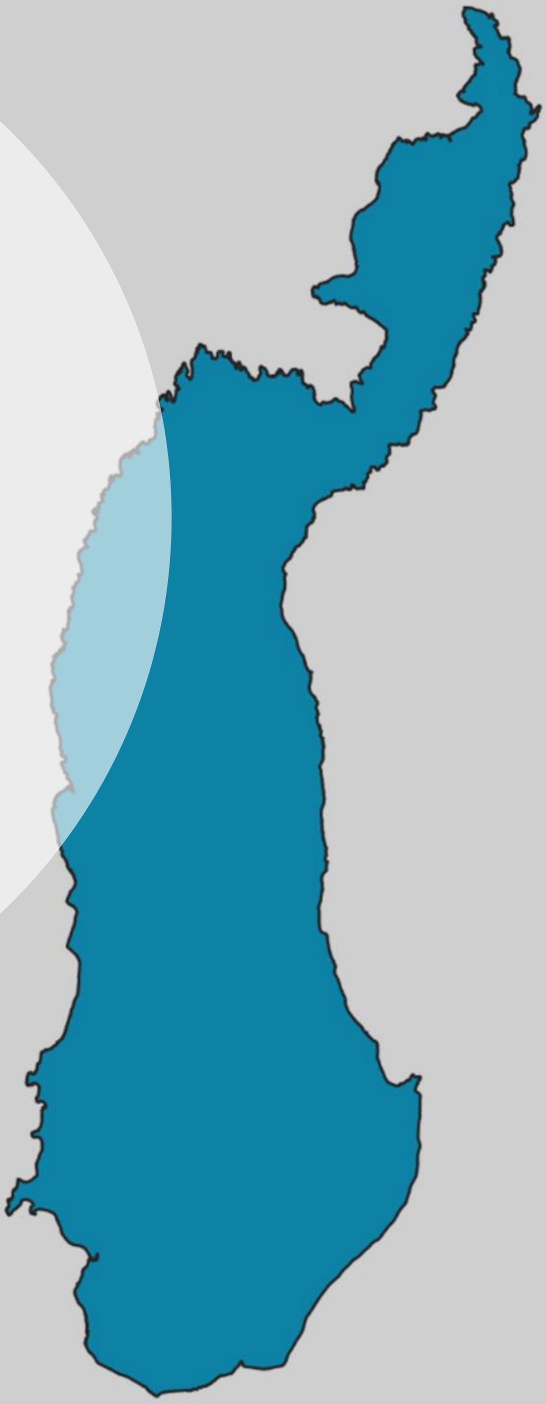
Carbon Audit for the agriculture, land use, land use change and forestry, and waste sectors

Raasay

March 2023



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1 Introduction

Scotland has set targets to reduce greenhouse gas (GHG) emissions to net zero by 2045 under the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019, which amends the Climate Change (Scotland) Act 2009. This also sets interim reduction targets of 75% by 2030 and 90% by 2040, from baseline emissions in 1990 for carbon dioxide, methane and nitrous oxide and from 1995 levels for hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride and nitrogen trifluoride.

The island of Raasay is part of the 'Carbon Neutral Islands' project funded by Scottish Government, which aims to reduce emissions to net zero on these islands by 2040. Emissions are however not currently well understood at an island level. This work was therefore to undertake a baseline carbon audit, quantifying emissions from agriculture, land-use, land-use change and forestry (LULUCF) and waste. This will help establish an evidence base on which to plan for the transition to Net Zero.

The emission estimates were calculating using island specific data as far as possible, gap filling with local authority or national datasets where needed. This report presents an overview of emission estimates from Raasay (section 2) along with the methodology, assumptions and improvements in sections 3 to 5. The methodology under the IPCC[1] has been followed, which aligns with the GHG protocol[2].

For agriculture and LULUCF only scope 1 emissions have been calculated. For example scope 3 emissions from LULUCF from animal feed have not been included as overall (worldwide) the process is seen as carbon neutral. However, as waste is often exported off island and treated elsewhere waste treatment (where this process produces GHG emissions) outside of the island has been included as scope 3 emissions. Scope 3 emissions from the transport of that waste outside of the island have not been included. Such emissions would be allocated under the transport (energy) sector. In addition the production of refuse derived fuel or recycling does not produce waste treatment emissions (emissions will be from energy use) and as such these processes have not been included in estimates.

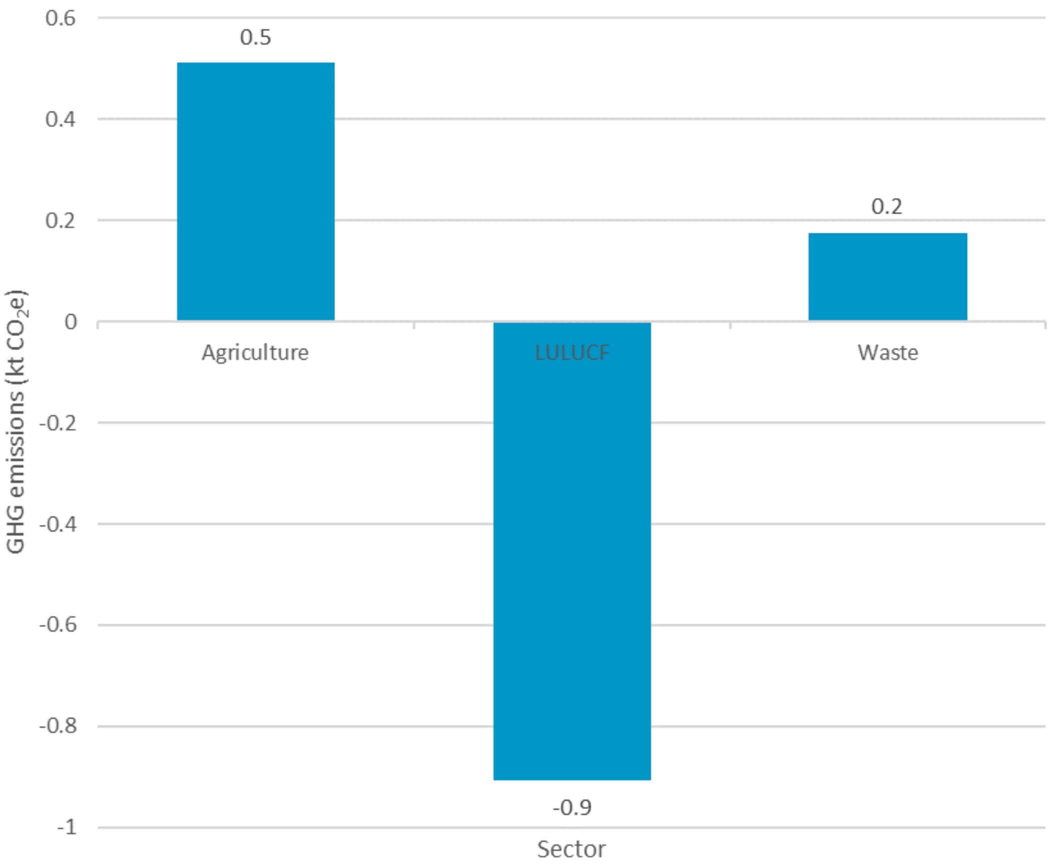
The work presented here can be considered a first step in not only quantifying emissions but also in identifying data gaps that would be necessary for more accurate quantification and tracking of GHG emissions towards carbon neutrality going forward.

