Office for National Statistics

Statistical bulletin

UK Natural Capital: Experimental carbon stock accounts, preliminary estimates

The first experimental estimates of carbon stocks being compiled to support the incorporation of natural capital into the UK Environmental Accounts by 2020.

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1. Main points

This is the first edition of a new experimental release designed to provide partial estimates for stocks and flows of selected categories of carbon within the UK.

There was an estimated 143 billion tonnes of carbon stored in the UK's fossil fuel (coal, oil and natural gas) stocks at the end of 2013.

Materials extracted from UK fossil fuel stocks during 2014 contained the equivalent of 62 million tonnes of carbon (MtC).

There was an estimated 4,266 MtC of recorded biocarbon in the UK in 2007, of which 94.2% (4,019 MtC) was contained in soil stocks and 5.8% (247 MtC) in vegetation stocks.

Between 1998 and 2007, UK biocarbon stocks declined by approximately 19.9 MtC (-0.5%), on the back of a fall in the volume of carbon stored in soil stocks.

Carbon contained in UK vegetation rose by 1.3 MtC (+0.5%) during the decade to 2007, driven by an increase in categories of forest tree cover.

2. Summary

This article sets out preliminary physical stock and flow accounts for geocarbon over the 2013 to 2014 period and for biocarbon carbon between 1998 and 2007. In addition, it presents possible methods for estimating the physical biocarbon flows over the 2008 to 2014 period. Some discussion is also given on valuing the ecosystem services related to carbon sequestration.

The estimates are for particular types of carbon stocks, namely: geocarbon (coal, oil, gas) and biocarbon (in soil and vegetation). Notable omissions at this stage include estimates of limestone and other carbonate rocks, inorganic soil carbon, and carbon stored in urban habitats.

The carbon accounts and ecosystem accounts provide evidence to inform and improve decision making by integrating environmental and economic information. In particular, the carbon account supports the identification of links between the ecosystem and the benefits which humans receive from the natural environment.

The methodology to develop the stock and flow estimates for carbon remains under development and the estimates reported should be considered experimental. Feedback from experts in the various disciplines covered in the article will be essential for the successful development of the carbon stock accounts. All feedback is welcome and can be sent to environmental.accounts@ons.gov.uk.

3. Acknowledgements

This article has benefitted from the comments of: Rocky Harris and Colin Smith (Defra); Emily Conners, Suzanne Fry, Geoff Bright and Freddie Haslehurst (ONS); David Robinson (CEH); Ruth Greg (Natural England); Michael Vardon (Australian National University); and Peter Comisari (Australian Bureau of Statistics). We are also grateful to our colleagues within the ONS Office of the Chief Economic Adviser for their earlier carbon accounting work.

4. Introduction

Natural capital can be thought of as the stock of our physical natural resources and the ecosystem services that they provide. The Natural Capital Committee's State of Natural Capital Report (2013) defines natural capital as: "the elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land minerals, the air and oceans, as well as natural processes and functions".

In 2011, the UK Government committed to working with ONS to incorporate natural capital in UK Environmental Accounts by 2020. This work is being completed in partnership with the Department for Environment, Food and Rural Affairs (Defra). For more information on the programme of work see our Environmental Accounts publications and the Natural Capital Accounting Roadmap.

The roadmap identified carbon as an important characteristic of habitat types and proposed the development of a cross-cutting carbon account to enable changes in the UK stocks of carbon to be monitored over time. Through this, a comprehensive overview of the role of carbon in the environment and the economy could be developed.

The carbon accounts, and ecosystem accounts in general provide evidence to inform and improve decision making by integrating environmental and economic information (i.e. through environmental-economic accounts). For instance, the aim will be for the carbon stock accounts to complement the existing annual greenhouse gas flow accounts produced by the Department of Energy and Climate Change (DECC), by providing consistent opening and closing stock balances.

Furthermore, the carbon stock accounts can be a tool to help decision makers understand the trade-offs between different ecosystem services and between alternative land uses. By providing a link between the ecosystem and the benefits which we receive from the natural environment, the accounts help us to understand the contribution the environment makes to economic activity and our well-being.

In general the elements of the individual natural capital accounts provide the basis for the cross-cutting carbon account. For instance, habitat based estimates of biocarbon[1] could ultimately be drawn from the data presented in the ecosystem accounts for woodland, coastal margins, and freshwater. Similarly, the geocarbon[2] elements of the carbon account can be populated using adjusted data contained within the ONS energy and minerals asset accounts.

These accounts utilise both the System of Environmental-Economic Accounting Central Framework (SEEA-CF)[3], an international standard for valuing physical environmental assets, and the System of Environmental-Economic Accounting–Experimental Ecosystem Accounting guidelines (SEEA-EEA)[4], international guidance endorsed by the UN Statistical Commission.

What is carbon? — Carbon as an element and the carbon cycle

Scientifically carbon (C) is a chemical element — a basic substance that cannot be broken down. Carbon is also an incredibly versatile element. Arrange carbon atoms in one way and they become soft, pliable graphite. Reorganise the arrangement and the atoms form one of the hardest materials on Earth: diamonds. The highly versatile nature of carbon results in it being present in multiple forms across the Earth's spheres.

Carbon is also the key ingredient for most life on Earth, with the compounds formed by carbon and other elements such as hydrogen, oxygen and nitrogen essential for life. Carbon exists in all living matter, in vegetation and organisms, and the soils that support life (Ajani & Comisari, 2014).

The global carbon cycle refers to the cycle by which carbon flows between and inside the Earth's various geographic spheres. Broad definitions of these are presented in Table 1. In addition to the movement and storage of carbon due to natural processes, carbon accumulations can also be found within the economy in the products produced through human activities.

Table 1: The geographical spheres where carbon is held and exchanged

Geosphere:	Carbon contained in the solid part of the Earth consisting of the crust and outer mantle
Biosphere:	The global ecological system integrating all living beings, consisting of the carbon in soil, plants, animals and other life forms (living and dead).
Atmosphere:	The blanket of gases surrounding the Earth including carbon dioxide and trace carbon gases
Oceans:	The carbon dissolved in ocean water

Source: Office for National Statistics

It is the combination of natural processes, which may occur over very long periods of time, and human activity, which generally occur over relatively short periods of time, which change the size of the respective carbon stores (Ajani & Comisari, 2014). Furthermore, it is these stocks and flows that give the underlying context for carbon accounting (Vardon, 2014).

Accounting for carbon

The accounting framework adopted in this work is based upon SEEA-EEA carbon stock account. The high level structure of a carbon stock account is shown in Table 1 of the reference tables. It provides a complete articulation of carbon accounting based on the carbon cycle. (SEEA-EEA, p.89).

The stocks and flows of the carbon cycle give the underlying context for carbon accounting in the carbon stock account. A stock represents the total quantity of a category of carbon at a given time. Physical flows represent changes in the level of a given carbon stock between one period and another. Annex 1 provides a detailed overview of the types of additions to, and reductions in, the carbon stock account.

Only geocarbon and biocarbon accounts are presented in this article. Carbon estimates relating to the economy, the oceans and the atmosphere have not been included at this time, but are discussed later.

Notes:

1. Carbon contained in the solid part of the Earth consisting of the crust and outer mantle.

2. Carbon contained in the solid part of the Earth consisting of the crust and outer mantle.

3. The United Nations was the lead author of the SEEA-CF, with other joint authors being: European Union, Food and Agriculture Organization of the United Nations, International Monetary Fund, Organisation for Economic Co-operation and Development, and The World Bank.

4. The United Nations was the lead author of the SEEA-EEA, with other joint authors being: European Union, Food and Agriculture Organization of the United Nations, Organisation for Economic Co-operation and Development, Eurostat, and The World Bank.

5. Geocarbon

Geocarbon refers to the carbon stored in the geosphere – the solid part of the earth consisting of the crust and outer mantle. It is disaggregated into: oil, gas, coal resources, rocks (primarily limestone), and minerals, e.g. carbonate rocks used in cement production, methane clathrates and marine sediments (SEEA-EEA, 2012).

The high commercial interest in certain forms of geocarbon, notably fossil fuels, means data availability is good relative to the other carbon pool categories. However, there remains a high degree of technical uncertainty surrounding estimates of geocarbon reflecting uncertainty around the location, size and types of geocarbon stocks, as well as the respective average carbon contents contained within them.

Table 2 presents information on the conversion factors applied when determining the carbon content of the respective carbon stocks. The set of geocarbon stock and flow accounts by geocarbon category are also provided in reference Tables 2 to 4.

Table 2: Estimated carbon content of UK geocarbon resources

Geocarbon resource		Carbon Content	Source
Oil		0.85%	Biomass Energy Centre
Gas		0.75%	
Coal	Hard Coal	0.75%	
	Lignite	0.30%	U.S. EIA

Source: Office for National Statistics

This article provides UK carbon stock estimates for the geocarbon categories of oil, gas and coal for the period 2013 to 2014. Data limitations mean estimates of carbon contained in UK shale deposits are not included at this time. Stock and change estimates for the high level geocarbon categories can be found in reference Table 1.

Results

Approximately 143,095 million tonnes of carbon (MtC) relating to UK oil, gas and coal deposits was stored in the geosphere at the end of 2013. Of this, coal stocks accounted for 98% of total stocks. During 2014, extraction processes resulted in a combined total of 62 MtC carbon being removed from the respective categories of geocarbon.

