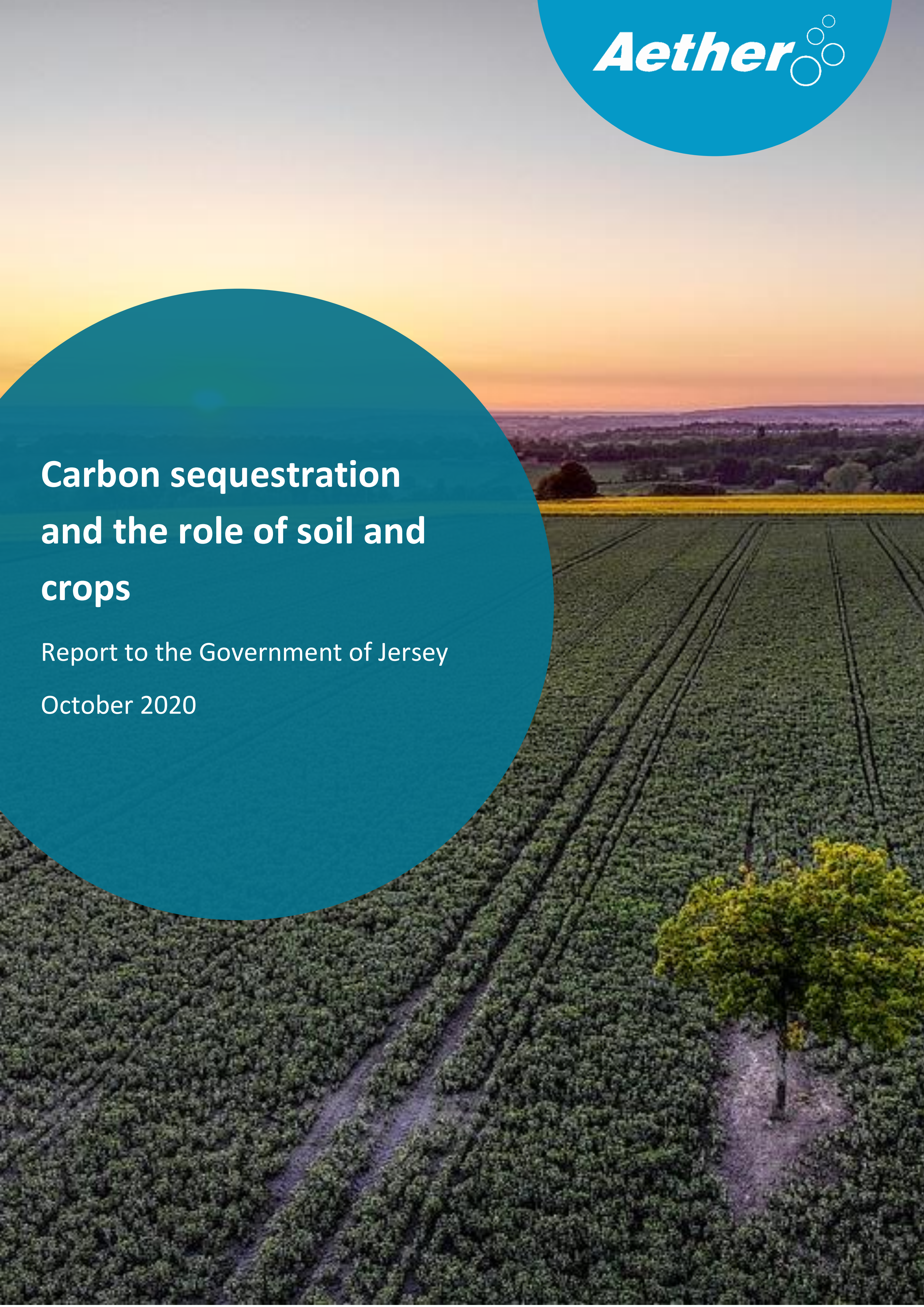

Carbon sequestration and the role of soil and crops

Report to the Government of Jersey

October 2020

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Executive summary

In 2019, the States Assembly declared a climate emergency and in doing so has recognised that climate change could have profound effects in Jersey. In response to the climate emergency declaration, the Minister for the Environment will present plans on how Jersey could aim to be carbon neutral by 2030.

Land sector can contribute towards Jersey's aim, by not only reducing emissions but also by sequestering carbon from the atmosphere. Therefore, the Government of Jersey (GoJ) have requested this report for better understanding the role of carbon storage and management in the context of its greenhouse gas (GHG) emissions inventory.

Carbon sequestration can be defined as the act of capturing CO_2 from the atmosphere, storing it, and preventing it from being re-released. This typically includes a range of man-made and natural processes that capture CO_2 as part of either industrial or agricultural/ land-use activities.