[1] https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
[2] https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities

2 Overview

On Raasay, the emissions/removals have been calculated for three sectors: agriculture, waste and LULUCF. When emissions from agriculture and waste sectors are combined, the total emissions were 0.69 kt CO_2e in 2019. If LULUCF emissions/removals are also included, the total emissions are -0.22 kt CO_2e. The GHG emissions are shown in Figure 1 below, shown to 1 decimal place. Table 1 provides the emission estimates on a sub-sector basis.

Figure 1 GHG emissions per sector (kt CO_2e) in 2019



Source: Calculated emissions under this project. The sector methodology sections provide detail on the data sources.

Table 1 GHG emissions per sector (kt CO_2e) in 2019

Sector	Sub-sector	Emissions (kt CO_2e)
Agriculture	Crop residues	0.006
	Enteric fermentation (digestive emissions from livestock)	0.30
	Fertiliser applied	0.12
	Liming	0.05
	Manure management	0.02

	Manure application	0.003
	Pasture, range and paddock (emissions from manure on grazing area)	0.02
	Urea application	0.001
LULUCF	Biomass Burning	0.00
	Cropland	0.00
	Forest land	-6.30
	Grassland	5.23
	Harvested wood products	0.00
	Other land	0.06
	Settlement	0.07
	Wetlands	0.01
Waste	Landfill	0.12
	Wastewater treatment and disposal	0.06

3 Agriculture

3.1 Methodology

Calculations for emissions from the agricultural sector in Raasay are based upon country level data in addition to island specific data such as livestock numbers. Table 2 below outlines the methodologies used per emission category.

Table 2 Methodology used to calculate emissions from the agriculture sector categories. Improvements and uncertainties are also listed.

Emission Category	Methodology	Uncertainty	Improvements
Enteric fermentation	Implied emission factors based on Scotland GHG emissions[3] are used. Livestock numbers are sourced from local data.	Medium: Local livestock numbers were used reducing uncertainty. However, Scotland wide EFs were used which increases uncertainty.	Consider island specific characteristics (animal features, manure management practice distribution).
Manure to soil	Implied emission factors based on Scotland GHG emissions[3] are used.	Medium: Local livestock numbers were used reducing uncertainty. However, Scotland wide EFs were used which increases uncertainty.	Consider island specific characteristics (animal features, manure management practice distribution).
Mineral fertiliser	Implied emission factors based on Scotland GHG emissions[3] are used to estimate application rate and the emission factors.	High: NAEI data was used to determine both the EFs and fertiliser application rate.	Consider island specific data on application rate of fertilisers and N content.
Other organic fertiliser	Assume no sewage applied to soils.	Medium: Based on wastewater treatment information it is unlikely that sewerage sludge is used as a fertiliser.	Consider island specific data on amount of other organic fertilisers applied to soils.
Pasture, range, paddock	Implied emission factors based on Scotland GHG emissions from NAEI 2022[3] are used.	Medium: Local livestock numbers were used reducing uncertainty. However, Scotland wide EFs were used which increases uncertainty.	Consider island specific characteristics (animal features, manure management practice distribution).
Crop residue	Implied emission factors based on Scotland GHG emissions from NAEI 2022[3] are used.	High: NAEI data was used to determine both the EFs and activity data.	Consider island specific crop production.
Urea	IPCC 2006 Tier 1 methodology used. Default application rate is back-calculated from the NAEI[3] (Urea + Urea ammonium nitrate, assuming the latter is 35% urea) from N	High: NAEI data was used to determine both the EFs and fertiliser application rate.	Consider island specific data.

[3] https://naei.beis.gov.uk/reports/reports?report_id=1072

	applied, and divided by land area to get an application rate.		
Liming	IPCC 2006 Tier 1 methodology used. Default application rate is from table SC1.4 of the British Survey of Fertiliser Practise (BSFP)[4].	High: NAEI data was used to determine both the EFs and fertiliser application rate.	Consider island specific data.

[4] https://www.gov.uk/government/statistics/british-survey-of-fertiliser-practice-2021#:~:text=The%20British%20Survey%20of%20Fertiliser,for%20agricultural%20crops%20and%20grassland.

Other data sources were investigated as part of the carbon audit, these are presented in the table below.

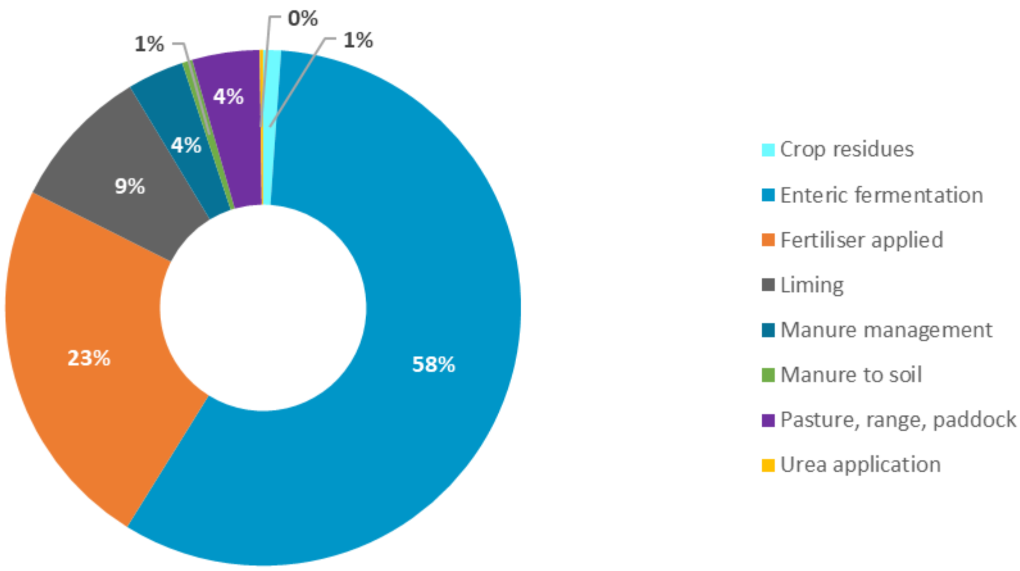
Table 3 Other Agriculture data investigated but not used.

Dataset	Description	Reason for not using under this project
Agriculture survey data	The crofting commission was contacted. Island level data from the June agricultural survey 2019 was requested.	The Crofting Commission have confirmed that they do not hold livestock numbers for crofts.

3.2 Emissions

For the agriculture sector, the majority of the GHG emissions come from the enteric fermentation subsector, accounting for 58% of all emissions (0.30 kt CO_2e). This is followed by emissions from inorganic fertiliser application (0.12 kt CO_2e). Figure 2 shows the emissions subsector split for the agriculture sector, given to the nearest % and Table 4 provides the emission estimates in kt CO_2e.

Figure 2 GHG emissions by agriculture subsector in 2019



Source: Calculated emissions under this project.

Table 4 GHG emissions by agriculture subsector in 2019

Subsector	Emissions (CO_2e)
Crop residues	0.006
Enteric fermentation	0.296
Fertiliser applied	0.121

Liming	0.046
Manure management	0.018
Manure application	0.003
Pasture, range and paddock	0.022
Urea application	0.001

4 LULUCF

4.1 Methodology

The LULUCF emission estimates are predominantly based upon UK land cover maps, with a 25m raster, supplemented with additional data on peatlands and expert judgement. The below sections detail the methodology used and potential improvements. Further details on the methodology for the LULUCF emission estimates are additionally provided in Annex I.