Coal

The carbon contained in UK coal resources totalled 140,523 MtC at the end of 2013. Coal types presented are for hard coal and lignite. Hard coal represents almost the entire share of UK coal stocks (99.8%). Stock data for coal is only available at the start of the period providing an opening balance figure. We have assumed no significant changes to have occurred in coal stocks over the year.

Oil and Natural Gas

The UK Oil and Gas Authority (OGA) provides the most comprehensive range of data on UK oil and gas stocks. The estimates for oil and gas are split into reserves, possible, potential additional resources (PARs) and undiscovered resources. While the OGA categorisation is different to SEEA-CF, SEEA Class A reserves could broadly be categorised as proven and probable reserves. This article uses the SEEA definition of reserves. Table 3 below provides an explanation of the classification terms used in this section.

Table 3: Definitions of geocarbon deposit types

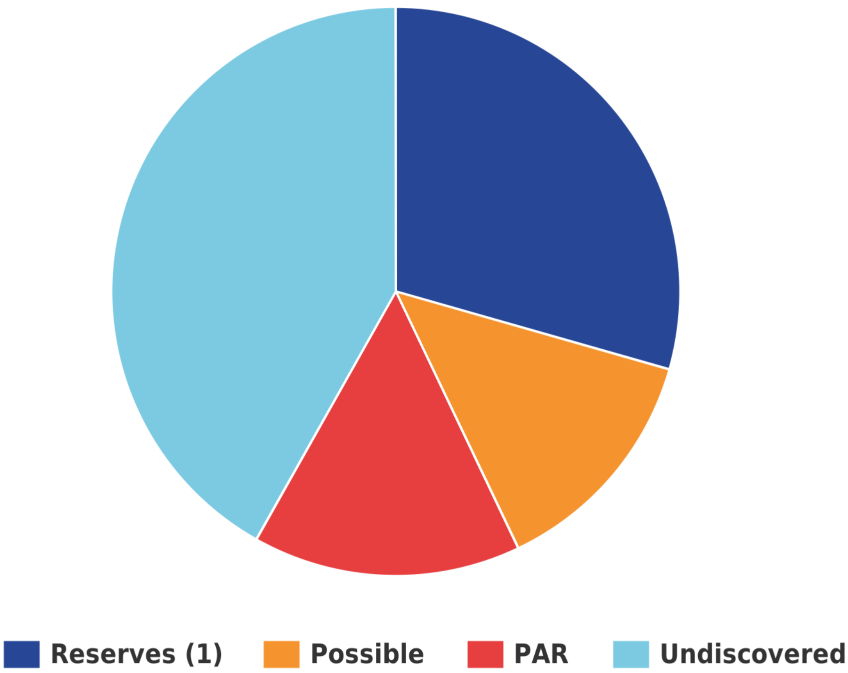
Deposit Type		Definition
SEEA Reserves	Proven	Virtually certain to be technically and commercially producible i.e. have a better than 90% chance of being produced.
	Probable	Not yet proven, but have a more than 50% chance of being produced
Possible		Cannot be regarded as probable, but which are estimated to have a significant – but less than 50% – chance of being technically and commercially producible.
Potential additional resources (PAR's)		Not currently technically or commercially producible.
Undiscovered		Provide a broad indication of the level of oil resources which are expected to exist. However, they are subject to higher levels of uncertainty than reserves and PAR's.

Source: SEEA Central Framework, OGA

Natural Gas

The total amount of carbon stored in UK natural gas deposits was 739 MtC in 2014. Of this, undiscovered gas contained the largest stock of carbon followed by proven plus probable gas reserves. Figure 1 presents the breakdown by deposit type.

Figure 1: Proportion of carbon stored in UK natural gas stocks (MtC), by type of deposit , 2014 closing balance



Source: Oil and Gas Authority

Notes:

1. Based on System of Environmental-Economic Accounting proven plus probable definition of reserves.

For proven plus probable reserves, estimates can also be disaggregated by type of gas for: dry gas; condensate gas; and associated gas. A full breakdown of the carbon contained in each natural gas category is presented in reference Table 3.

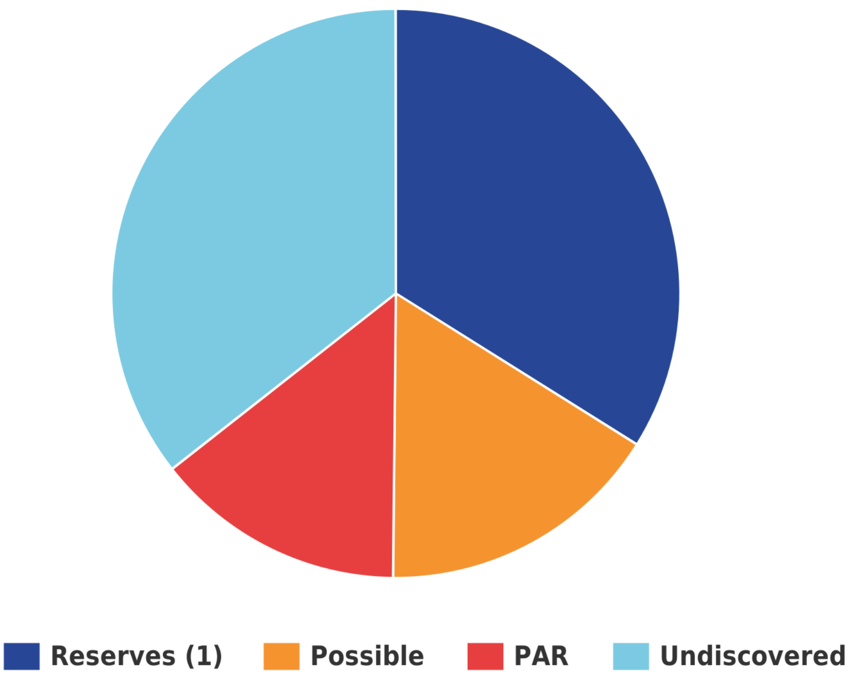
In terms of changes in natural gas carbon stocks, the resource category recorded a fall of 32 MtC over the 2013 to 2014 period. The majority of this reduction can be attributed to natural gas proven plus probable reserves, which recorded a managed contraction (i.e. due to extraction) in its carbon stock equal to 19 MtC, as well as a downward reappraisal equal to 5 MtC. The only stock categories to increase over the 2014 period were probable condensate gas resources and undiscovered natural gas resources owing to a reappraisal, which found stocks to be higher than previously estimated.

No flow information was available at the proven plus probable reserve category levels for dry gas, condensate gas and associated gas.

Oil

Total UK stocks of oil held a carbon mass equal to 1,796 MtC. Of this, undiscovered deposits held the largest proportion of total oil carbon stocks, followed by proven plus probable reserves.

Figure 2: Proportion of carbon stored in UK oil stocks (MtC), by type of deposit, 2014 closing balance



Source: Oil and Gas Authority

Notes:

1. Based on the System of Environmental-Economic Accounting proven plus probable definition of reserves.

Between 2013 and 2014, the total carbon stored within UK oil stocks fell by 3 MtC. At the sub-category level, oil proven plus probable reserves recorded a net reduction in stocks. Of this, a decline in proven reserves through extraction was offset by an upward reappraisal to the geocarbon stock category. PAR oil reserves were also subject to an upward reappraisal equal to 23 MtC.

A full breakdown of the carbon contained in each deposit category of oil is presented in Table 2 of the reference tables.

6. Biocarbon

The carbon stored in plants, soils, animals and ecosystems as a whole are all components of the biocarbon stock. Biocarbon reservoirs can be separated by type of ecosystem, which at the highest level are terrestrial, aquatic and marine (SEEA-EEA, 2012).

The primary focus of this article is on terrestrial (land) habitat based ecosystems. Coastal margin carbon storage data is presented separately. This is because the intertidal characteristics [1] of coastal margins habitat ecosystems can create potential issues with double counting. Furthermore, a lack of data on the carbon stored within, and sequestered by, open water (aquatic) ecosystems means they are excluded from the analysis at this stage.

