Mara and MRV Scotia, 2015 to 2019.

	Alba na Mara		**Scotia**	
Period	Fuel (tonnes per year)	Emissions (tonnes CO_2-eq. per year)	Fuel (tonnes per year)	Emissions (tonnes CO_2-eq. per year)
2015-2016	254	774	1794	5462
2016-2017	279	850	1706	5195
2017-2018	241	733	1413	4302
2018-2019	246	750	1420	4323
Average	255	777	1583	4821

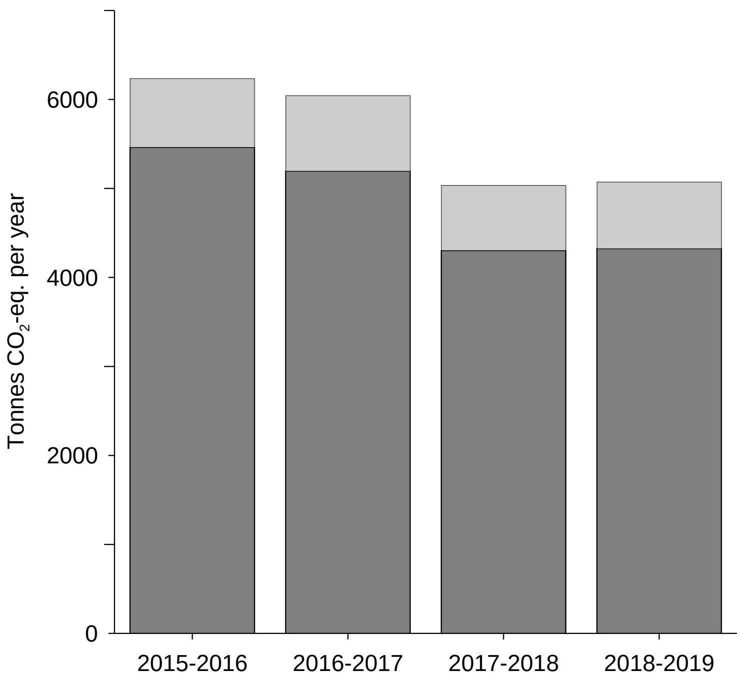


Figure 10: Annual emissions of Marine Scotland research vessels, 2015/2016 to 2018/2019. Dark grey – MRV Scotia. Light grey – MRV Alba na Mara.

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Annex 1 - UK Protein Consumption Calculations

These calculations are presented in order to compare the supply of protein from the UK fishing industry (Section 2) to the total overall protein requirement of the uk population.

First, we consider the eating habits of people in the UK. From Seafish (2019):

Diet	Food Standards Agency (2017)		Grocer (2018)		Compare the Market (2018)	
	%	N (million)	%	N (million)	%	N (million)
Vegetarians	3	1.98	6	3.96	14	9.25
Vegans	1	0.66	2	1.32	7	4.62
Meat and Fish	96	63.40	88	58.12	48	31.70
Pescatarians	0	0	4	2.64	31	20.47
UK population for mid-2017	100	66.04	100	66.04	100	66.04

The Compare the Market (2018) figures have been used in this study.

Seafish (2019, Figure 2) gives the following figures for protein consumption in the UK in 2017:

Protein Source	g / person / week	Percent
Meat	375	71.4
Fish	140	26.7
Tofu / Novel protein	10	1.9
Total	525	100.0

These figures imply that an average person consumes 525 g of protein per week, or 75 g per day.

The British Nutrition Foundation (2016) states that the Reference Nutrient Intake (RNI) is set at 0.75 g of protein per kilogram bodyweight per day in adults. The BBC (2010) states that the average man in England weighed 13.16 stone (83.6 kg) and the average woman in England weighed 11 stone (70.2 kg).

Using these figures, if it is assumed that the average person in the UK in 2017 weighed 12 stone (76.2 kg) then the RNI protein intake would be 57 g per day.

Thus the minimum recommended protein intake for an average UK person is 57 g, whereas in reality we are consuming 75 g per day.