4.1.1 Development of the land use maps

Land cover maps[5] from 2000 and 2019 of a 25m raster from the UK Centre for Ecology and Hydrology were used to determine the changes in land use between those years. This land use change is assumed to be linear, however, this is likely not the case in a small territory, where any land use change is often non-linear. A mapping of the allocation of land categories in the UKCEH data to those used in the carbon audit was undertaken (Annex I), although discussions with local experts have led to some island specific changes to these. A summary of these changes is detailed below with further details provided in Annex I. Due to different resolution of satellite images and classification used, the overlay of land cover map 2000 and land cover map 2019 might lead to changes that have not occurred in the terrain. It has been assumed that Land cover map 2019 is more accurate than that of land cover map 2000. Therefore, where local knowledge suggested there has been no land use change, 2019 areas have been used for the whole period. Additionally, small changes of less than 0.05% have not been included. There were some areas which were unclassified or missing in the 2000 maps but classified in the 2019 maps, in those cases the 2019 land use was used throughout the timeseries.

The land cover maps were supplemented with data on soils from the Soils World Reference Base (WRB) Map[6] and peatland areas from 1990[7], which detailed the peatlands condition. Where land use change was included in the land cover maps the peatlands condition was also updated. It was assumed that where there was no land use change the peatland condition had also not changed and if there was a change to grassland or woodland then it was assumed to be re-wetted peatland. The peatland conditions were also matched to a condition/drainage status for which EFs under the UK national inventory were available. The only areas considered organic soils in this work

[5] https://www.ceh.ac.uk/data/ukceh-land-cover-maps
[6] https://www.hutton.ac.uk/learning/natural-resource-datasets/soilshutton/soils-maps-scotland/download#soilmapdata
[7] https://cagmap.snh.gov.uk/natural-spaces/dataset.jsp?code=PEATACT-DEPTH

were those considered peatland in the peatland areas map, as such some areas classified as histosols in the Soils World Reference Base Map have been considered mineral soils. Details of peat classifications and emission factors used are provided in Annex I.

A shapefile from National Records of Scotland[8] was used to filter the land-use data to the Island area. It is assumed that these provide a correct total area.

The base maps where further modified assuming:

- There has been no increase in freshwater wetland, and no change in saltwater wetland.
- There has been no change between coniferous and broadleaves forest.
- There have been conversions from forestland to other grassland.
- There was no change from other land to other land uses, and other land gains comes from other grassland.
- Loss of improved grassland only occurs to settlements

The original land cover maps and land use areas before and after local input are presented in Annex I.

Improvements

Peat extraction is known to occur within Raasay, mostly at domestic rather than industrial scale. However, it was not possible to obtain data on amount of peat extraction and use to be included in the estimates. This might be an important source of emissions and therefore gathering this data and estimating emissions from this activity is a potential improvement.

According to local knowledge, very few land use changes have occurred in the last 20 years, which would mean that the carbon is in equilibrium. This assumption could be verified in future. If this assumption were verified the next stage would be to investigate the 2019 land cover data represents the land uses where the carbon is in equilibrium. Assumptions made for the adjustment of areas were done at an aggregated level but could be revisited by looking into specific polygons in the land cover maps. For specific sites and land use changes, a visual interpretation and field survey would be useful to confirm assumptions and improve accuracy, noting that the overlay of the land cover maps can lead to spurious changes due to land cover identification.

Since the peatland category determines the emission factor (and extent of the resulting emissions) applied further work could be undertaken to categorise the peatland, rather than building on the peatland baseline map. For example, other data sources such as the those included in Table 5 can be used for sense check areas and even to update peat conditions.

It would be relevant to understand the actual drivers behind land use conversions and peatland condition modification, beyond the methodology approach in this report.

[8] https://www.nrscotland.gov.uk/statistics-and-data/geography/our-products/other-national-records-of-scotland-nrs-geographies-datasets/islands

4.1.2 Emission factors

The EFs from the UK national GHG inventory and IPCC were used, except for eroded peatlands, eroded modified bog and modified bog where literature[9] EFs were used as the peatland descriptions matched better to those being used under the carbon audit. Details of the emission factors used in the assessment are provided in Annex I.

4.1.3 Uncertainty

In general, uncertainties in the LULUCF sector are higher than for other sectors. This is the case for emission estimates on the national level as well as at a local level.

Land use area identification, especially areas in the earlier years of the time series where satellite data technology was less advanced, present uncertainties due to: satellite images resolution, minimum mapping unit and land categories definitions which can vary over time. In addition, data on management practices might not be available and some assumptions are required (e.g. management practices have not changed for the last 20 years). Although new data can be collected, data for whole timeseries would not be available, and expert judgement or proxies are normally needed. However, uncertainty for satellite land identification is considered an order of a few % to 10% for total land area in each category, although greater for changes in area, since these are derived directly. This uncertainty does however increase with the assumptions made to produce the final land use matrices and the fact that it was not possible to check mapping identification of the land use areas changes[10].

The emission factors also introduce uncertainty. Firstly, the variability of ecosystems introduce uncertainty to the carbon stock parameters and other GHG fluxes, since the available emission factors might not totally represent the ecosystem identified to a specific IPPC land use. In addition, the UK NAEI estimates emission factor uncertainties are considered between 15-45% for CO_2 estimates, 35-90% for CH_4 and 40-165% for N_2O, depending on the land use category[11]. Further details on uncertainties for emission factors of peatlands are provided in the UK GHG inventory report[3] and Evans et al 2017[9].

A number of additional data sources were investigated as part of the carbon audit compilation. The table below details the data sources and why they were not used.

[9] Evans, C., Artz, R., Moxley, J., Smyth, M-A., Taylor, E., Archer, N., Burden, A., Williamson, J., Donnelly, D., Thomson, A., Buys, G., Malcolm, H., Wilson, D., Renou-Wilson, F., Potts J. (2017). Implementation of an emission inventory for UK peatlands. Report to the Department for Business, Energy and Industrial Strategy, Centre for Ecology and Hydrology, Bangor.88pp.

[10] Table 3.7 of IPCC 2006 Vol 4, chapter 3

[11] Table A2.3.1 to Table A2.3.4 for the UK GHG inventory report[3]

Table 5 Other LULUCF data investigated but not used.