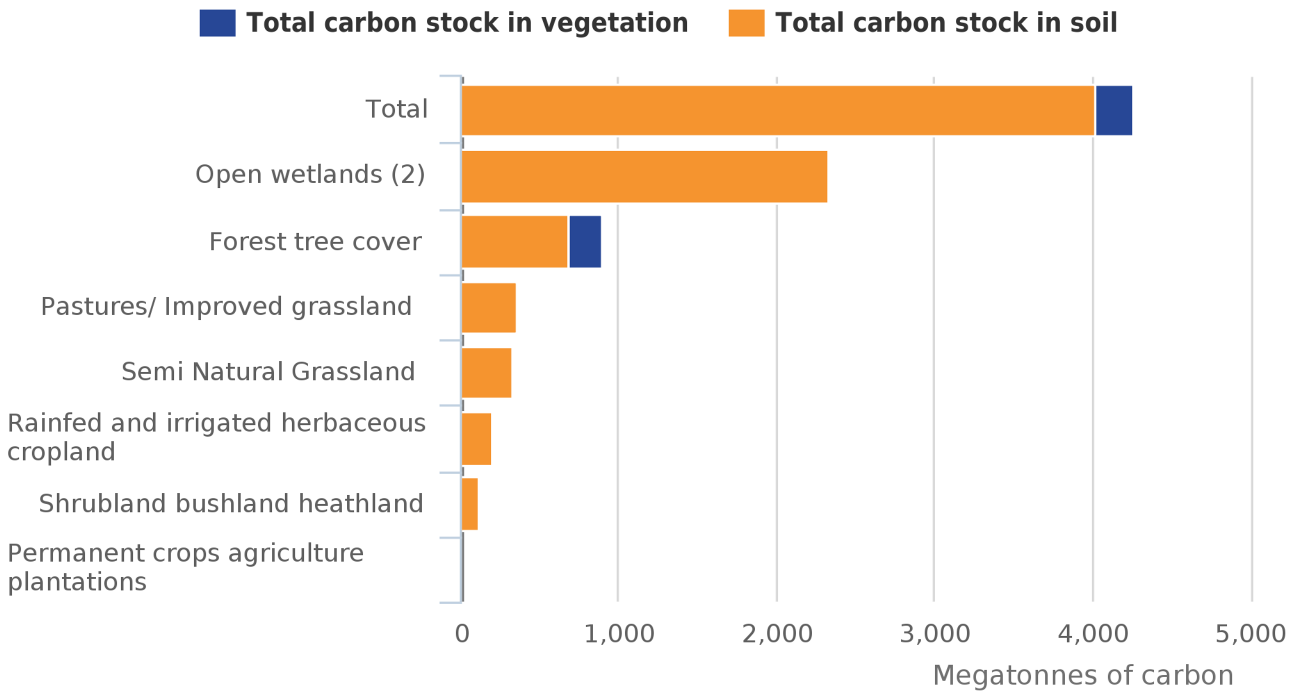
The carbon content of animals living within the ecosystems are also absent from current estimates due to a lack of available data. A more detailed discussion on the potential scope of biocarbon estimates is contained in the Biocarbon: background and methods section.

Finally, urban green space is often overlooked in terms of carbon storage. However, this land class could potentially be a significant store stock of carbon (Natural England, 2016). Research is very limited and the habitat class is not covered in the carbon accounts at this stage. However, the inclusion of biocarbon data for urban habitats could be very useful to urban planners, particularly when designing future green infrastructure projects. We will look to investigate this during the development of an Urban Ecosystem Account.

Results

Approximately 4,266 million tonnes of carbon (MtC) was stored within the UK's land based biocarbon reservoirs [2] in 2007. This is an underestimate since the vegetation carbon data excludes data for the Fen, marsh and swamp habitat classification, as well as the carbon content of animals living within the ecosystem habitats. Reference Table 5 provides a breakdown of UK biocarbon stocks by SEEA-EEA habitat classes and at subcategory level based on the Countryside (CS) Survey Broad habitat classes as at 2007.

Figure 3: UK biocarbon stock estimates (MtC), by SEEA-EEA habitat class, 2007 [1]



Source: Centre for Ecology and Hydrology, Office for National Statistics

Notes:

1. 2007, unless otherwise stated in the reference tables.

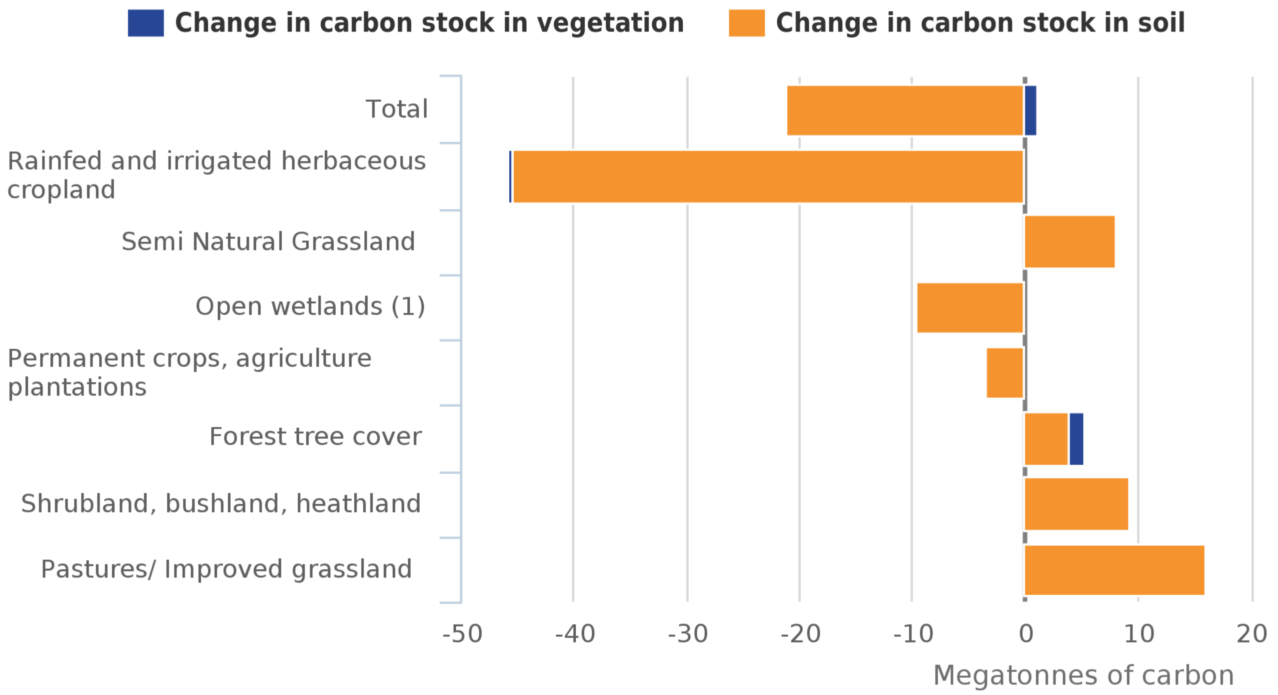
2. Excludes vegetation carbon stored in Fen, marsh and swamp habitats classification.

As Figure 3 shows, the carbon stored in UK soils is by far the largest component of the biocarbon stock containing approximately 4,019 million tonnes of carbon (MtC), or 94.2% of the total [3]. The amount of carbon stored in UK terrestrial vegetation was considerably lower containing an estimated stock of 247 MtC, or 5.8% of the total.

The carbon stored in Open wetlands (peat soils) makes up the largest portion of soil carbon stocks (57.3 %), followed by Improved grassland habitat (9.0%). The volume of carbon stored in the latter is primarily down to the wide extent of this habitat class rather than its capacity to store carbon i.e. carbon density. Soil carbon contained in Forest tree cover habitats also makes a significant contribution to total soil carbon stocks (16.7%).

In terms of the carbon stored in UK vegetation, forest tree cover habitats had the largest proportion of total stocks (91.4%). Vegetation carbon in Forest tree cover can be further disaggregated into Coniferous Woodland habitat, and Broadleaf, mixed and yew woodland habitat, which contain 48.0% and 43.4% of total stocks respectively.

Figure 4: Terrestrial carbon stock change estimates (MtC), by SEEA-EEA habitat class, 1998 to 2007



Source: Centre for Ecology & Hydrology, Office for National Statistics

Notes:

1. (1) Excludes vegetation carbon stored in Fen, marsh and swamp habitats classification.

Figure 4 presents the total (soil carbon plus vegetation carbon) change in biocarbon stock by habitat over the 1998 to 2007 period. UK biocarbon stocks[4] recorded a net decline of 19.9 MtC (-0.5%) during the period 1998 to 2007. A net rise in the carbon stored in UK vegetation over the period (+1.3 MtC), was offset by a larger net decline in UK soil carbon stocks (-21.2 MtC).

At habitat level, the most significant falls were recorded in the soil carbon stocks held in Rainfed and irrigated herbaceous cropland. The decline was due to the combined effect of a decrease in the habitat's land cover extent and a fall in its average soil carbon content (-4.5 tonnes of carbon per hectare, 1998 to 2007). Most increases in soil carbon stock by habitat were due to a rise in their respective extents over the 1998 to 2007. These included: Shrubland, bushland and heathland; and Pastures/Improved grassland. The rise in the soil carbon stocks within the Semi natural grassland resulted from increases in the habitat's extent and average carbon content per hectare.

The most notable changes within vegetation carbon stocks came from the forest tree cover habitats. A 6.1 MtC in Coniferous woodland habitat was offset by a 7.4 MtC increase in Broadleaf, mixed and yew woodland habitat.

For a more complete picture of the changes in biocarbon stocks see reference Table 6.

Coastal margins habitats

Natural England (2012) publishes carbon stock average estimates by broad habitat. The report gives a figure of 48 tonnes of soil carbon stored per hectare of Coastal margins habitat. Combining this with the 2007 SEEA-EEA Land Cover estimate for Coastal margins habitats of 153,000 hectares produces an estimate of 7.3 MtC stored in the respective soil assets. Estimates of vegetation carbon contained within this habitat class could not be produced owing to data limitations. The Coastal margins habitat account is given in reference Table 7.

Other approaches to the recording of biocarbon stock changes

DECC reports on flows of carbon from land use, land use change and forestry (LULUCF) as part of the annual UK Greenhouse Gas Inventory. The LULUCF classification does not include marine ecosystems including those intertidal areas recorded within the Coastal Margins Land Cover category. The flow data are reported on a net (emissions less removals) basis and calculated based on annual stock changes. Carbon uptake by UK forests is calculated by using a carbon accounting model, CARBINE. These are recorded as gains and losses in pools of carbon in standing trees, litter and soil in conifer, broadleaf trees, and in harvested wood products (DECC, 2014). It is not clear how changes in vegetation across the other habitat classes are calculated. Changes in soil carbon content due to land use change are estimated using dynamic models. The models combine soil carbon density information (Milne and Brown, 1997, Cruickshank et al. 1998, Bradley et al, 1995) with land use change matrixes, of which information from the CS Survey is a key input. DECC data does not distinguish between soil and vegetation carbon at this stage, so change statistics are presented on an aggregate basis.