Using the Seafish (2019) percentage figures, it would appear that people in the UK in 2017 following particular diets consume the following percentages of protein from vegetables, meat and fish:

	Protein Source		
Diet	**Vegetable**	**Meat**	**Fish**
	%	%	%
Vegetarian	90	0	10
Vegan	100	0	0
Pescatarian	80	0	20
Meat and Fish	2	72	26

Thus, assuming each consumes a total of 75 g of protein per day, the following protein is consumed per day by different diets:

	Protein Per Day			
Diet	**Vegetable**	**Meat**	**Fish**	**Total**
	g	g	g	g
Vegetarian	67.5	0	7.5	75
Vegan	75	0	0	75
Pescatarian	60	0	15	75
Meat and Fish	1.5	54	19.5	75

Using the Compare the Market survey figures for the number of people in the UK in 2017 following each type of diet, the total protein consumption per day for the UK becomes:

	% Population	N million	Vegetable tonnes	Meat tonnes	Fish tonnes	**Total tonnes**
Vegetarian	14	9.2	624	0	69	**693**
Vegan	7	4.6	347	0	0	**347**
Pescatarian	31	20.5	1,228	0	307	**1,535**
Meat and Fish	48	31.7	48	1,712	618	**2,377**
Total	**100**	**66.0**	**2,247**	**1,712**	**995**	**4,953**

And hence for the annual protein consumption in the UK in 2017, we get the table below.

Diet	% Population	N million	Vegetable tonnes	Meat tonnes	Fish tonnes	**Total tonnes**
Vegetarian	14	9.2	227,788	0	25,310	**253,098**
Vegan	7	4.6	126,549	0	0	**126,549**
Pescatarian	31	20.5	448,346	0	112,086	**560,432**
Meat and Fish	48	31.7	17,355	624,791	225,619	**867,766**
Total	**100**	**66.0**	**820,038**	**624,791**	**363,015**	**1,807,845**

However, this assumes the full population are adults. If we apply an age model we get the following reductions:

Ages	**Fraction of population**	**Fraction of an adults appetite**	**Weighting**	**Protein source**	**All adults**	**Age Model Applied**
0-5	0.05	0.1	0.005	Vegetable	820,038	606,828
5-10	0.05	0.2	0.01	Meat	624,791	462,345
10-15	0.05	0.5	0.025	Fish	363,015	268,631
15-60	0.55	1	0.55	Total	1,807,845	1,337,805
60-100	0.3	0.5	0.15			
	1		**0.74**			

With age proportions applied:

Diet	% Population	N million	Vegetable tonnes	Meat tonnes	Fish tonnes	**Total tonnes**
Vegetarian	14	9.2	168,500	0	18,700	**187,200**
Vegan	7	4.6	93,600	0	0	**93,600**
Pescatarian	31	20.5	331,800	0	82,900	**414,700**
Meat and Fish	48	31.7	12,800	462,300	167,000	**642,100**
Total	**100**	**66.0**	**606,700**	**462,300**	**268,600**	**1,337,600**

Annex 2 - Blue Carbon – Inclusion in UK Emission Accounting

Emission Accounting – General Principles

The general principles set for countries to count their GHG emissions have been established by the Conference of Parties to the Kyoto Protocol, and the UN Framework Convention on Climate Change (UNFCCC). In Europe, these international agreements have been adopted by the EU in Regulations and Decisions such as Regulation 525/2013 (a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change, repealing Decision No 280/2004/EC) and Decision no 529/2013/EU (on accounting rules on greenhouse gas emissions and removals resulting from activities relating to land use, land-use change and forestry (LULUCF) and on information concerning actions relating to those activities).

Some general points to note:

1. Accounting aims to only record emissions or sequestrations that are made, controlled or protected by human action.

2. As the LULUCF sector can contribute to climate change mitigation in several ways in particular by reducing emissions, and maintaining and enhancing sinks and carbon stocks, the long-term stability and adaptability of carbon pools is essential. The LULUCF accounting rules aim to record efforts made in the agriculture and forestry sectors to enhance the contribution of <u>changes made</u> to the use of land resources to reducing emissions.