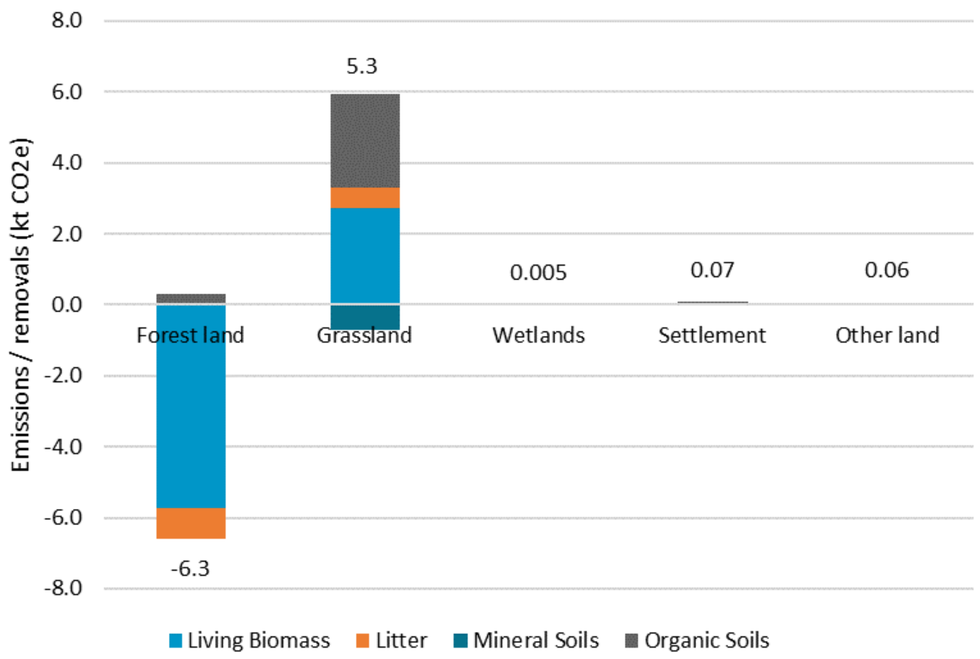
Dataset	Description	Reason for not using under this project
Carbon and Peatland 2016 map[12].	The map is a predictive tool which provides an indication of the likely presence of peat on each individually mapped area, at a coarse scale. The types of peat shown on the map are: carbon-rich soils, deep peat, priority peatland habitat	The map does not present the data with comparable information (in terms of peatland condition) to the peatland baseline map 1990.
Peatland ACTION - Peat depth[13]	Nature Scot (NS) has prepared a consolidated spatial dataset of peat depth measurement collected across Scotland. The information was collected during peat depth surveys conducted as part of various assessments carried out on sites that formed part of the Peatland ACTION project (2013-2020).	Not all peatland areas are covered. Some of the points do not match peatland areas in 1990 baseline. It is a point map, and so it was not possible to assess and make assumptions based on the information provided within the timeline of the project.

4.2 Emissions

For the LULUCF sector, the majority of emissions can be attributed to the loss of carbon in living biomass due to conversions from forest to grassland and from the organic soils carbon pool in grassland, in particular the near natural fen (circa 537 ha) emits 2.9 kt CO_2e (5.41 kt direct CO_2 per ha/year). However, forestland is shown to be a significant sink. Emissions and removals from the LULUCF sector are shown in Figure 3 below, given to one decimal place and Table 6 provides the emission estimates in kt CO_2e. Definitions of LULUCF categories and carbon pools (e.g. organic soils) are included in Annex I.

[12] https://soils.environment.gov.scot/maps/thematic-maps/carbon-and-peatland-2016-map/
[13] https://cagmap.snh.gov.uk/natural-spaces/dataset.jsp?code=PEATACT-DEPTH

Figure 3 Emissions/removals from the LULUCF sector in 2019



Source: Calculated emissions under this project.

Table 6 Emissions/removals from the LULUCF sector in 2019 (kt CO_2e)

Land Category	Carbon pool				Total
	Living Biomass	Litter	Mineral Soils	Organic Soils	
Forest land	-5.7	-0.9	0.0	0.3	-6.3
Cropland	0.0	0.0	0.0	0.0	0.0
Grassland	2.7	0.6	-0.7	2.6	5.3
Wetlands	0.0	0.0	0.0	0.0	0.005
Settlement	0.05	0.008	0.005	0.01	0.07
Other land	0.1	0.0	0.0	0.0	0.06

5 Waste

5.1 Methodology

The methodology for each emission category in the waste sector is given below in Table 7. It is important to note that only emissions from waste treatment have been included. Scope 3 emissions from the transport of that waste outside of the island have not been included. Such emissions would be allocated under the transport (energy) sector. In addition the production of refuse derived fuel or recycling does not produce waste treatment emissions (emissions will be from energy use) and as such these processes have not been included in estimates.

Table 7 Methodology used to calculate emissions from the waste sector categories. Uncertainties and improvements are also listed.

Emission Category	Methodology	Uncertainty	Improvements
Landfill	The amount of waste sent to landfill is calculated using the data for 2022 received from Highland Council, for the amount of waste received at the Portree Transfer Station and the recycling rate (%), with all other waste is sent to landfill. This data is used in addition to the Zero Waste Scotland data[14] in the IPCC landfill model[15], which uses a first order decay methodology to calculate emissions. An average of the calculated waste generation per person (using the waste data and the population from the 2011 census) for the years where data was available is extrapolated back to 1950. The population data is extrapolated between census years and prior to the 2001 census is extrapolated back using the Scotland total population. It was assumed, similarly to the UK national inventory[16], that landfill sites are "managed - deep" from 1980 and "uncategorised" prior to this. DOC and DOC dissimilated were also sourced from the UK 2021 National Inventory Report (Annex 3.5)[16]. It is assumed that there is no gas recovery at this landfill site.	Medium: Local waste data, from the waste transfer facility Raasay's waste is sent to was used. However as the data is from 2022 some uncertainty is introduced from the assumption that the amount of waste received is correct for 2019 also. A Scotland wide waste composition study was used, also introducing some uncertainty. The parameters used to calculate emissions were sourced from the NAEI or the IPCC introducing some uncertainty.	Raasay specific composition was not available for the original emission estimates however would improve the accuracy of any future emission estimates. Other parameters such as DOC and DOC dissimilated could be made Raasay specific although this would be lower priortiy.
Biological Treatment	No biological treatment of Raasay's waste	NA	NA
Incineration and open burning	Not applicable to 2019, however from 2023 waste not recycled is being sent to EfW. The amount of waste sent to EfW is calculated using the total amount of waste generated received from the Council multiplied by the proportion of waste not recycled. The CO_2 emissions are calculated using	NA	NA

[14] https://www.zerowastescotland.org.uk/composition-household-waste-kerbside
[15] https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol5.html
[16] https://naei.beis.gov.uk/reports/reports?report_id=1072

	the waste composition from Zero Waste Scotland and dry matter content, carbon content and fossil carbon content from the IPCC 2019 refinement. CH_4 and N_2O emissions are calculated using the emission factors from the IPCC 2019 refinement. Open burning is assumed to not occur as this is banned.		
Wastewater treatment and disposal	The number of households using direct sea discharge was available and it is assumed all other houses use. This was used to determin the percentage of the population using septic tanks or direct to sea discharge. Emissions from septic tanks and direct sea discharge were calculated using the IPCC methodology. For CH_4 this uses population from the 2011 census and parameters and emissions factors from the IPCC. For the N_2O emissions the protein consumption for the UK was used in addition to parameters and EFs from the IPCC. Data on industrial wastewater was received for the distillery, it is assumed there are no other significant sources. The remaining parameters for estimating emissions from industrial wastewater were sourced from the IPCC.	Medium: Local data was used to determin the proportion of the population using septic tanks/direct sea discharge. In addition data on the wastewater from the distillery was used. Parameters sourced from the IPCC, UK protein consumption however introduces uncertainty.	Island specific data for the other parameters is lower priority.

Other data sources were investigated as part of the carbon audit, these are presented in the table below.