In GHG inventories, following the 2006 IPCC Guidelines, carbon sequestration refers to carbon removals resulting from increase in carbon stock change in different pools (living biomass, dead organic matter, and soil organic carbon). These removals are reported under the LULUCF sector (Land use, Land use change and Forestry). The UK NAEI represents an emissions inventory with a very complete LULUCF sector, however the lack of activity data results in some categories not being estimated for Jersey (such as any new land converted to forest) or estimated using a relatively simple “Tier 1” approach (such as soil organic carbon in grassland converted to cropland).

The case studies in this report show that there is likely to be scope to increase carbon sequestration in croplands by a change in soil management practices and crop types. The increase of carbon inputs by the use of cover crops, artificial soil covers or crop residues, or through external sources such as compost or manure would lead to the major sequestration in soils (currently estimated to be +44% in the first 20 years based on 2006 IPCC Guidelines Tier 1 approach).

Regarding crop replacement, the afforestation of available croplands and the sustainable production of harvested wood products offers an opportunity for carbon sequestration. However, the amount of carbon sequestered relies on the available areas of croplands that can be converted to woodlands. Due to Jersey’s limited land area this would be relatively small, and issues beyond carbon sequestration would need to be considered before going ahead with a programme of extensive afforestation. The replacement of annual crops by perennial crops would result in limited carbon sequestration over the first 20 years (based on the 2019 Refinement to the 2006 IPCC Guidelines). Finally, the potential of hemp plantations and harvested products for carbon sequestration is still uncertain, and requires more Jersey-specific research before it can be accurately represented in the GHG emissions inventory.

To achieve more complete and accurate carbon sequestration, or rather carbon stock change, data would need to be collected on land use and management changes in future years. This would support calculations for Jersey that used either Tier 1 IPCC default values, UK NAEI parameters, or newly developed Jersey specific parameters (such as soil organic carbon values or biomass growth rates).

Contents

Glossary

ALL	Agricultural Land Law (Jersey)
C	Carbon
CO_2	Carbon dioxide
DOM	Dead organic carbon
GHG	Greenhouse gas
GIS	Geographic Information System
GoJ	Government of Jersey
ha	hectares
HSP	Healthy Soils Program (State of California)
HWP	Harvest wood products
IPCC	Inter-governmental Panel on Climate Change
LB	Living biomass
LULUCF	Land use, land use change and forestry
N_2O	Nitrous oxide
NAEI	National Atmospheric Emissions Inventory
PCN	Potato Cyst Nematode
SOC	Soil organic carbon
tC	Tonnes of carbon
UNFCCC	United Nations Framework Convention on Climate Change

1 Project background

The Government of Jersey (GoJ), have requested this report on the calculation methodologies, scale and potential of carbon sequestration in Jersey. This report will support Jersey in better understanding the role of carbon storage and management in the context of its greenhouse gas (GHG) emissions inventory. This report will also improve the GoJ's awareness of opportunities to mitigate GHG emissions through land management practices in croplands and forestlands. This report will answer the following questions:

1. How is carbon sequestration due to land use and land use changes estimated and reported in a GHG emissions inventory that is based on UK GHG inventory methods?
2. What role does soil organic carbon have in carbon sequestration? What is the potential for storing carbon in soils in Jersey?
3. How would rural crop diversification and the planting of different crops be estimated and reported in Jersey's GHG emissions inventory? Would these changes be represented in the emissions estimates?

Much of the information in Sections 2, 3, 5 and 6 of this report is taken directly from the international guidance used for quantifying GHG emissions (2006 IPCC Guidelines for National Greenhouse Gas Inventories). More detailed information on the methodologies referenced can be found on the IPCC website (1).

2 Introduction to carbon sequestration

Carbon sequestration is the act of capturing carbon dioxide (CO_2) from the atmosphere, storing it, and preventing it from being re-released. Carbon sequestration describes a range of man-made and natural processes that capture CO_2 as part of either industrial or agricultural and land-use activities.

In the context of GHG inventories, the uptake and storage of CO_2 is covered under the land-use, land-use change and forestry (LULUCF) sector. 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 (see Figure 1 for an illustration of GHG emission sources/removals and processes in the Agriculture and LULUCF sectors).

A **carbon pool** or reservoir is a system which has the capacity to accumulate or release carbon. Living biomass, dead organic matter and soils are carbon pools. The absolute quantity of carbon held in a carbon pool at a specified time is called **carbon stock**.