There is still considerable work to be done if the if the carbon information available at DECC is to be optimally utilised to bring it into a consistent, compatible format for use within the carbon stock and flows account. Further research is required in the future, particularly relating to vegetation carbon beyond forest habitat and, more broadly, soil content by habitat. Even so, Table 4 presents an attempt to gauge an indication of net changes in carbon stocks using the current available data. It should be emphasised that this work is highly experimental and will be subject to significant revisions as the developmental process progresses.

DECC data are compiled based on a land use Classification basis, which accords to the Intergovernmental Panel on Climate Change (IPCC) reporting guidelines. IPCC land use Classifications were mapped to the SEEA-EEA habitat classes using guidance provided by Weber (2014) (see Annex 2). Data relates only to carbon dioxide emissions, which are then converted into carbon equivalents[5]. Emissions are generally recorded in C_O2 equivalent (CO2e) terms, whereas the stocks are in terms of carbon. This is because most of the matter in carbon stocks is held in non-oxidised form. A lack of detailed information on the emissions of other trace carbon gases, such as methane from within the LULUCF classification, means we have been unable to include them in the calculations. Carbon flows presented in Table 4 are based on the aggregated net changes between 2008 and 2014.

Table 4: Estimated net additions to (+) / reductions in (-) biocarbon stocks within UK terrestrial habitats

SEEA-EEA Habitat classes (1)	IPCC Land Use (2)	2008	2009	2010	2011	2012	2013	2014	Change in carbon stock, 2008-14
Broadleaved, mixed and yew woodland	Forest land	+4.9	+4.9	+4.9	+4.9	+4.8	+4.8	+4.7	+33.9
Coniferous Woodland									
Rainfed and irrigated herbaceous cropland	Cropland	-3.5	-3.5	-3.5	-3.4	-3.4	-3.3	-3.2	-23.8
Permanent crops, agriculture plantations									
Pastures/Improved grassland	Grassland	+2.3	+2.3	+2.3	+2.4	+2.5	+2.5	+2.5	+16.8
Semi natural grassland									
Open wetlands	Wetlands	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.7
Shrubland, bushland, heathland	Other	+0.3	+0.3	+0.3	+0.3	+0.3	+0.3	+0.3	+2.1

Source: Department of Energy and Climate Change

Notes:

(1) System of Environmental-Economic Accounting — Experimental Ecosystem Accounting

(2) Intergovernmental Panel on Climate Change

The carbon stock change data presented in Table 4 relates to net flows of carbon resulting from the regulatory ecosystem service of carbon sequestration. In order to present a more comprehensive picture, the changes in carbon stocks relating to provisioning ecosystem services need to also be included. Provisioning ecosystem services in this context relate to the carbon contained in timber harvested (removed) from Forest Land. In addition to annual estimates of UK timber production, the Forestry Commission produces annual statistics on changes to UK timber stocks, which includes information on new plantings, removals and felling residues. Furthermore, the annual timber stock estimates published in the ONS Environmental Accounts factor in various entries relating to additions and reductions to stock when calculating stock change estimates. While both represent valuable data inputs, further work is required before the respective data sets are in a suitable format that can be used in the carbon stock account.

Notes:

1. Can encompass both marine and terrestrial habitats.
2. Estimate is partial owing to the exclusion of certain UK habitats, including Coastal Margins.
3. Total carbon in this case equates to the combined estimated value for soil carbon and vegetation carbon.
4. Estimates are partial owing to the exclusion of certain UK habitats, including coastal margins.
5. One unit of Carbon = 3.667 units of Carbon Dioxide.

7. Conclusion

Preliminary estimates for categories of UK geocarbon stocks reported that approximately 143,095 MtC was stored in UK oil, gas and coal deposits at the end of 2013 (Table 5). Of this coal stocks accounted for 98% of the total. During 2014, extraction processes resulted in a combined total of 62 MtC carbon being removed from the respective categories of geocarbon.

Approximately 4,266 MtC was stored within the UK's land-based biocarbon reservoirs [1] in 2007. The carbon stored in UK terrestrial soils is by far the largest component of the biocarbon stock containing approximately 4,019 million tonnes of carbon (MtC) or 94.2% of the total. UK biocarbon stocks declined by approximately 19.9 MtC (-0.5%) in the decade to 2007, on the back of a fall in the volume of carbon stored in soil stocks. Carbon contained in UK vegetation rose by 1.3 MtC (+0.5%) over the same period, driven by an increase in categories of forest tree cover.

Table 5: Preliminary estimates for selected categories of UK carbon stocks (MtC)

Geocarbon (1)			Biocarbon (2)		
Oil	Gas	Coal	Terrestrial Ecosystems		Coastal Ecosystems
			Soil	Vegetation	
1,799	773	140,523	4,019	247	7

Source: Office for National Statistics

Notes:

(1) 2013 reference year

(2) 2007 reference year

MtC. Megatonnes of carbon

Data limitations mean that current estimates of UK geocarbon stocks are partial due to the omission of several resource sub-classes including shale, limestone and carbonate rocks. Furthermore, the limited account given to spatial variation in the respective geocarbon deposits suggests the margins for error arising from the approach used in this article are relatively broad. In particular, further work is needed to investigate the carbon content of subcategories of geocarbon resources i.e. oil, gas, coal, etc.

The carbon stock account is missing estimates for a number of biocarbon subcategories. These include: Aquatic ecosystems; and vegetation carbon stored in Fen, marsh and swamp habitats classification. Furthermore, cross cutting carbon stock categories such as the carbon contained in animals living within the ecosystems, as well as inorganic carbon stocks contained in soils have also been excluded from current estimates. Further work to include these and other categories is required if a fully representational picture of the UK's carbon stock is to be presented. Finally, while the urban green space habitat class is not covered in the carbon accounts at this stage, its inclusion could represent a valuable addition in the future. We will look to investigate this during the development of the Urban Ecosystem Account.

The cross cutting nature of certain ecosystems make it challenging to present carbon stock data by distinct categories of habitat. This point is particularly pertinent to Coastal margins, where the intertidal characteristics of such habitat ecosystems can create potential issues with double counting. In addition, while peatlands have been classified within the SEEA-EEA Open wetland habitat class in this article, their land use often means these such soils can also be included in Arable or Grassland habitats. This can result in their mismanagement isn't accurately represented. The development of distinct asset accounts for both Coast margin habitats and Peatland habitats will help fill such gaps in information. This approach is supported in Defra's Scoping the Natural Capital Accounts for Peatland (2015), while the upcoming Scoping UK Coastal Margin Ecosystem Accounts (ONS, 2016) Due for release on June 28th, 2016. will help inform on carbon stocks with this habiat class.

The aim for the carbon stock account is to complement and support the other natural capital accounts, as well as the existing annual greenhouse gas flow accounts produced by DECC. However, the current methodology used to generate the stock and flow estimates for carbon remains under development and the reported estimates should be considered experimental at this stage. Feedback from experts in the various disciplines covered in the article, as well as from stakeholders across government departments, will be essential for the successful development of the carbon stock accounts.

Notes:

1. Estimate is partial owing to the exclusion of certain UK habitats, including coastal margins.

8. Background and methods

Geocarbon

Scope and classifications

In these accounts a spatial definition of the UK consistent with the UK continental shelf has been adopted [1]. It includes all resources located within the UK's exclusive economic zone (EEZ) [2] as well as on-shore deposits. This commonly used definition is also adopted by the UK Oil & Gas Authority [3] (OGA), facilitating consistency with this and a wide range of other data sources.

SEEA Central Framework categorises mineral and energy resources into three classes – Class A: Commercially Recoverable Resources, Class B: Potentially Commercially Recoverable Resources and Class C: Non-Commercial and Other Known Deposits. SEEA Class A reserves could broadly be categorised as within the OGA' s proven and probable reserves classification. The scope excludes potential deposits where there is no expectation of them becoming economically viable and there is a lack of information to determine the feasibility of extraction or to have confidence in the geologic knowledge (SEEA-CF, UN et al 2014b, para 5.179).

The focus of this work is the carbon stored in, as opposed to the economic viability of, the respective geocarbon resources. As such, when determining scope this work adopts the broadest measure available of the respective geocarbon resources, while still attempting to align as close as is possible to SEEA concepts. Hence uneconomic resources are included when calculating estimates of geocarbon.

Data Sources

Oil & Gas

The OGA provides the most comprehensive selection of data on UK oil and gas stocks. The estimates for oil and gas are split into reserves, potential additional resources (PARs) and undiscovered resources. The OGA definition of reserves can be disaggregated into proven, probable and possible. PARs exist in discoveries for which there are no current plans for development and which are not currently technically or commercially producible (DECC, 2015). Methodology for estimating undiscovered resources combines mapped leads data from OGA with mapped prospects data from private oil companies. For areas where there is insufficient mapping of leads and prospects, an estimate is made based on knowledge of its respective geology (DECC, 2015). OGA give an upper and lower limit for estimates of undiscovered oil and gas reserves; this study uses the simple average of the two. It should also be noted that the factors which determine the commercial viability of the stock will also influence carbon content (i.e. deeper reserves are harder to extract, but hold a richer carbon content). This would apply to all geocarbon resources. Additional information on this will prove useful in the future.