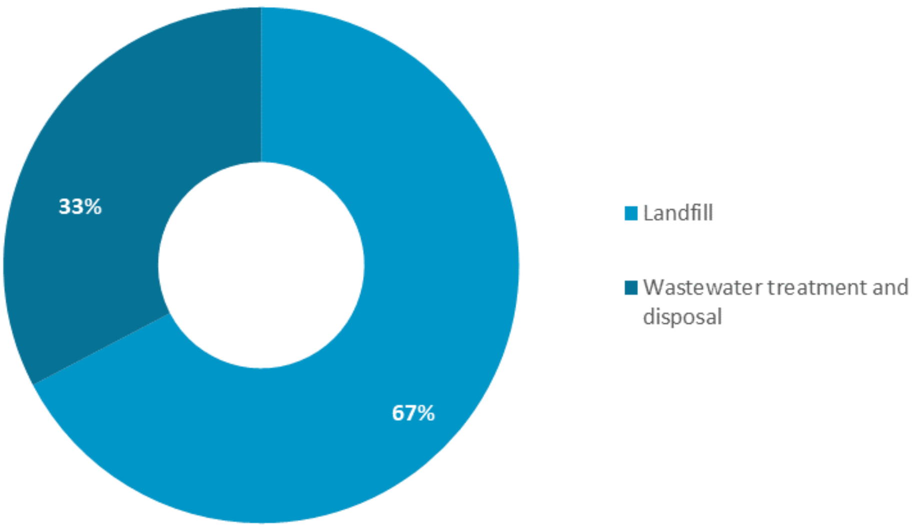
Table 8 Other Waste data investigated but not used.

Dataset	Description	Reason for not using under this project
SEPA - waste tonnages	SEPA was contacted to see if they held the amount (and treatment pathways) of waste from the Islands	While data received at sites is available the source of the data is not. Therefore this data could not be provided. It has been suggested that the local SEPA office may hold this information which could be followed up on in future work.
SEPA - proportion of households using the different treatment pathways	SEPA was contacted to see if they held data on the number of households using septic tanks/ central wastewater treatment facilities / direct sea discharge.	This data is not held by SEPA. It has been suggested that the local SEPA office may hold this information which could be followed up on in future work.

5.2 Emissions

For the waste sector, in 2019, the majority of emissions from the waste sector are due to landfill, equating to 67 % of emissions from this sector (0.12 kt CO_2e). This is followed by wastewater treatment and disposal (0.06 kt CO_2e). Figure 4 below shows the subsector emission split and Table 9 provides the emission estimates in kt CO_2e.

Figure 4 GHG emissions by waste subsector in 2019



Source: Calculated emissions under this project

Table 9 GHG emissions by waste subsector in 2019

Subsector	Emissions (CO_2e)
Landfill	0.12
Wastewater treatment and disposal	0.06

Annex I Additional LULUCF information

This Annex provides additional detail to the methodology behind the LULUCF estimates.

Overview of LULUCF estimates

Land use and management influence a variety of ecosystem processes that affect greenhouse gas fluxes. The key greenhouse gases of concern are CO_2, N_2O and CH_4. CO_2 fluxes between the atmosphere and ecosystems are primarily controlled by uptake through plant photosynthesis and releases via respiration, decomposition and combustion of organic matter.

Greenhouse gas fluxes in the AFOLU Sector can be estimated in two ways: 1) as net changes in C stocks over time (used for most CO_2 fluxes) and 2) directly as gas flux rates to and from the atmosphere (used for estimating non-CO_2 emissions and some CO_2 emissions and removals). The use of C stock changes to estimate CO_2 emissions and removals, is based on the fact that changes in ecosystem C stocks are predominately (but not exclusively) through CO_2 exchange between the land surface and the atmosphere (i.e. other C transfer process such as leaching are assumed to be negligible). Hence, increases in total C stocks over time are equated with a net removal of CO_2 from the atmosphere and decreases in total C stocks (less transfers to other pools such as harvested wood products) are equated with net emission of CO_2. Non-CO_2 emissions are largely a product of microbiological processes (i.e., within soils) and combustion of organic materials. Emission and removal estimates in the LULUCF Sector are organized by ecosystem components, i.e., 1) biomass, 2) dead organic matter, 3) soils. (IPCC 2006).

Losses of C are reported as negative values, leading to emissions (positive emissions value). Gains of C are reported as positive values, leading to absorption (negative emissions values).

Land use categories

The land-use categories for greenhouse gas inventory reporting are, as defined by 2006 IPCC:

- Forest Land: This category includes all land with woody vegetation consistent with thresholds used to define Forest Land in the national greenhouse gas inventory. It also includes systems with a vegetation structure that currently fall below, but in situ could potentially reach the threshold values used by a country to define the Forest Land category.
- Cropland: This category includes cropped land, including rice fields, and agro-forestry systems where the vegetation structure falls below the thresholds used for the Forest Land category.
- Grassland: This category includes rangelands and pasture land that are not considered Cropland. It also includes systems with woody vegetation and other non-grass vegetation such as herbs and brushes that fall below the threshold values used in the Forest Land category. The category also includes all grassland from wild lands to recreational areas as well as agricultural and silvi-pastural systems, consistent with national definitions.

- Wetlands: This category includes areas of peat extraction and land that is covered or saturated by water for all or part of the year (e.g., peatlands) and that does not fall into the Forest Land, Cropland, Grassland or Settlements categories. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.
- Settlements: This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. This should be consistent with national definitions.
- Other Land: This category includes bare soil, rock, ice, and all land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

Carbon pools definition

The carbon pools for greenhouse gas inventory estimates are, as defined by the IPCC, vol 4, chapter 1:

Pool		Description
Biomass	Above-ground biomass	All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage. Note: In cases where forest understory is a relatively small component of the above-ground biomass carbon pool, it is acceptable for the methodologies and associated data used in some tiers to exclude it, provided the tiers are used in a consistent manner throughout the inventory time series.
	Below-ground biomass	All biomass of live roots. Fine roots of less than (suggested) 2mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter.
Dead organic matter	Dead wood	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps, larger than or equal to 10 cm in diameter (or the diameter specified by the country).
	Litter	Includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2 mm) and less than the minimum diameter chosen for dead wood (e.g. 10 cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil (of less than the minimum diameter limit chosen for below-ground biomass) are included in litter where they cannot be distinguished from it empirically.
Soils	Soil organic matter[1]	Includes organic carbon in mineral soils to a specified depth chosen by the country and applied consistently through the time series[2]. Live and dead fine roots and DOM within the soil, that are less than the minimum diameter limit (suggested 2 mm) for roots and DOM, are included with soil organic matter where they cannot be distinguished from it empirically. The default for soil depth is 30 cm and guidance on determining country-specific depths is given in Chapter 2.3.3.1.

[1] Includes organic material (living and non-living) within the soil matrix, operationally defined as a specific size fraction (e.g., all matter passing through a 2 mm sieve). Soil C stock estimates may also include soil inorganic C if using a Tier 3 method. CO_2 emissions from liming and urea applications to soils are estimated as fluxes using Tier 1 or Tier 2 method.

[2] Carbon stocks in organic soils are not explicitly computed using Tier 1 or Tier 2 method, (which estimate only annual C flux from organic soils), but C stocks in organic soils can be estimated in a Tier 3 method. Definition of organic soils for classification purposes is provided in Chapter 3.

Source: IPCC 2006 Guidelines, Volume 4, Chapter 1, Table 1.1

Allocation of land cover classes to IPCC land use categories.

The UK CEH maps included a classification of land use classes which had to be mapped to the categories under the IPCC for reporting and to enable the assignment of emission. Forest land, Grassland and Wetlands are additionally subcategorised.