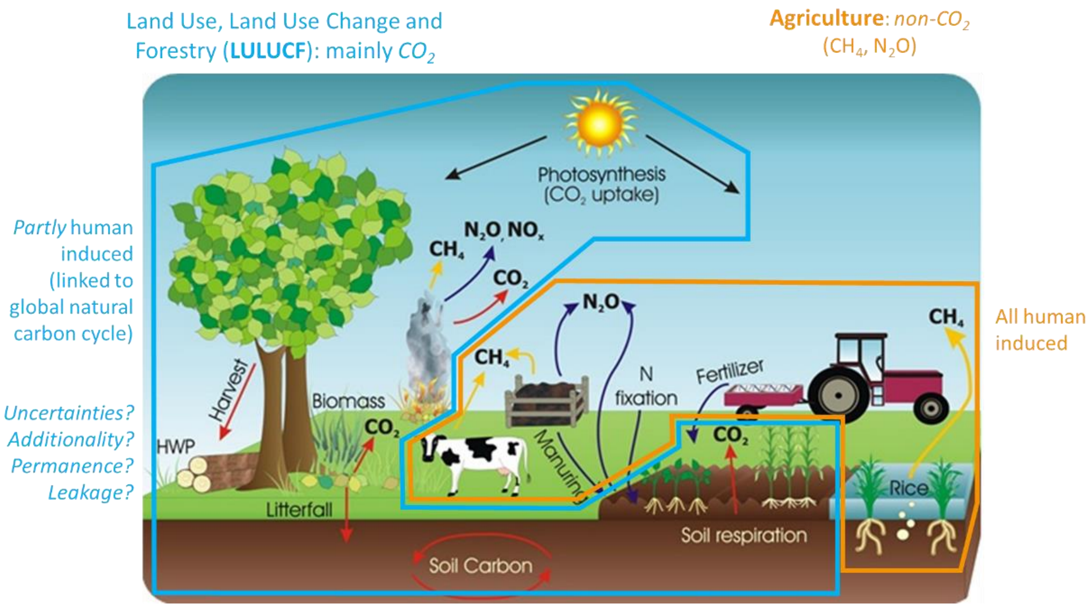

Figure 1. Sources and sinks of GHG emissions in agriculture, forests, and other land use systems. Source: IPCC 2006, Volume 4, Chapter 1 (2)

Increases in total carbon stocks over time represents a net removal of CO_2 from the atmosphere and decreases in total carbon stocks represents a net emission of CO_2.

Reservoirs that retain carbon and keep it from entering Earth's atmosphere are known as carbon **sinks**. For example, forest regrowth is a form of carbon sequestration, with the forests themselves serving as carbon sinks; while the loss of carbon in soil, for example converting grassland to settlement, is a **source**, i.e. a process that releases GHG emissions into the atmosphere.

It is important to note that carbon sequestered in carbon pools could be released again to the atmosphere through changes in land use or changes in management practices. For example, carbon could be temporarily released by a forest fire and re-captured by re-growth. Alternatively, carbon can be permanently released from a pool through the conversion of a forest to a settlement.

There are two distinct pathways for carbon emissions and removals: i) land use changes (e.g. cropland converted to grassland) and ii) management practices in an area with no change in main land use, i.e. areas that have not undergone any land use conversion for a period of at least 20 years as a default period[1] (e.g. cropland remaining cropland).

The amount of carbon stored in and emitted or removed from cropland depends on crop type, management practices, and soil and climate variables. Annual crops (cereals, vegetables) are harvested each year, so there is no long-term storage of carbon in **biomass**. However, perennial woody vegetation in orchards, vineyards, and agroforestry systems can store significant carbon in long-lived biomass, the amount depending on species type and cultivar, density, growth rates, and harvesting and pruning practices.

In general, croplands will have little or no **dead wood**, crop residues or **litter**, except for agroforestry. Agroforestry systems are not present in Jersey.

Carbon stocks in soils can be significant and changes in stocks can occur in conjunction with soil properties and management practices, including crop type and rotation, tillage, drainage, residue management (can include burning residues, using them for animal feed or fuel or leaving in situ) and adding organic matter to the soil (such as manure, sewage sludge or compost). Figure 2 illustrates a conceptual model of carbon stocks, pools and fluxes.