While the UK Continental Shelf's reserves' categorisation is different to SEEA Central Framework, SEEA Class A reserves could broadly be categorised as proven and probable reserves. This is the approach employed in this article.

Coal

Coal data used in this article is sourced from the German Federal Institute for Geosciences and Natural Resources (BGR) with a 2013 reference year. The BGR: Reserves, Resources and Availability of Energy Resources study presents data on the proportion of coal resources held by the top 20 countries (by volume of reserves) across the world. Most pertinent to the carbon accounts is that the estimates are separated into hard coal[4] and lignite resources enabling more accurate, although still imprecise, estimation of the respective carbon content of UK coal resources.

The Department of Energy and Climate Change (DECC) also produces 2013 stock estimates of the coal resources for Great Britain (GB) in its Identified GB Coal Resource Assessment. This data are broken down into two broad categories: underground mining and surface mining, which are further disaggregated by current mines and licences, and prospects. A regional breakdown is also available[5], which may prove useful when attempting to derive carbon content of different coal deposits across the region. However, the lack of a breakdown by type of coal[6] means the format of this data is less useful for the purposes of this article.

Shale

Geographic surveys suggest that the UK has substantial shale gas resources (UK Economic Affairs Committee). The 2010 BGS/DECC Shale Gas report and the 2014 UK data and analysis for shale gas prospectivity report identified significant potential shale development areas across the country. While the carbon content of these deposits could have a significant impact on UK carbon stocks, the fledgling nature of the industry means the availability of data are currently limited. The current set of carbon accounts does not include estimates for shale, although this will be an area for future research.

Limestone and other carbonate rocks

Deposits of limestone and other forms of carbonate rocks are widely distributed across the UK. However, differences in the respective chemistry and thickness means the carbon contents may vary considerably. Related stock data on the extent of such deposits is limited for the UK and is, therefore, not currently included.

ONS Environmental Accounts has published statistics on annual rates of domestic extraction for limestone, chalk and dolomite. However, at present flow data on chalk and dolomite is aggregated, while limestone statistics include gypsum making the identification of resource specific carbon content problematic. This is another area which requires further work and research in order to present meaningful statistics.

Changes in geocarbon stocks

Additions to stock for any specific category can take place in various ways. Firstly, there are reclassifications between forms of stock where reserves become commercially viable as a result of market forces, or changes in technology, (for example, PAR reserves could be upgraded to proven reserves, meaning a reduction in one reserve category is matched by an increase in another). Secondly, as existing reserves are reassessed using improved techniques, the content of the reserves may be subject to upwards reappraisal. Thirdly, new reserves may be discovered.

Conversely, reductions in oil or gas stocks can happen in the following ways. Firstly, managed reductions reflect the extraction of these reserves for consumption. The final two entries are the opposite movements from the first and second forms of additions to stock outlined above. A reclassification may have a negative impact on a particular stock where it results in a shift away from that stock; and as existing reserves are reassessed using improved techniques, the content of those reserves may be subject to downwards reappraisal although this may not be simultaneous[7].

There is currently only limited data available on additions to, and reductions in, UK geocarbon stocks. As part of the UK Environmental Accounts, we publish a material flow dataset which records the total mass of natural resources and products that are used by the economy. The Material Flow Account (MFA) draws on a range of primary data sources to populate its respective tables including: BGS for mineral flows, and Defra for flows related to agricultural products. While this includes broad based data on geocarbon resource categories for both fossil fuels and carbonate rocks, the aggregated structure of the data means it is not currently compatible with the stock estimates.

DECC publishes partial information on annual flows of oil and gas in its annual Digest of UK Energy Statistics (DUKES) report. Furthermore, BGR publishes data on UK coal production, together with its UK coal stock estimates. Retaining the same source for both stock and flow data allows for changes to the stock to be presented on a consistent basis over a given time period.

Unfortunately no information is available on the extent of changes to stocks resulting from reclassifications or discoveries. As a result, with the exception of flows from extraction/production (managed contraction), all other changes in stock are attributed to upward/downward reappraisals.

Carbon conversion factors

Carbon conversion factors allow for the physical volume of a given geocarbon stock to be converted into estimates of its respective carbon mass.

The carbon richness of a given geocarbon resource can vary dependent on their respective geological location. For instance, the pressure and temperature to which geocarbon stocks are exposed when in situ means their respective carbon contents can vary considerably, both between and within geocarbon categories. Table 2 presents a list of the carbon conversion factors for the respective components of geocarbon.

Oil

In its natural state, crude oil ranges in density and consistency from very thin, light weight and volatile fluidity to an extremely thick, semi-solid heavy weight oil (Chevron, n.d.). A breakdown of the types of crude oil contained within the UK continental shelf could not be found. A broad based study on carbon emissions from different fuels published by Biomass Energy Centre (BES) suggests that oil has a carbon content of around 85%[8]. While BES provides only limited detail on the method used to reach this estimate, it will be used in this study as it does correspond with the 85.5% crude oil carbon content weight used by Ajani & Comisari, 2014. However, the limited account given to spatial variation across deposit sites suggests the margins for error arising from the use of this approach are relatively broad.

Gas

OGA data separates gas reserves into three categories: dry gas, condensate field gas and associated gas. Like oil, information on the carbon content of the respective gas subdivisions is limited. The US EPA suggests that based on a weight of 0.714 kilograms (kg) per cubic metre, natural gas has a carbon mass of 0.5262 kg, or 74%. However, as with oil, the carbon intensity of natural gas is likely to vary with the depth and pressure of the deposit. The Biomass Energy Centre (BEA) has published estimates suggesting that the carbon content of natural gas is slightly higher at around 75% rich. Unfortunately, there is no information provided by BEA on the methodology underpinning this rate, however, it does concur with the ratio used by Ajani & Comisari, 2014 for categories of natural gas[9] .This underpinned the decision to use the BEA rate in carbon content calculations.

The estimation of the carbon stored in gas resources is calculated by the following steps:

One cubic metre of natural gas weighs 0.714 kg, which assumes a 75% carbon content:

1 cubic metre of natural gas = 0.714 kg 0.714 * 75% = 0.5355 kg

Coal

The carbon content of coal varies not just by the class of coal (lignite, sub-bituminous, bituminous and anthracite), but within each class (Ajani and Comisari, 2014). During the coalification process[10] the carbon content increases from as little as 15% in lignite[11] to as much as 95% in anthracite (BGS, 2010). To gather information containing this level of detail, extensive sampling across the UK to determine the carbon content of different coal deposits would be required. Unfortunately, such information is not readily available so this work is restricted to applying conversion factors for tonnes of coal to tonnes of carbon that are indicative only.

The coal resources presented in these accounts have been grouped into the categories: hard coal and lignite (brown coal). Hard coal comprises the aggregated stocks of sub-bituminous coal, bituminous coal and anthracite (BGR, 2014).

A range of sources have been consulted to determine suitable conversion factors. For hard coal, average carbon content estimates range from 63%[12]to as much as 85%[13].This work draws on the BEA estimate and applies an average carbon content for hard coal of 75%. The carbon content of lignite has been sourced from the US Energy Information Administration (EIA) and estimated to be 30%, which is the middle of the EIA range for lignite.

Biocarbon

Scope and classifications

The primary data source used to populate the biocarbon stock account is the Countryside (CS) Survey for 1998 and 2007. Conducted by the Centre for Ecology and Hydrology (CEH), the CS Survey is a long-term scientific study used to inform decision makers and the public on the status of the managed and natural UK environment, including soil carbon stocks and vegetation composition (Ostle, 2009). The CS Survey classifies its ecosystems by Priority[14] habitats, which are linked directly the Broad Habitat classifications used in the UK National Ecosystem Assessment (NEA). The NEA's approach to classification supports the identification and measurement of terrestrial, freshwater and marine ecosystems contained within eight collections of "broad habitat" types (NEA, 2016). The NEA Broad Habitats largely align with the SEEA-EEA provisional land cover classifications (SEEA-EEA, p.60), which uses a system based on the physical cover of the Earth's surface.

Biocarbon flows between 2008 and 2014 have been inferred using the land use, land use change and forestry (LULUCF) data produced by DECC within its UK Greenhouse Gas Inventory. DECC data are compiled based on a land use Classification, which accords to the Intergovernmental Panel on Climate Change (IPCC) reporting guidelines.

The CS Broad Habitat classes were mapped to the SEEA-EEA nomenclature using guidance within the Land Cover Accounts. This process enables average carbon content per hectare by habitat figures to be combined with SEEA-EEA consistent land cover data for the UK. Separately, IPCC Land Use Classifications were mapped to SEEA-EEA classifications using guidance provided by Weber (2014). Both revised habitat classifications were then adapted to the UK context. The concordance tables used to map the CS Broad Habitat classes and IPCC Land Use Classifications to the SEEA-EEA nomenclature are presented in Appendix 3.

Data sources

Terrestrial habitat soils

Soil is a major component in the global carbon cycle and vulnerable to impacts from human activity. Thus, even small rates of carbon loss from soils can have significant consequences for the overall carbon budget and, in turn, atmospheric CO2 concentrations (Dawson and Smith, 2006).