Table 10 Classifications of the Land Cover Map 2000

UKCEH Land Cover Class 2000	IPCC	Island audit code	Audit code definition
Missing / Unclassified			
Sea / Estuary			
Littoral rock, Littoral sediment, Supra-littoral rock, Supra-littoral sediment, Inland bare ground	Other land	OL	Other Land
Water (inland)	Wetland	WLf	Wetland (freshwater)
Saltmarsh	Wetland	WLs	Wetland (saltwater)
Improved grassland	Grassland	Glim	Grassland (improved)
Bog (deep peat)	Grassland	GLb	Grassland (bog)
Dense dwarf shrub heath, Open dwarf shrub heath, Neutral grassland, Setaside grassland, Bracken, Calcareous grassland, Acid grassland	Grassland	GLo	Grassland (other)
Montane habitats	Forestland	FL	Forest Land[17]
Broad-leaved / mixed woodland	Forestland	FLb	Forest Land (broadleaved/mixed)
Coniferous woodland	Forestland	FLc	Forest Land (coniferous)
Arable cereals, Arable horticulture, Arable non-rotational	Cropland	CL	Cropland
Suburban / rural developed, Continuous urban	Settlements	SL	Settlements

Table 11 Classifications of the Land Cover Map 2019

UKCEH Land Cover Class 2019	IPCC	Island audit code	Audit code definition
Missing / Unclassified			
Broadleaved woodland	Forest land	FLb	Forest Land (broadleaved/mixed)
Coniferous Woodland	Forest land	FLc	Forest Land (coniferous)

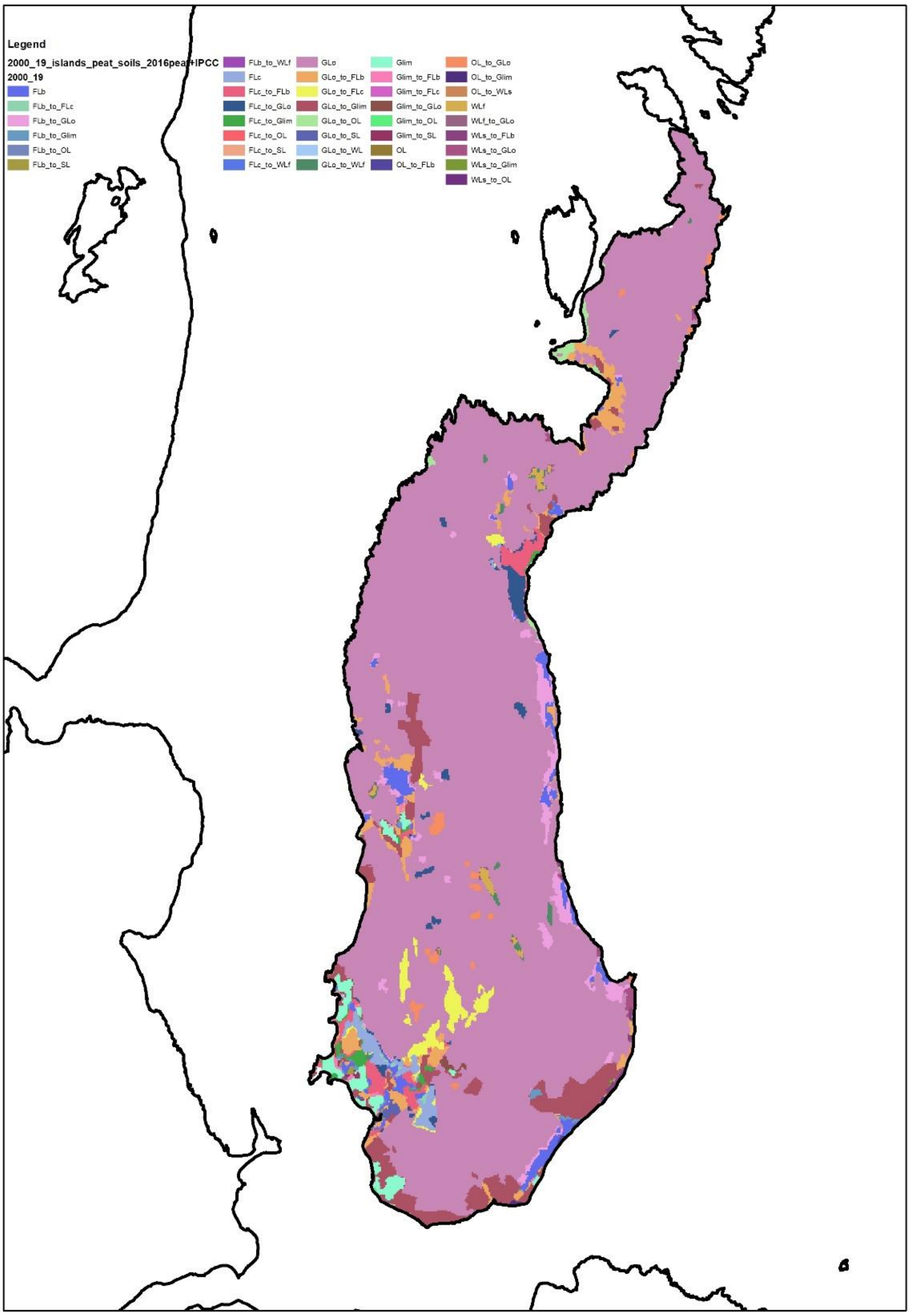
[17] Note that *Montane habitats* should be assigned to GL based on LCM definition. This misallocation does not affect estimates since this category does not appear in Raasay.

Arable and Horticulture	Cropland	CL	Cropland
Improved Grassland	Grassland	Glim	Grassland (improved)
Neutral Grassland, Calcareous Grassland, Acid grassland, Heather grassland, Heather	Grassland	GLo	Grassland (other)
Bog	Grassland	GLb	Grassland (bog)
Fen, Marsh and Swamp	Wetland	WLm	Wetland (marsh)
Inland Rock, Supralittoral Rock, Supralittoral Sediment, Littoral Rock, Littoral sediment	Otherland	OL	Other Land
Saltwater	Wetland	WLs	Wetland (saltwater)
Freshwater	Wetland	WLf	Wetland (freshwater)
Saltmarsh	Wetland	WLs	Wetland (saltwater)
Urban, Suburban	Settlements	SL	Settlements

Area of land uses

As detailed in the methodology section the UK CEH maps supplemented with data on peatland conditions and soils were used to produce a land use matrix which was sent to local experts for input. Based on feedback this matrix was then modified to produce the final matrix used to produce the emission estimates. Figure 5 presents the land use changes from the UK CEH land cover maps and Figure 6 presents the peatland condition maps. The tables below present the resulting land use and land use changes for the period 2000-2019 before and after local input. The values in the diagonal corresponds to land remaining in the same land use since 2000. The values in other cells corresponds to land uses changes between 2000 and 2019. For example, in Table 12 the maps overlay present a conversion of 290 ha from other grassland to improved grassland between 2000-2019, and a conversion of 32 ha other grassland to other land.