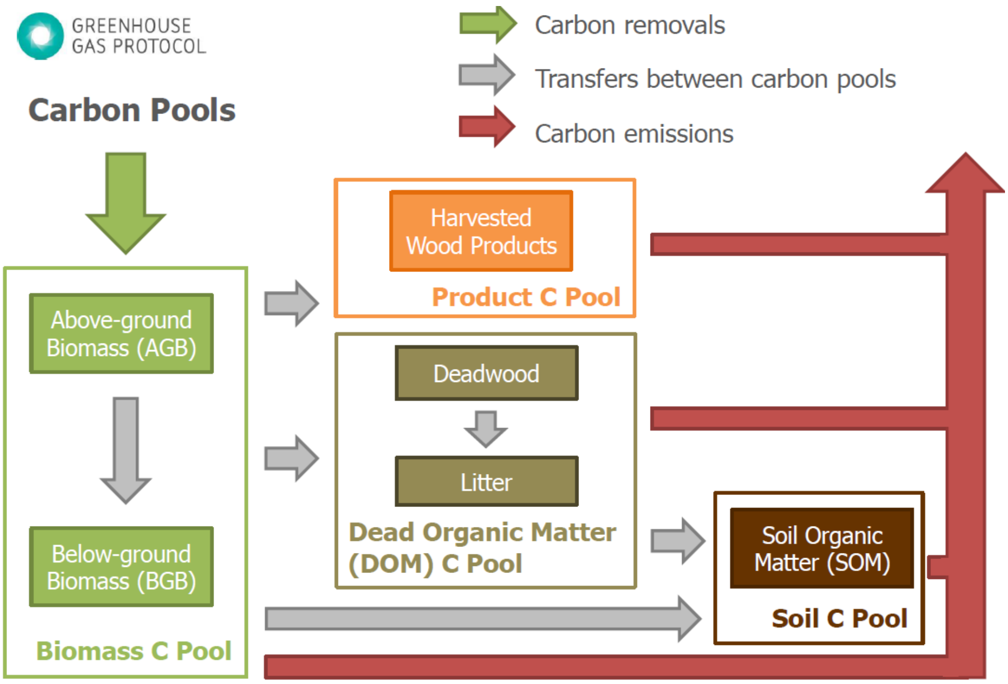

Figure 2. Generalized carbon cycle of terrestrial Agriculture and LULUCF ecosystems showing the flows of carbon into and out of the system as well as between the six carbon pools (including Harvested Wood Products) and within the system. Adapted from IPCC 2006, Volume 4, Chapter 2 (3) for the GHG Protocol Land use technical working group presentations.

[1] Land remains in a conversion category after a change in land use for 20 years (the time period assumed for carbon stocks to come to equilibrium for the purposes of calculating default coefficients included in the international guidance. Other periods may be used at higher Tiers depending on national circumstances). IPCC 2006, Volume 4, Chapter 2.

3 Estimating and reporting carbon sequestration in GHG emission inventories

This section provides an overview of the approach for estimating carbon sequestration, while **Section 5, Section 6 and Section 7** describe the methodologies in detail.

The 2006 IPCC Guidelines provide a three-tiered approach. Using higher Tier methodologies improves the accuracy of the inventory and reduces uncertainty, but the complexity and resources required for conducting inventories also increases for higher Tier methodologies.

- **Tier 1** methods are designed to be the simplest to use. Equations and default parameter values (e.g., emission and stock change factors) are provided. Country-specific activity data are needed.
- **Tier 2** methods use the same methodological approach as Tier 1 but applies stock change factors that are based on country- or region-specific data. Country-defined emission factors are more appropriate for the climatic regions and land-use systems in that country.
- At **Tier 3**, higher order methods are used, including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at sub-national level. Such systems may include comprehensive field sampling repeated at regular time intervals and/or GIS-based systems of age, class/production data, soils data, and land-use and management activity data, integrating several types of monitoring. The location of land-use change can usually be tracked over time, at least statistically. Models should undergo quality checks, audits, and validations and be thoroughly documented.

In addition, the methodology considers three carbon pools: living biomass (LB, both above and below ground), dead organic matter (including dead wood and litter), and soil organic carbon (in mineral and organic soils). Under Tier 1, changes in carbon stocks within each pool are not calculated for areas that remain in a land-use category, except for forestlands.

There are two main methods used for quantifying GHG emission estimates in the LULUCF sector as presented in the 2006 IPCC Guidelines:

- The **Gain-Loss Method** estimates the net balance based on the separate estimation of gains and losses of carbon in a pool for each individual reported year (i.e. biomass growth in a year and biomass harvested in the same year). The gain-loss method for dead organic matter and soil organic carbon pools requires models that simulate dead organic matter and soil organic carbon dynamics.
- The **Stock-Difference Method** based on Carbon stocks in relevant pools measured or estimated at two points in time to assess Carbon stock changes.

The Gain-Loss Method can smooth out inter-annual variability to a greater extent than the stock-difference method, since measures of Carbon stocks are not normally annual (for example measures for a National Forest Inventory can be done every 5 or 10 years). Whilst both methods are valid, this is the advantage of using the Gain-Loss Method if the data is available.

4 Land use, land use change and forestry estimates in Jersey GHG inventory

Jersey's GHG emissions have been steadily decreasing since the end of the 20th Century (Figure 3. Jersey's GHG inventory timeseries broken down by sector). LULUCF sector emissions, which capture the impact of GHG emissions from carbon sequestration and crop management, have not contributed significantly to these emissions. In Jersey's 2018 GHG inventory, LULUCF emissions amounted to a net decrease in tonnes of carbon dioxide equivalent (CO_2eq), representing approximately -0.2% of Jersey's annual GHG emissions.