The majority of organic carbon in terrestrial ecosystems is stored below ground (Janzen, 2004). As a result, stock estimates of soil carbon vary depending on the depth of the soil considered. The most disaggregated and up to date soil carbon stock estimates are contained in the CS Survey, which records tons of carbon per hectare in Great Britain. Estimates for the total soil carbon stock of each Broad Habitat in the UK have been produced by combining the tonnes per hectare by habitat units, with land area estimates from the Land Cover Accounts.

Limitations on the scope of the CS survey mean estimates need to be supplemented with data from additional sources in order to present a fuller picture of soil carbon stocks across the UK. A key limitation of the CS survey is that it only reports on soils to a depth of 15cm. Peat depth varies on average between half a metre and three metres, although depths of up to eight metres are not uncommon (SNH). Limiting estimates of carbon stored in UK peat resources to a soil depth 15cm would, therefore, result in a significant underestimate and represent a major omission. This would have greatest impact on estimates for Scotland (Ostle et al, 2009).

The compilation of accurate volume estimates of UK peat resources requires information on: the extent and condition of peat resources; the depth of peat resources; and the carbon composition per unit volume of peat. There have been several attempts to undertake this since the 1990s. Milne and Brown (1997) provide carbon values for peat within Great Britain to a depth of four metres. For Scottish peatland resources, the authors assume carbon densities increase with depth. DECC uses the biomass carbon density for each land type from this study[15] when estimating changes in biocarbon stocks due to land use change in its annual Inventory of Greenhouse Gas Emissions (CEH, 2010). However, only limited information is available on how changes in bulk density were calculated. Furthermore, Milne and Brown (1997) do not separate figures for peat from other soil types in England and Wales.

The most up-to-date overview of data sources on UK peatland is Defra's Scoping the Natural Capital Accounts for Peatland study. However, while the report includes comprehensive information on the extent and condition of peatland resources across the UK, it provides only limited information on peat depth and bulk densities under the rationale that: 'as depth of peat soil is not usually known with accuracy, and many peat soils extend significantly deeper than this, any depth estimate is only a guide for those identifying the presence of peatlands (p.10)'.

This Carbon Account uses the work of Billet et al. (2010)[16] ,which draws on a range of separate country centric studies to produce a total stock estimate for the carbon stored in peatland resources across the UK. For carbon estimates up to one metre in depth, Chapman et al. (2009)[17] is used for Scotland, while Bradley et al. (2005)[18] is used for England, Wales and Northern Ireland. For carbon estimates in excess of one metre in depth, Chapman et al. (2007) is used for Scotland, Smith et al. (2007)[19] is used for Wales, while estimates for England and Northern Ireland use Scottish data to produce pro rata estimates.

Peatland assets fit within the SEEA-EEA Open wetlands ecosystems classification. In line with the Freshwater Ecosystem Assets and Services Accounts, all peatland assets are allocated to the Bog subcategory of the Open wetlands Broad Habitat.

Finally, soil carbon stocks beneath UK woodland resources have been supplemented by using data from the Forestry Commission's (FC) 2012 report Understanding the carbon and greenhouse gas balance of forests in Britain. The FC uses results from the BioSoil Survey[20] ,which describes and samples soils down to a one metre depth on a 16x16 km grid network that fall onto forested land. The report provides a figure for the average carbon stored in soil per hectare of UK woodlands. It does not, however, distinguish between different classes of woodland i.e. conifer or broadleaf.

Terrestrial habitat vegetation

Estimates of vegetation carbon by Broad Habitat are primarily sourced from Natural England's Carbon storage by habitat, which itself draws on Ostle et al, 2009 to estimate carbon stocks per hectare for the UK. These are combined with ONS estimates of UK land cover to create estimates for carbon stock in vegetation by habitat based ecosystem.

The ecosystem subcategories of Coniferous forest, and Broad leaf, mixed and yew woodland have been populated using more accurate data from the FC's National Forest Inventory report on the carbon content of

British woodland. Estimates are based on a broad definition of Woodland carbon as: "comprising carbon stored in all living plant material in both the above and below ground parts of trees (including major roots, stumps, stems, branches, twigs and foliage) in stands with a mean diameter (at breast height) of 7 cm or more" (p.2).

Finally, the exclusion of vegetation carbon data for the Fen, marsh and swamp habitat classification means the total biocarbon stock figure is an underestimate. This could be an area for future research.

Coastal margins

Coastal margin ecosystems can occur in both terrestrial and marine habitats simultaneously, which creates double-counting problems. For instance, other habitats or land cover categories, e.g. grassland or urban areas, can be situated on what would be called "the coast" (ONS, 2016). To avoid potential issues with double-counting, this article presents carbon stock information related to Coastal margin habitats separate from the terrestrial habitats.

The SEEA Central Framework classifies 'coastal water bodies and intertidal areas' as "defined on the basis of geographical features of the land in relation to the sea (coastal water bodies, i.e., lagoons and estuaries) and abiotic surfaces subject to water persistence (intertidal areas, i.e., coastal flats and coral reefs)".

The UK NEA defines six main habitat sub-classes as coastal: Sand dunes, Machair, Saltmarsh, Shingle, Sea Cliffs and Coastal Lagoons. This includes small islands, sand and shingle beaches, but excludes coastal grasslands, mudflats, rocky shores and estuaries, and coastal urban areas. Sand dunes, saltmarsh and machair comprise over 90% of the UK Coastal margin habitat (Beaumont et al., 2014).

Coastal margins produce significant benefits in terms of carbon storage and carbon sequestration. Basic quantification of the carbon pools stored in coastal margins is difficult. This is in part because of a grey area between coastal margins and the marine environment, meaning they are commonly grouped together (ONS, 2016), but also because the coastal margins constitute a narrow zone of land, which are not a distinct habitat. As such, in many cases data gathering does not differentiate between key aspects. Furthermore, coastal habitats were excluded from the 1998/2007 CS Surveys due to a lack of representative coverage.

The UK NEA provides estimates for the carbon stored in UK Coastal Margins. Drawing on CEH data it estimates coastal margins vegetation and soils combined to hold at least 7.24 MtC carbon (UK NEA (2011), Chapter 11). While this figure underestimates the carbon storage component in Saltmarsh soil[21], where soil depth remains largely unquantified, it is broadly in line with the Beaumont et al. (2010) estimate of 6.8 MtC held in UK coastal margin vegetation and soils.

This article uses the soil carbon stock average estimate for Coastal margin habitats published in Natural England (2012), which is combined with the 2007 SEEA-EEA Land Cover estimate for Coastal margins habitats.

While this produces a higher estimate than the combined vegetation and soil carbon figure reported in UK NEA (2011), this still only represents a partial estimate, since the land cover data for coastal margins only includes certain habitat sub-classes.

Open waters

Open waters form part of the UK NEA Freshwaters Broad Habitat classification. The Open waters sub-class broadly matches up with the SEEA-EEA based habitat class: Inland water bodies. Open waters can be further subdivided into two categories: standing waters[22] and flowing waters[23](ONS, 2015). Wetlands act as transitions between terrestrial and open water systems.

Information on the carbon stocks in, and flows to and from, open water ecosystems form an important aspect of this field of analysis. Deposition of organic sediments within lakes, ponds and reservoirs is an important component of the carbon budget (UK NEA: Chapter 9).

There is currently a lack of data to quantify the total stock of carbon stored within the UK aquatic environment, and it is therefore excluded from the analysis at this stage. We will look to investigate this during the next process to update the ONS Freshwater Ecosystems Account.

Changes in biocarbon stocks

Terrestrial ecosystems

The delivery of ecosystem services by the UK's natural environment can have a significant impact on the stocks of carbon stored within its respective habitats. For instance, the delivery of provisioning services, such as the removal of timber to support economic activities, can result in a reduction in the carbon stocks held within woodland habitats, coupled with an equal increase of carbon in the inventories of timber in the economy (see Section 4). Conversely, the delivery of regulating services, such as carbon sequestration [24], can be reflected as an addition to vegetation carbon stocks held by the respective UK habitat class.

The data set used in this work does not allow for separation between ecosystem services. Furthermore, a given habitat's ability to provide ecosystem services is significantly influenced by its condition. However, a lack of suitable information means habitat condition is not factored into estimates at this time. Finally, we are unable to separately identify additions to, and reductions in, stocks at this stage so changes are presented on a net basis.

Ideally, the best approach to measure changes in carbon stocks between reference periods would be to use the data on carbon flows from the land use, land use change and forestry (LULUCF) sector reported by DECC as part of its annual UK Greenhouse Gas Inventory publication. Unfortunately, LULUCF data does not contain the appropriate level of detail required for use within the carbon stock account. This will be an area which would benefit significantly from closer collaboration with our colleagues in DECC. Section 3.6 below provides further detail on the adjustments required as well as some broad aggregate estimates on carbon flows when using a LULUCF based approach.

The Land Cover accounts show estimates by SEEA-EEA-based habitat classes for the years 1998 and 2007. The CS Survey also contains estimates for GB of changes in carbon soil content by terrestrial habitat between 1998 and 2007. These are presented in Appendix 4. By combining the two data sets, estimates for the change in soil stocks by habitat can be generated.

Exceptions to this relate to estimates of changes on soil carbon content gathered from sources outside of the CS survey. For instance, the data sources used to support estimates of soil carbon in the woodland, and the bog (peat) habitat classes did not include information on changes in the soil content. Thus, in cases where change data was unavailable, movements in the carbon stock of the respective habitats are based only on land cover changes between 1998 and 2007. The same applies to all estimates for the carbon content of vegetation, including those sourced from the CS Survey. Data was only available for one reference year. Therefore, the average vegetation carbon content for all habitats is assumed to have stayed constant over the 1998 to 2007 reference period. Again, any changes are based solely on land cover.