Figure 5 Land use change maps 2000-2019 before local input



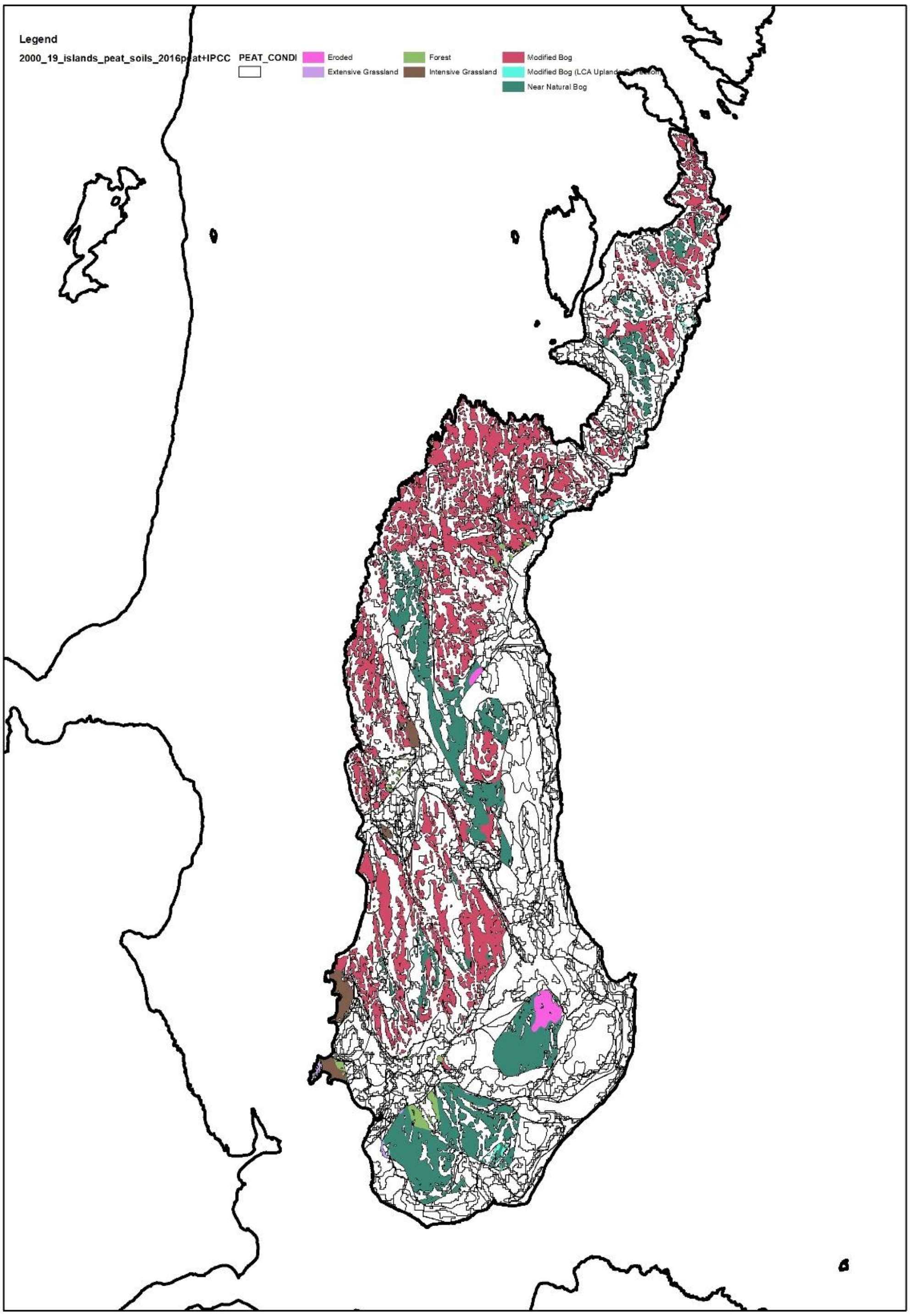


Figure 6 Peatland condition maps 1990

Table 12 Original land use and land use change matrix, as result of overlaying of LCM 2000 and LCM 2019 reclassified to 2006 IPCC categories, 2000-2019, ha

		2019								Total 2000
		FLb	FLc	Glim	GLo	OL	SL	WLf	WLs	
2000	FLb	112	4	12	115	3	2	0		248
	FLc	71	50	21	55	0	0	0		197
	Glim	8	0	75	6	1	2			91
	GLo	165	82	290	4,881	32	9	14	1	5,473
	OL	3		2	41	4			0	50
	WLf				4			16		20
	WLs	8		1	12	1			0	22
Total 2019		366	135	400	5,113	41	14	31	1	6,101

Table Adjusted land use and land use change matrix. 2000-2019, ha

		2019								Total 2000
		FLb	FLc	GLim	GLo	WLs	WLf	SL	OL	
2000	FLb	220	-	-	115	-	-	2	-	337
	FLc	-	74	-	55	-	-	0	-	130
	GLim	-	-	75	-	-	-	2	-	77
	GLo	165	82	290	4,944	-	-	9	32	5,521
	WLs	-	-	-	-	1	-	-	-	1
	WLf	-	-	-	-	-	31	-	-	31
	SL	-	-	-	-	-	-	-	-	-
Total 2019		385	156	365	5,113	1	31	14	32	6,097

Additional considerations for emissions/removals from peatlands

As previously mentioned peatland areas and condition were identified using the baseline map for 1990[7]. The peatland conditions prescribed to each land use type in 1990 were based on the Land Cover Map of Scotland 1988 (LCS88). The LCS88 splits land into polygons, each with their own classification. To produce the emissions estimates in 2019, the peatland conditions were updated based on the land use changes seen between 2000-2019, and assumptions on the drained/undrained status. Only those land use changes in the final land use matrices after adjustment have been considered. Semi-natural peatland polygons were classified as 'eroded' in LCS88 if they contained visible erosional features such as gullies, bare peat or haggs. However, in the UK NAEI only a proportion of these polygons were considered to be actively eroding (i.e. exposed bare peat). This was based on a visual assessment of a range of polygons, and a default estimate of 12.5% for the extent of active erosion within these polygons was applied in the UK NAEI 1990-2000. The emission factor (EF) presented in the UK NAEI 2022 corresponds to Eroding Modified Bog (bare peat), but the adjustment based on active eroding proportion is not applied in the current estimates. Therefore, the EF used is that in Evans et al 2017 instead of the EF given by the UK NAEI 2022.

Updates to the Tier 2 EFs developed by Evans et al. (2017) include amendment to the Eroded Modified Bog EF to represent emissions from actively Eroding Modified Bog (bare peat) only, with emissions from the not actively eroding bog captured by the EFs for Modified Bog. Therefore, the EF in Evans at al 2017, instead of those in UK NAEI 1990-2020, have been used for the categories Eroded Modified Bog and Modified Bog.

Each updated condition and drainage status is assigned to a peatland condition. The drainage statuses used are those for which emissions factors are available in UK NIR 1990-2020. Several assumptions have been made when assigning these conditions and drainage statuses:

- If there has not been land use change, the peatland condition is not changed.
- If there has been a change to a land use type of either GLb or WL, then it is assumed to be re-wetted peatland.

Table 13 Specific assumptions regarding update of peatland condition based on peatland base condition in 1990 and land use of 2000 and 2019.