3. The rules aim to exclude the effects of natural and country-specific characteristics. Hence natural sequestration of carbon that would take place without man intervening is not includable. Thus countries with very large areas of forest do not have an advantage over countries with little forest, if they take no action to protect or enhance that forest, or permanently remove carbon from it (i.e. enhancing carbon sequestration).

4. Formally: ‘emissions’ means <u>anthropogenic</u> emissions of greenhouse gases into the atmosphere by sources; ‘removals’ means <u>anthropogenic</u> removals of greenhouse gases from the atmosphere by sinks;

5. Protection of a sink or store of carbon can be accountable. For example emissions saved by management actions which prevent deforestation or

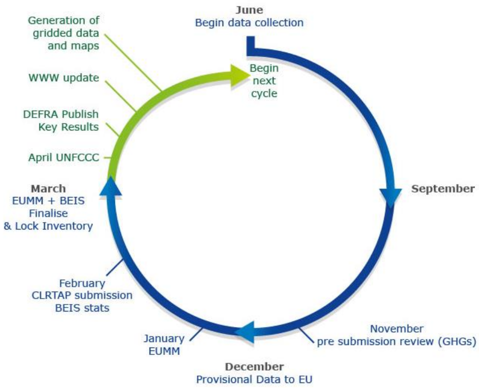
strengthening protection against natural disturbances such as fire, pests, and storms in forests is includable.

The UK Accounting System

In the UK, emission accounts are provided by the UK National Atmospheric Emissions Inventory (UK NAEI):

Home Page: http://naei.beis.gov.uk/
Reports: http://naei.beis.gov.uk/reports/reports?report_id=894

The detailed statistics are generated by a series of commissioned studies by external consultants. There is an annual cycle of data collection and assessment, similar to that in ICES for fishery advice:



From the NAEI website: "The National Inventory System (NIS) is a requirement of the GHG Inventory only. However, the benefits of the system apply to the AQ inventory also. The Marrakesh Accords of the Kyoto Protocol (Decision 20/CP7) define the requirements for National Inventory Systems (NIS), including the need to establish legal, procedural and institutional arrangements to ensure that all parties to the Protocol estimate and report their GHG emissions in accordance with relevant decisions of the COP, facilitate UNFCCC Reviews and improve the quality of their inventories. Under related EU legislation set out in Decision 280/2004/EC, the UK was required to have in place it's NIS by 31 December 2005."

Summary of Key Data Sources

Energy	Digest of UK Energy Statistics (DUKES) published by the Department for Business, Energy & Industrial Strategy (BEIS)
Industrial processes	Ricardo Energy & Environment Individual plant operators Pollution inventories of the EA, SEPA. NIEA, NRW (Reporting annual emission estimates to these UK inventories is a statutory requirement for industrial operators of installations regulated under the Integrated Pollution Prevention and Control (IPPC) regulations and Environmental Permitting Regulations (EPR))
Agricultural	Rothamsted Research Defra and Das
Land-use and Land-Use Change	Centre for Ecology and Hydrology (CEH)
Forestry	Forestry Commission
Others	Commissioned research projects / reports

UK Wetlands

Relevant extracts from BEIS (2016):

“Relevant EU Decision: Decision 529/2013/EU

Actions in the Land Use and Land use Change and Forestry (LULUCF) category include those aimed at limiting or reducing GHG emissions, and maintaining or increasing GHG removals resulting from Afforestation, Reforestation and Deforestation (ARD), Forest Management (FM), Cropland Management (CM), Grazing Land Management (GM), Wetland Drainage and Rewetting (WDR), and Revegetation (RV) as defined in Articles 3(1), 3(2) and 3(3) of the Decision.

Peatland restoration (rewetting) has been identified as a measure to reduce greenhouse gas emissions, although the amount of abatement that can be achieved is still being investigated.

Wetland Drainage and Rewetting (WDR) is a system of practices for draining and rewetting on land with organic soil. The activity applies to all lands that have been drained since 1990 and to all lands that have been rewetted since 1990 and that are not accounted for under any other KP activity.

This activity was only introduced for the second commitment period. The UK has decided to elect this activity. Work is being undertaken to establish systems for reporting and accounting for WDR in the LULUCF inventory and WDR will be reported in future LULUCF inventories in preparation for the submission of WDR accounts for the period 2013-2020 under both EU and KP."