Coastal margins

The Coastal margins scoping study (ONS, 2016) presents an extensive overview of potential data sources that could report on carbon stock changes related to coastal margin habitats. While there have been a number of studies that have included physical carbon flow estimates in the context of ecosystems services, the level of detail provided is not of a sufficient level required to support meaningful estimates for use within a carbon stock account.

Aquatic ecosystems

There is currently a lack of data to quantify the changes in the stock of carbon stored within the UK open water ecosystems. This will be investigated during the next process to update the ONS Freshwater Ecosystems Account.

Notes:

1. The UK Continental Shelf (UKCS) comprises those areas of the sea bed and subsoil beyond the territorial sea over which the UK exercises sovereign rights of exploration and exploitation of natural resources. (OGA, n.d.).

2. The EEZ extends from the baseline (mean low water mark) out to 200 nautical miles from the UK's coast (UNCLOS, 2012).

3. The OGA is an executive agency sponsored by the Department of Energy and Climate Change (DECC).

4. Hard coal resources contains only bituminous coal and anthracite according to BGR classification.

5. At the NUTS 2 level.

6. Different types of coal have different carbon contents.

7. This is not a simultaneous movement to the addition.

8. Biomasse Energy Centre: Carbon emissions of different fuels.
9. Ajani & Comisari apply the following rates: condensate, 75%; LPG 77%; natural gas 74%.
10. Process by which vegetation is converted into the various grades of coal.
11. Also known as brown coal.
12. Ajani and Comisari, 2014: Figure determined as the average carbon content found in Australian coal stocks of anthracite, bituminous and sub-bituminous.
13. Geology.com (n.d.).
14. Priority Habitats are habitats that have been identified as a priority for conservation in the UK Biodiversity Action Plan.
15. DECC use data only down to one metre from the study.
16. Billett, M. F. Charman, D. J. Clark, J. M. Evans, C. D. Evans, M. G. Ostle, N. J, Worrall, F. Burden, A. Dinsmore, K. J. Jones, T. McNamara, N. P. Parry, L. Rowson, J. G. and Rose, R. 2010. Carbon balance of UK peatlands: current state of knowledge and future research challenges. Climate Research 45: 13-29.
17. Chapman SJ, Bell J, Donnelly D, Lilly A (2009) Carbon stocks in Scottish peatlands. Soil Use Management 25:105–112
18. Bradley RI, Milne R, Bell J, Lilly A, Jordan C, Higgins A (2005), A soil carbon and land use database for the United Kingdom, Soil Use Management 21:363–369.
19. Smith P, Smith J, Flynn H, Killham K and others (2007), ECOSSE: estimating carbon in organic soils—sequestration and emissions. Scottish Executive Environment and Rural Affairs Department, Edinburgh, www.scotland.gov, uk/Publications/2007/03/16170508/0.
20. The BioSoil Survey is a large EU soil and biodiversity survey in forestry, and is part of the programme of the Forest Focus regulation (2003–6). , The BoiSoil survey was the single largest soil monitoring exercise implemented so far at the EU scale.
21. Estimates only based on a soil depth of 15cm.
22. Standing waters include natural systems - such as lakes, meres and pools, and man-made waters such as reservoirs, canals, ponds and gravel pits.
23. Flowing waters include rivers and streams that flow into the sea or a lake.
24. Carbon sequestration refers to the removal of carbon from the atmosphere during the process of photosynthesis.

9. Annex 1: Changes in stock classifications

The presentation of the row entries in the account follows the basic form of the asset account in the SEEA Central Framework; the entries being opening stock, additions, reductions and closing stock. Additions to, and reductions in, stock have been split between managed and natural expansion and contraction.

There are six types of additions in the carbon stock account:

Natural expansion

Reflects increases in the stock of carbon over an accounting period due to natural growth. Effectively, this will be recorded only for biocarbon and may arise from climatic variation, ecological factors such as reduction in grazing pressure, and indirect human impacts such as the CO2 fertilisation effect (where higher atmospheric CO2 concentrations cause faster plant growth). Soils (the major biocarbon store) have a carbon equilibrium that, when reached, mean a habitat C stocks will plateau.

Managed expansion

Reflects increases in the stock of carbon over an accounting period due to human-managed growth. This will be recorded for biocarbon in ecosystems and accumulations in the economy, in inventories, consumer durables, fixed assets and waste stored in controlled landfill sites, and also includes greenhouse gases injected into the earth. The displacement effect, where carbon stocks increase due to proactive management in one area (i.e. via agricultural environment schemes) may result in increased productivity elsewhere, and, therefore, a reduction in its respective stock.

Discoveries of new stock

Encompasses the emergence of new resources added to a stock, which commonly arise through exploration and evaluation. This applies mainly, and perhaps exclusively, to geocarbon.

Upward reappraisals

Reflect changes due to the use of updated information permitting a reassessment of the physical size of the stock. The use of updated information may require the revision of estimates for previous periods so as to ensure a continuity of time series.

Reclassifications of carbon assets

Generally occurs in situations where another environmental asset is used for a different purpose. For example, increases in carbon in semi-natural ecosystems following the establishment of a national park on an area previously used for agriculture would be offset by an equivalent decrease in agricultural ecosystems. In this case, it is only the particular land use that has changed, that is, reclassifications may have no impact on the total physical quantity of carbon during the period in which they occur.

Imports

Recorded to enable accounting for imports of produced goods (e.g., petroleum products). Imports are shown separately from the other additions so that they can be compared to exports.

There are six types of reductions recorded in the carbon stock account:

Natural contractions

Reflect natural losses of stock during the course of an accounting period. They may be due to changing distribution of ecosystems (e.g., a contraction of natural ecosystems) or biocarbon losses that might reasonably be expected to occur based on past experience. Natural contraction includes losses from episodic events including drought, some fires and floods, and pest and disease attacks, and also includes losses due to volcanic eruptions, tidal waves and hurricanes.

Managed contractions

Relate to reductions in stock due to human activities and include the removal or harvest of carbon through a process of production. This includes mining of fossil fuels and felling of timber. Extraction from ecosystems includes both those quantities that continue to flow through the economy as products (including waste products) and those quantities of stock that are immediately returned to the environment after extraction because they are unwanted e.g. felling residues. Managed contraction also includes losses as a result of a war, riots and other political events; and technological accidents such as major toxic releases.

Downward reappraisals,

Reflect changes due to the use of updated information that permits a reassessment of the physical size of the stock. The reassessments may also relate to changes in the assessed quality or grade of the natural resource. The use of updated information may require the revision of estimates for previous periods to ensure a continuity of time series.

Reclassifications

Generally occur in situations where another environmental asset is used for a different purpose. For example, decreases in carbon in agricultural ecosystems following the establishment of a national park on an area used for agriculture would be offset by an equivalent increase in semi-natural ecosystems. In this case, it is only the particular land use that has changed; that is, reclassifications have no impact on the total physical quantity of carbon during the period in which they occur.

Exports

Recorded to enable accounting for exports of produced goods (e.g., petroleum products). Exports are shown separately from the other reductions so that they can be compared to imports.

Catastrophic losses,

Shown as a single entry, but are allocated between managed contraction and natural contraction. Catastrophic losses in managed contraction would include fires deliberately lit to reduce the risk of uncontrolled wild fires. For the purposes of accounting, reductions due to human accidents, such as rupture of oil wells, would also be included under managed contraction. Catastrophic losses could, however, be separately identified.

10. Annex 2: Concordance tables

Table A: Concordance between SEEA-EEA based habitat classes, Countryside Survey broad habitats and IPCC Land Use classifications

SEEA-EEA-based habitat classes	Countryside Survey broad habitats	IPCC Land Use Classification
Rainfed and irrigated herbaceous cropland	Arable and horticulture if herbaceous crops	CL - Cropland
Permanent crops, agriculture plantations	Arable and horticulture if permanent crops	
Pastures/Improved grassland	Improved grassland	GL - Grass Land
Semi-natural grassland	Neutral grassland	
	Calcareous grassland	
	Acid grassland	
	Bracken	
Forest tree cover	Broadleaved, mixed and yew woodland	FL - Forest Land
	Coniferous Woodland	
Shrubland, bushland, heathland	Dwarf shrub heath	OL - Other land
Barren land/Sparsely vegetated areas	Inland rock	
	Montane if covered by rock by more than 95%	
	Any land if vegetation cover is less than 10%	
Open wetlands	Fen, marsh, swamp	WL - Wetlands
	Bog	
Inland water bodies	Standing open waters	WBR - Water bodies, rivers
	Rivers and streams	
Coastal margins	Supra-littoral rock	
	Supra-littoral sediment	

Source: SEEA-EEA, IPCC, Weber-2014

11. Annex 3: Accumulations in the economy

The SEEA-EEA recommends including accumulations of carbon in the economy in its carbon stock account. Accumulations in the economy (AIE) refer to the stocks of carbon stored within products produced through economic activity. Due to a range of conceptual and data limitations no attempt has been made to produce estimates of AIE in this article. It should be noted, however, that carbon related to AIE are small relative to geocarbon and biocarbon stocks. The following section outlines factors that should be taken into account when developing AIE estimates.