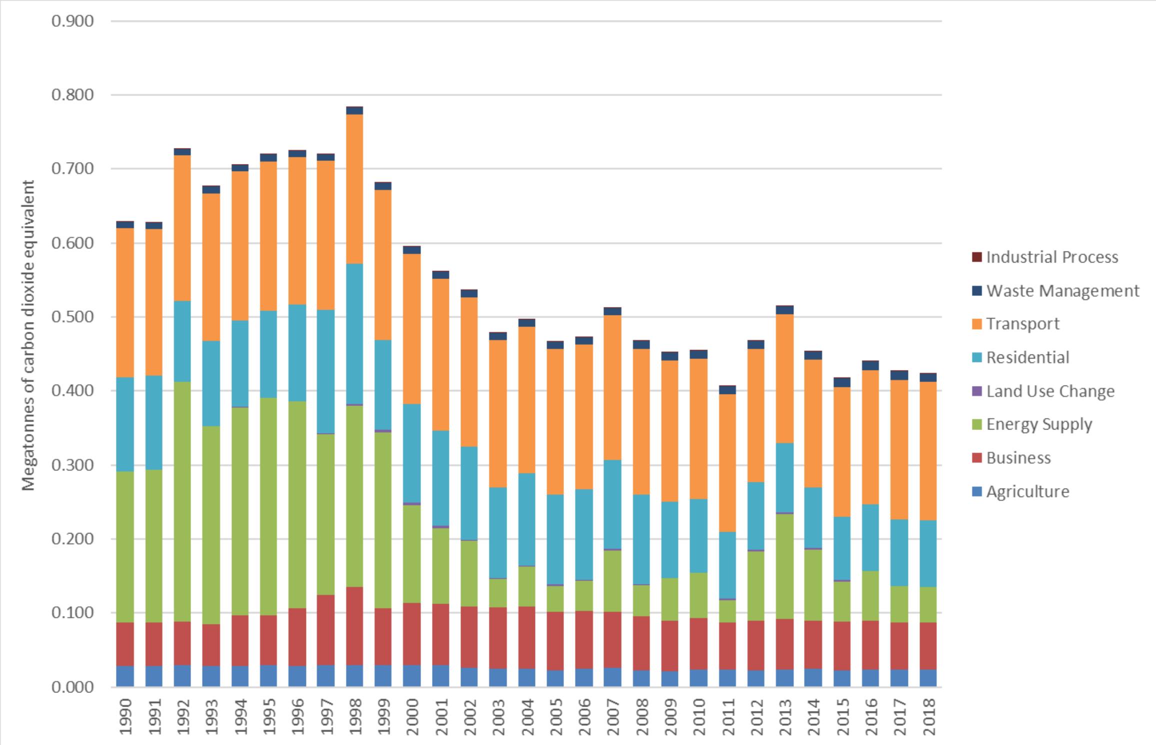

Figure 3. Jersey's GHG inventory timeseries broken down by sector (4)

LULUCF estimates include CO_2 emissions and removals and N_2O emissions due to land use change (Table 1). The decreasing emissions, and increasing sinks, is primarily a result of increasing amount of cropland converted to grassland (Figure 4). It should be noted that all carbon pools in 'forestland remaining forestland' are considered in equilibrium and that the conversion of other lands to forestlands is not currently accounted for in the inventory based on the assumption that there is no large scale afforestation ongoing (see Section 07 for more information on forestland accounting in the GHG inventory).

Table 1. Jersey's land use areas 1990-2018

Land area (kha)	1990	1995	2000	2005	2010	2015	2016	2017	2018
Cropland	6.44	6.61	6.15	5.21	5.43	4.94	4.90	4.90	4.90
Grassland	1.96	1.79	2.03	2.59	2.19	2.78	2.80	2.80	2.80
Settlements	2.65	2.65	2.88	3.24	3.45	3.42	3.44	3.44	3.44
Wetlands	0.05	0.05	0.05	0.06	0.07	0.08	0.08	0.08	0.08
Forest land	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
Other land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