Conclusion

Currently in the UK only management actions and the emissions associated with them in inland peatlands are included in the LULUCF category. No coastal wetlands are included.

Coastal Wetlands – New IPCC Advice

IPCC (2014; Chapter 4) provides guidance as to how to include coastal wetlands in national emission accounting schemes. They note:

This chapter provides guidance on estimating and reporting anthropogenic greenhouse gas (GHG) emissions and removals from managed coastal wetlands. Coastal wetlands hold large reservoirs of carbon (C) in biomass and especially soil [global stocks: mangroves, ~8 Pg C (Donato et al., 2011); tidal marshes, ~0.8 Pg C (midrange; Pendleton et al., 2012); and seagrass meadows, 4.2 – 8.4 Pg C (Fourqurean et al., 2012)]. Soil carbon originates largely in situ, from root biomass and litter, and can result in a significant pool in coastal wetlands, especially when compared with terrestrial forests (Pidgeon, 2009).

The activities which result in emission changes and which can be accounted for include:

Activity	Sub-Activity	Vegetation Type
Activities relevant to CO_2 emissions and removals		
Forest Management Practices in Mangroves	Planting, thinning, harvest, wood removal, fuelwood removal, charcoal production	Mangrove
Extraction	Excavation to enable port, harbour and marina construction and filling or dredging to facilitate raising the elevation of land	Mangrove Tidal Marsh Seagrass Meadow
	Aquaculture (construction)	Mangrove Tidal Marsh
	Salt production (construction)	Mangrove Tidal Marsh
Drainage	Agriculture, forestry, mosquito control	Mangrove Tidal Marsh
Rewetting Revegetation and Creation	Conversion from drained to saturated soils by restoring hydrology and reestablishment of vegetation	Mangrove Tidal Marsh
	Reestablishment of vegetation on undrained soils	Seagrass Meadow
Activities relevant to non-CO_2 emissions		
Aquaculture (use)	N_2O emissions from aquaculture use	Mangrove Tidal Marsh Seagrass Meadow
Rewetted Soils	CH_4 emissions from change to natural vegetation following modifications to restore hydrology	Mangrove Tidal Marsh

Conclusion

In the future human activities which affect seagrass meadows and salt marshes could be included in UK and Scottish emission estimates, but they will most likely be negligible.

Blue Carbon – Emissions Offset Accounting

From Siikamaki et al., (2013), the following is how to calculate the emission offset for a blue carbon scheme:

Assume that the scheme protects A_{Prot} (m^2) of sea area from any form of human activity which might reduce its ability to store or create blue carbon. Within that sea area, assume that V is the proportion of the area which is composed of marine habitat that is vulnerable to degradation in one year. The area of vulnerable habitat that is protected by the scheme is therefore $V.A_{Prot}$ (m^2).
The carbon the scheme protects from emission to the atmosphere each year, C_{Scheme} (Mt C / year), is then given by

$$\underline{C_{Scheme}} = V.A_{Prot} \;.\; (C_{Store} + C_{Seq}) \qquad \text{(Mt C / year)}$$

Where C_{Store} (Mt C / m^2) is the carbon content stored in the vulnerable habitat liable to degradation, and C_{Seq} (Mt C / m^2) is the carbon sequestered from the atmosphere by the vulnerable habitat in one year.

To convert to Mt CO_2-eq. per year, we multiply C_{Scheme} by 44/12, which is the ratio of the molecular weight of carbon dioxide to that of carbon.

Unlike terrestrial forests, most carbon storage in blue carbon habitats such as salt marshes and seagrass meadows is within the sediment rather than within the living plant material. Thus V needs to consider what proportion of the seabed will be disturbed by human activity in a year, and C_{Store} needs to be an assessment of the carbon stored in the depth of sediment that might be disturbed by the human activity excluded from the protected area.

Also see the extensive IOC UNESCO manual – Howard et al. (2014).

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Copies of this report are available from the Marine Scotland website at:
www.gov.scot/marinescotland