The SEEA applies the accounting concepts, structures, rules and principles of the System of National Accounts (SNA)[1]. Through using this approach, the anthropogenic (human-created) stockpiles of carbon bearing materials generated through economic activity can be disaggregated and organised into categories based on the SNA. These are outlined in Table B below:

Table B: Stockpiles of carbon bearing products within the economy

Categories	Definitions	Examples
Fixed Assets	Refer to carbon containing products that are purchased, but not fully consumed within one accounting year[1].	Wood and concrete in buildings, bitumen in roads
Consumer durables		Wood in furniture and plastic products
Inventories	Carbon contained in produced assets that are held in stock for sale, use in production or other use at a later date.	Petroleum products in storage; excludes carbon in agricultural ecosystems that are extracted on an annual basis
Waste	Products deposited and stored in managed land fill sites are treated as being part of the economy.	Disposed plastic, wood and paper products

Source: SNA-2008, Ajani & Comisari-2014

Notes:

[1] Materials that are extracted and consumed within a year e.g. the mining and combustion of fossil fuels or the products extracted from agricultural systems operating on an annual cycle, are excluded from AIE.

Accounting for the carbon contained in waste products follows the conventions of the SEEA-CF (SEEA-EEA, 2012). Only waste products deposited and stored in managed landfill sites are treated as being part of the economy. Non-managed waste deposit sites are excluded from the AIE scope. Another consideration when accounting for waste relates to the stocks of carbon created through geosequestration. Geosequestration involves the capturing of atmospheric CO2 from significant point sources i.e. coal burning power stations, and burying it securely underground. Such carbon stocks are also accounted for as part of the waste sector.

In order to maintain consistency across our natural capital accounts, the carbon stock account should employ the approach taken in the Farmland Ecosystems account and place livestock within the AIE category, while trees [2] and other cultivations will be treated as being within the environment (biocarbon). For geocarbon, the boundary at which the product crosses into the economy is the point before (materials in resources) reservoirs containing geocarbon are extracted (mined).

Imports and exports of carbon

Imports and exports of carbon are directly connected to AIE, in that they are another form of anthropogenic carbon stocks created through economic activities. Reference Table 1 includes additional rows for imports and exports. Imports are recorded to enable accounting for the carbon contained in the imports of produced goods (e. g., paper products) into the economy. Exports are recorded to enable accounting for the carbon contained in the exports of produced goods (e.g., petroleum products) out of the economy. Imports and exports are presented separately in the carbon stock account to enable comparison between the respective categories.

Notes:

1. The System of National Accounts (SNA) is the internationally agreed standard set of recommendations on how to compile measures of economic activity (UNSD, 2016).

2. This is because the UK does not have a concept of ‘plantations’, since in theory almost all woodland is available for timber irrespective of whether is has been naturally regenerated.

12. Annex 4: Atmosphere and Oceans

The atmosphere and oceans are the receiving environments for carbon released from the primary reservoirs (biosphere or geosphere) and Accumulations in the economy.

Measuring the carbon stock of, and flows between, the atmospheric and oceanic carbon pools is an important but complex aspect of environmental accounting. The oceans represent the globe’s largest reservoir (World Ocean Review, 2015) containing approximately 37,500 gigatons of carbon (GtC). This represents about fifteen times as much carbon present as is within Earth’s terrestrial biosphere[1] (2,477 Gt, IPCC 2000). The global store of carbon within the atmosphere was approximately 836 GtC in 2012 (CDIAC, n.d.). This is considerably higher than atmospheric carbon levels at the start of the industrial era (c.1750); global stocks are estimated to have been in the region of 592 GtC at that time.

Trace carbon gases in the atmosphere (or residuals) can be sourced from carbon pools within the biosphere or geosphere and from indirect flows via the economy. The main carbon bearing trace gases in the atmosphere are CO_2, methane (CH4) and carbon monoxide (CO), with CO_2 having by far the dominant representation[2]. The IPCC report - Climate Change 2013: The Physical Science Basis reports the 2011 stock of CO_2 within the global atmosphere to have a mass equal to c.828 GtC; methane CH_4 to have a mass equal to c.3.7 GtC; and CO to have a mass equal to c.0.2 GtC. Emissions to the atmosphere from the geosphere are effectively one way and therefore relatively easy to account for.

Accumulations of atmospheric carbon are the most accurately measured quantity in the global carbon cycle (Global Carbon Budget). They result from both anthropogenic and natural processes. Estimates of atmospheric carbon stocks can be crudely derived by combining the concentration of carbon dioxide (CO_2) and other trace carbon gases (in parts per million) in the atmosphere with data on the total volume of the atmosphere (Vardon, 2014).

Carbon in the oceans is commonly estimated through calibrated modelling (Ajani & Comisari, 2014). Researchers have developed a variety of methods to quantify the present role of the oceans in the carbon cycle, however, comprehensive estimates remain a challenge. McNeil (2006) states that “while the ocean within each exclusive economic zone (EEZ) has a vast capacity to absorb anthropogenic CO_2 ... it is not mentioned within the Kyoto Protocol most likely due to inadequate quantitative estimates.” Measuring the change in the amount of dissolved inorganic carbon in the oceans is similarly difficult because the annual increase is small compared to the regional and temporal variability. While some broad based estimates exist for the flows into and out of the atmospheres and oceans (Global Carbon Project, 2015), there remain large gaps in knowledge.

The SEEA-CF excludes the ocean and the atmosphere from its measurement scope under the rationale that ‘the associated volumes of water and air are too large to be meaningful for analytical purposes at the country level’. Although ecosystem accounting is the focus of SEEA-EEA, the accounting framework lists important differences in ecosystems for ecosystem accounting purposes and the wider needs of the users of carbon stock information (Ajani & Comisari, 2014). Even so, there remain significant knowledge gaps and as such broadening the scope of SEEA consistent carbon accounts to include information on atmospheric and oceanic carbon is challenging.

Notes:

1. Global carbon stocks in vegetation and soil carbon pools down to a depth of one metre.

2. Other related gases include perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and non-methane volatile organic compounds (NMVOCs).

13. Annex 5: Net present value model

The following Net Present Value (NPV) formula is used to calculate the monetary asset value for UK ecosystems providing carbon sequestration services:

Net Present Value equation

$$Value\ of\ component = \sum_{t=0}^{n} \frac{resource\ rent\ in\ year\ t}{(1+r)^t}$$

The Net Present Value (NPV) equation is used to calculate the sum of discounted resource rents.

Where:

N = total number of periods (50 years)

t = year

r = social discount rate (SDR, 3.5% up to 30 years declining to 3.0% thereafter).

14. Annex 6: Estimating values for carbon sequestration

This section includes a discussion on placing monetary values on ecosystem services related to carbon sequestration and the ecosystem assets that provide them.

Beyond the extent to which carbon improves the quality of soil used for agricultural production, the actual value of the carbon contained in the biomass of soils and vegetation is relatively small. In the context of carbon stock account, the values relate to the distinct benefits provided to society through carbon sequestration (i.e. the removal of carbon from the atmosphere through photosynthesis) and carbon storage (within biomass).

According to SEEA-EEA, the service of sequestering carbon is equal to the net accumulation of carbon in an ecosystem due to both growth of the vegetation and accumulation in below-ground carbon reservoirs (p.65). There is considerable difficulty in attaching a clear definition to carbon storage. Its valuation is a relatively unexplored area and beyond the scope of this article.

Experimental estimates for carbon sequestration services and the ecosystem assets which provide them were published as part of the UK Natural Capital – Initial and Partial Monetary Estimates. The methodology employed is presently under review. Revised estimates of carbon sequestration will be included in the next release of the publication due out at the end of 2016.

Current methodology used to produce value estimates of carbon sequestration services combines data on the net flows of carbon from the IPCC sector: Land Use, Land Use Change and Forestry (LULUCF) , with information from the projected non-traded price of carbon schedule. Both datasets are produced by DECC.

Selecting net carbon flow data requires the identification of flows resulting from natural processes (i.e. carbon sequestration). This is challenging since LULUCF data provides only limited detail on such flows. Current ONS methodology has identified flows resulting from natural processes within elements of the LULUCF habitat sub-classes: Forest Land; and Grassland. However, the approach is still developmental and ongoing research is required to better identify and explain the relevant net flows within each habitat class.

SEEA-EEA guidance advises asset values for ecosystems providing carbon sequestration services can be estimated by using the Net Present Value (NPV) approach. This involves combining data on expected rates of carbon sequestration with projections for the future price of carbon, over a 50-year period. The projected annual value of carbon sequestration services are then discounted using the social discount rate published by HM Treasury's The Green Book. A breakdown of the model is given in Annex 5.

As part of the annual Greenhouse Gas Inventory reporting cycle, the Centre for Ecology and Hydrology produce net carbon flow projections to 2050 for the LULUCF sector under various emission scenarios. Our methodology uses the 'business as usual' scenario. The projection basis employed is regularly revised to incorporate changes in the methodology used to produce the annual Greenhouse Gas Inventory.

The non-traded carbon price schedule, produced by DECC, projects the future price of carbon out to the year 2100. The values are in constant prices and can be interpreted as simulated exchange values in that they are based on the marginal abatement cost of meeting UK policy targets (demand) and abatement costs (supply).

Fledgling ecosystem carbon markets e.g. using the UK Woodland Carbon Code are not suitable because they are sensitive to the wider institutional framework around carbon markets; they also include other non-carbon values. The price of carbon in existing markets should become more representative of the value of carbon sequestration in the future as the institutional setup of markets becomes more established.