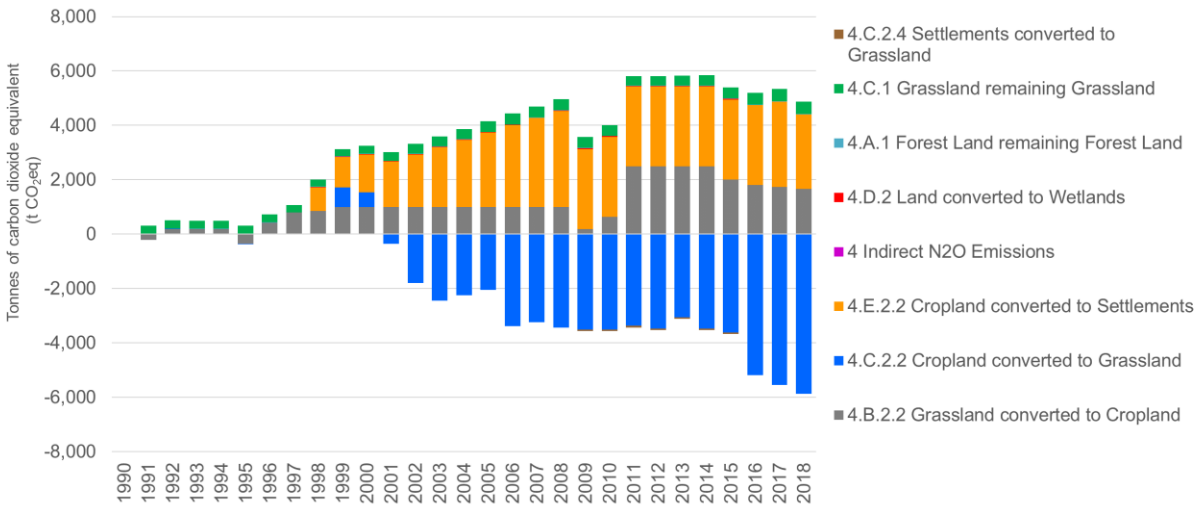

Figure 4. Jersey's GHG emissions and sequestration from LULUCF. Source: UK NAEI 1990-2018

The UK NAEI follows IPCC 2006 methodologies and uses higher tiers approaches (Tier 2 or Tier 3) when country specific data and models are available.

For Jersey, estimates of all emissions/removals are done at a Tier 1 level. This is because the detailed data required for Tier 2 or 3 methodologies are not available. UK stock change factors for biomass are applied to Jersey as a close geographical proxy. The stock-difference method is applied for all estimates. Currently, carbon stock in forestlands in Jersey is considered in equilibrium.

5 Role of soil organic carbon in carbon sequestration and GHG inventories in croplands and forestlands

5.1 Definition of soil organic carbon

Soil organic matter includes organic carbon in mineral soils to a specified depth. Live and dead fine roots and dead organic matter within the soil, that are less than the minimum diameter limit (suggested 2 mm) for roots and dead organic matter, are included with soil organic matter where they cannot be distinguished from it empirically.

Overall, the influence of land use and management on soil organic carbon is dramatically different in a mineral soil compared to an organic soil. Organic (e.g. peat and muck) soils have a minimum of 12 to 20% organic matter by mass and develop under poorly drained conditions of wetlands. Under IPCC guidelines, mineral soils, which include all other types of soil, have relatively low amounts of organic matter, occurring under moderate to well drained conditions, and predominate in most ecosystems except wetlands. This report focuses on mineral soils since in the UK NAEI it is considered that no organic soils are cultivated in Jersey.

Soil organic carbon stocks are influenced by land-use and management activities that affect litter input rates and soil organic matter loss rates. Although the dominant processes governing the balance of soil organic carbon stocks are carbon inputs from plant residues and carbon emissions from decomposition, losses as particulate or dissolved carbon can be significant in some ecosystems. Inputs are primarily controlled by decisions impacting net primary production and/or the retention of dead organic matter, such as how much harvested biomass is removed as products and how much is left as residues. Outputs are mostly influenced by management decisions that affect microbial and physical decomposition of soil organic matter, such as tillage intensity. Depending on interactions with previous land use, climate and soil properties, changes in management practices may induce increases or decreases in soil carbon stocks.

Generally, management-induced carbon stock changes are manifested over a period of several years to a few decades, until soil carbon stocks approach a new equilibrium. In addition to the influence of human activities, climate variability and other environmental factors affect soil carbon dynamics (as well as biomass and dead organic matter).

Land use change and management activity can also influence soil organic carbon storage by changing erosion rates and subsequent loss of carbon from a site; however, the net effect of changing soil erosion through land management is highly uncertain.

The default method to estimate carbon stock changes in mineral soils is based on changes in soil carbon stocks over a finite period of time. The change is calculated relative to a reference condition. For default reference carbon stocks, the reference condition is assumed to be native vegetation that is not degraded or improved. For any changes to the land use that mean a conversion to a different land use type, a change factor will be applied to the carbon stocks of the new land use system. The following assumptions are made in doing this calculation:

- Over time, soil organic carbon reaches a spatially averaged, stable value specific to the soil, climate, land use and management practices; and
- Soil organic carbon stock changes during the transition to a new equilibrium soil organic carbon occurs in a linear fashion.