Peat condition in 1990 data	Emission Factor category	Reason for chosen emission factor category
Modified Bog	Modified bog drained	WL and GLb assumed to be undrained. Where LU hasn't changed assumed to be undrained. Otherwise drained
	Modified bog undrained	
Domestic Extraction	Extracted domestic	Extracted Domestic assumed to continue, except if the land use is GLb or WL in 2019, then it is classified as Modified Bog Undrained. EF applies to abandoned and active peatland extraction areas.
Eroded	Rewetted bog	

	Eroding modified bog drained Modified bog undrained	Classified as Eroding Modified Bog drained, unless rewetted (GLb or WL in 2019). Rewetted Bog if it is GLb in 2019. WLf assigned Modified Bog Undrained.
Extensive Grassland	Semi-natural	Either considered semi natural GL, rewetted or other drained LU type depending on the LCM2000 and LCM2019. Classifications are Based upon expert judgement
	Drained Rewetted bog Rewetted fen Semi-natural	Assumed to be "semi-natural" when there is no change in LU, unless the land use in 2019 is GLb. For all other LU type changes, the peat land condition may be assigned semi-natural, drained, rewetted bog or rewetted fen based upon expert judgement.
Forest	Drained Rewetted bog Modified bog undrained	FL assigned drained unless rewetted (GLb or WL in 2019), or SL in 2019. Assigned as Rewetted Bog if classified as GLb in 2019. Assigned as Modified Bog Undrained" if WL in 2019. Settlement if SL in 2019.
Intensive Grassland	Drained Intensive pasture Rewetted bog Modified bog undrained Rewetted fen Intensive pasture Semi-natural Drained Settlement	The peatland condition will either be the same in 2019 as it was in 2000, rewetted or another drained LU type depending on the LCM2000 and LCM2019. The peat land condition is assigned based upon expert judgement.
Near Natural Bog	Drained Near natural fen Near natural bog	If the 2019 land use is WL or GLb, or there has been no LU change between 2000 and 2019 then assumed to be near natural. Otherwise, it is assumed to be drained
Saltmarsh	Near natural fen Saltmarsh Intensive pasture	If land use hasn't changed assigned same peatland condition. Note that "saltmarsh habitat is not yet implemented in the GHG inventory" (NAEI 1990-2020), so it does not lead to emissions/removals
Settlement	Rewetted bog Settlement	Settlement assumed unless rewetted

Table 14 Peatland areas, ha, 2019

Condition	Area (ha)
Drained	32.85
Eroding modified bog drained	27.35
Intensive pasture	38.53
Modified bog drained	60.69
Modified bog undrained	809.56
Near natural fen	537.40
Rewetted fen	0.34
Semi-natural	3.00
Total	1,509.71

Emission factors for peatland

Emission factors for peat condition types are presented in the table below. All fluxes are shown in tCO_2e ha-1year-1 (unless otherwise indicated in the column heading) a positive EF indicates net GHG emission, and a negative EF indicates net GHG removal. Note that the EFs for Direct CH_4 include a correction for CH_4 lost in ditches (1- fraction of ditches in the landscape) as per Equation 2.6 and Table 2.4 in IPCC (2014).

Table 15 Emission factors for Peatlands

Peat condition	Drainage status	Direct CO_2	CO_2 from DOC	CO_2 from POC	Direct CH_4 (kg gas mass)	Direct CH_4	CH_4 from ditches	Direct N_2O (kg N_2O-N)	Direct N_2O	Total
Forest	Drained	7.39	1.14	0.31	2.4	0.06	0.14	4.4	1.31	10.35
Cropland	Drained	28.6	1.14	0.31	0.8	0.02	1.46	13	6.09	37.62
Eroding modified bog	Drained	0.85	1.14	0.89	47.6	1.19	0.66	0.06	0.06	4.79
Modified bog	Drained	-0.14	1.14	0.3	54.4	1.36	0.66	0.11	0.05	3.37
	Undrained	-0.14	0.69	0.1	54.4	1.36	0	0.11	0.05	2.06
Extensive grassland	Drained	6.96	1.14	0.3	78.4	1.96	0.66	4.3	2.01	13.03
Intensive grassland	Drained	21.31	1.14	0.3	27.2	0.68	1.46	5.7	2.67	27.56
Rewetted bog	Rewetted	-0.69	0.88	0.1	143.6	3.59	0	0.09	0.04	3.92
Rewetted fen	Rewetted	4.27	0.88	0.1	112.4	2.81	0	0	0	8.06
Near natural bog	Undrained	-3.54	0.69	0	113.2	2.83	0	0	0	-0.02
Near natural fen	Undrained	-5.41	0.69	0	151.6	3.79	0	0	0	-0.93
Extracted domestic	Drained	10.27	1.14	1.01	5.6	0.14	0.68	0.3	0.14	13.38
Settlement	Drained	0.07	-0.16	0.15	25.2	0.63	0.16	0.03	0.03	0.88

(peach)	Evans et al., (2017) Table 4.1.
(blue)	IPCC 2014
(green)	UK NAEI 1990-2020 Table A 3.4.26 (updated literature analysis incorporating data from Evans et al. 2017)
(white)	Calculated based on Ef in CO_2-eq

** Note that the Emission factor for Forests used in the UK NAEI sourced based on Forest Research CARBINE model implied EF for 1990 to 2020, and varies over the timeseries (1990-2020) due to increase in age of forests on organic soils from decreasing afforestation on organic soil. In this report, the value from Evans et al., (2017) Table 4.1 has been selected, but this could be revisited for improvement.*

Annex II Emission factors for other sectors

The below table lists the emission factors used in this assessment, excluding those sourced from the IPCC guidance. Where emission factors are based off a number of parameters implied emission factors are presented.

Table 16 Emission factors and implied emission factors used in this assessment

Sector	Unit	(Implied) Emission Factor	Source
Landfill	kt CO_2e/kt waste	0.86	Parameters from NAEI and IPCC
Wastewater treatment in central treatment facilities	kt CO_2e /million people	19.564	NAEI
Enteric fermentation-Dairy	kg CO_2e/head	3093	NAEI
Enteric fermentation-Other cattle	kg CO_2e/head	1737	NAEI
Enteric fermentation-Sheep	kg CO_2e/head	113	NAEI
Enteric fermentation-Pig	kg CO_2e/head	208	NAEI
Enteric fermentation-Poultry	kg CO_2e/head	NA	NAEI
Enteric fermentation-Goats	kg CO_2e/head	243	NAEI
Enteric fermentation-Horses	kg CO_2e/head	668	NAEI
Manure management -Dairy	kg CO_2e/head	1241	NAEI
Manure management -Other cattle	kg CO_2e/head	371	NAEI
Manure management -Sheep	kg CO_2e/head	4	NAEI
Manure management -Pig	kg CO_2e/head	170	NAEI
Manure management -Poultry	kg CO_2e/head	2	NAEI
Manure management -Goats	kg CO_2e/head	18	NAEI
Manure management -Total Horses	kg CO_2e/head	219	NAEI
Inorganic fertilisers-Arable land	kg N_2O/kg N	0.018	NAEI

Inorganic fertilisers-Grass land	kg N_2O/kg N	0.02	NAEI
Manure application-Dairy	kg CO_2e/head	332	NAEI
Manure application-Other cattle	kg CO_2e/head	66	NAEI
Manure application-Sheep	kg CO_2e/head	1	NAEI
Manure application-Pig	kg CO_2e/head	25	NAEI
Manure application-Poultry	kg CO_2e/head	3	NAEI
Manure application-Goats	kg CO_2e/head	1	NAEI
Manure application-Horses	kg CO_2e/head	37	NAEI
Pasture, range, paddock-Dairy	kg CO_2e/head	61	NAEI
Pasture, range, paddock-Other cattle	kg CO_2e/head	60	NAEI
Pasture, range, paddock-Sheep	kg CO_2e/head	8	NAEI
Pasture, range, paddock-Pig	kg CO_2e/head	5	NAEI
Pasture, range, paddock-Poultry	kg CO_2e/head	0	NAEI
Pasture, range, paddock-Goats	kg CO_2e/head	15	NAEI
Pasture, range, paddock-Total Horses	kg CO_2e/head	80	NAEI
Crop residues-Arable land	kg CO_2e/t ha	5.7	NAEI
Crop residues-Grass land	kg CO_2e/t ha	5.0	NAEI

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