5.2 Estimates of soil organic carbon in croplands

In the case of cropland remaining cropland, i.e. areas that have not undergone any land use conversion for a period of at least 20 years as a default period:

The 2006 IPCC Guidelines presents a method to estimate carbon stock change in soil organic carbon due to changes in management practices. Cropland management classes must be stratified according to climate regions and major soil types, which can either be based on default or country-specific classifications. Management practices are defined by three factors: land use, input and management (see Annex I for further information):

- **Land use** refers to type of crop, there are four possible types: *Long-term cultivated, Paddy rice*, *Perennial / Tree crop and Set aside (over 20 years).*
- **Input** refers to residues and fertiliser management and are defined as either *low*, *medium* or *high* input.
- **Management** refers to tillage intensity and can be *full tillage*, *reduced tillage* or *no-till* (5)

The **UK NAEI** uses reviewed UK relevant literature on the effects of cropland management practices on soil carbon stocks. Increases in inputs of fertiliser, manure and crop residues were found to increase soil carbon stocks of tillage land, but changes in the tillage regime from conventional tillage to reduced or zero tillage were found to have no significant effect in a UK context. Tillage crops are divided into Medium and Low residue groups based on the data on total crop biomass. Where land receives inputs of fertiliser or manure the inputs moved up a class (e.g. cropland producing a Low residue crop which receives manure is considered to receive Medium inputs, while land producing a Medium residue crop which received manure inputs is considered to receive High inputs). If crop residues are removed from land the input level drops (NAEI 2019).

The GHG estimates for **Jersey** assume no carbon stock change in soil in cropland remaining cropland because management practices are generally kept stable between years. This data has also not been available for previous inventory compilation cycles but could be made available if requested (6). Since 2019, crop type by land parcel data have been collected, these could help solve a possible double counting of crops areas due to the rotation system (potatoes, vegetables and cereals, grass).

In the case of new croplands, aged less than 20 years that were Grasslands previously:

Carbon stock in cropland and grassland are estimated based on stock references and factors that consider land use, input and management (described above).

In the **UK NAEI,** the carbon stocks for each land use category are calculated as averages for Scotland, England, Northern Ireland, and Wales using a database of soil carbon density for the UK, and Tier 2 carbon stock change values are derived.

In the case of **Jersey**, Tier 1 approach and default values for soil organic carbon and management factors are used. Grassland converted to Cropland is considered as natural grassland to annual cropland, and the new carbon equilibrium in the soil is reached after 20 years. The climate zone for Jersey's inventory is assumed cold temperate, moist and all cropland and grassland soils are considered soils with high activity clay[2]. This means a loss of 0.95 tC/ha year in the conversion from grassland to cropland, for 20 years after the conversion. Table 2 below outlines the management systems characteristics for cropland and grassland in Jersey. Figure 5 illustrates how different land management practices impact on biomass and soil carbon stocks.

[2] Other types of soils are: HAC, LAC, Sandy, Spodic, Volcanic or Wetland (see 2006 IPCC vil 4 chapter 2, table 2.3 Default reference (under native vegetation) soil organic carbon stocks for mineral soils (tonnes C ha-1 in 0-30 cm depth)).

Table 2. Assumptions for estimating carbon stock change in soil organic carbon in the conversion Grassland to Cropland in Jersey.

Management systems characteristics	Cropland	Grassland
Land use	Long term cultivated, represents area that has been continuously managed for over 20 years, to predominantly annual crops. Input and tillage factors are also applied to estimate carbon stock changes.	Permanent grassland
Input	Medium, annual cropping with cereals where all crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g., manure) is added. Also requires mineral fertilization or N-fixing crop in rotation.	Medium, improved grassland where no additional management inputs have been used.
Management	Full tillage, Substantial soil disturbance with full inversion and/or frequent (within year) tillage operations. At planting time, little (e.g., <30%) of the surface is covered by residues.	Nominally managed (non-degraded). Represents non-degraded and sustainably managed grassland, but without significant management improvements.

Currently, carbon stock change in croplands soils is only reported in the Jersey GHG inventory when there is a change in land use, i.e. Grassland to Croplands. It is assumed that all croplands are annual crops, with medium level of residues or fertiliser input and under full tillage. The conversion from Grassland to Cropland produces loss of carbon in soils for 20 years.

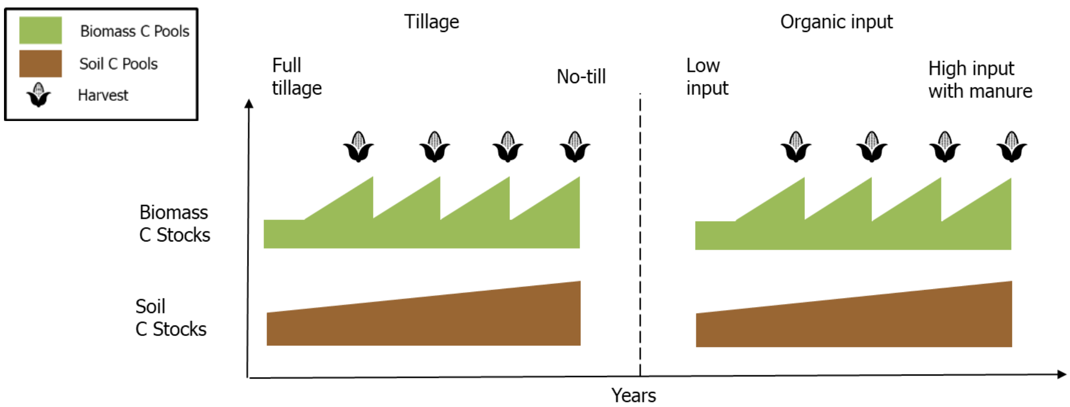

Figure 5. Land management practices and carbon stocks. Source: presentation of the Land use technical working of the GHG Protocol.

5.3 Estimates of soil organic carbon in forestlands

In the case of forestland remaining forestland , i.e. areas that have not undergone any land use conversion for a period of at least 20 years as a default period, the **2006 IPCC Guidelines** Tier 1 method assumes that forest soil carbon stocks do not change with management, due to incomplete scientific basis and resulting uncertainty.

In the case of new forestland, for example due to afforestation, and that are younger than 20 years, following the **2006 IPCC Guidelines** the initial carbon stock in the pre-conversion land use (e.g. cropland) and the carbon stock in the new forest are estimated based on stock references and factors that consider land use, input and management. Annual rates of stock changes are calculated as the difference in stocks (over time) divided by the time dependence of the stock change factors (default is 20 years).

In a Tier 2 approach, stock change factors are derived based on a country-specific classification scheme for management, forest types, and natural disturbance regimes. Tier 3 approaches will require considerable knowledge and data allowing for the development of an accurate and comprehensive domestic estimation methodology, including evaluation of model results and implementation of a domestic monitoring scheme and/or modelling tool.

The **UK NAEI** uses a Tier 3 carbon accounting model, CARBINE, for forestland remaining forestland (forest management) and for land converted to forestland (afforestation). Overall carbon uptake is calculated as the net change in the pools of carbon in standing trees, dead organic matter, soil and products from harvested material, for conifer and broadleaf forests (7).

For **Jersey** it is currently assumed in the inventory that all carbon stock pools in forestlands that remains forestlands are in equilibrium. This is based on the assumption that all existing forestlands have reached maturity and no conversions from other land uses to forestlands occur on the island (see Section 7 for the IPCC definition of forestland). Therefore, with the current accounting methods no emissions or removals are reported from forestland areas.

Figure 6 illustrates the impact of forest management practices on biomass and soil carbon stocks.

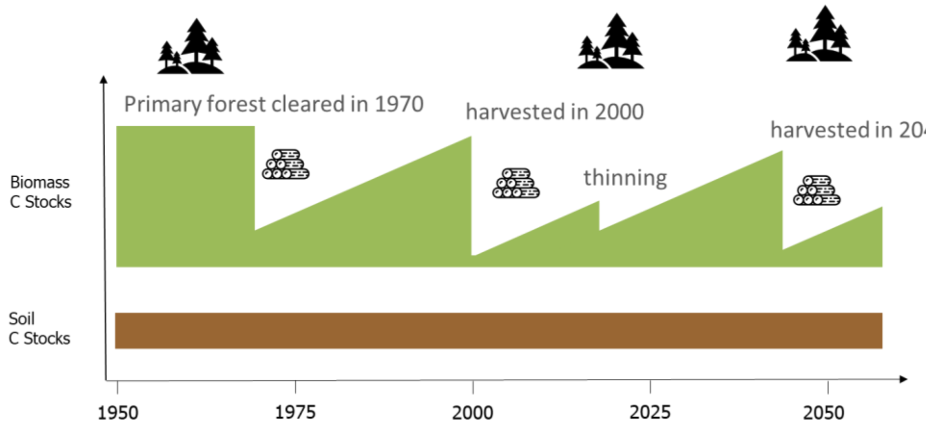

Figure 6. Forestland management and carbon stocks. Source: presentation of the Land use technical working of the GHG Protocol.

5.4 Data requirements for the estimate of carbon sequestration in soils

For the estimate of soil carbon stock changes, information on soil organic carbon in different land-uses and management practices systems would be needed. Data requirements depend on the Tier level approach to apply.

Table 3. Data requirements and availability for estimating carbon sequestration in soils

Tier level	Data required
Tier 1	In the case of land with no change of use or management practices, the assumption is that soil organic carbon is in equilibrium. Therefore, no data is needed but the stable state of land use and practices should be justified. For land with use or management practices changes, information on soil type, land use, inputs and management for different crops systems. This would allow calculation of carbon stock change based on IPCC default values.
Tier 2	Country-specific information is incorporated to specify better the stock change factors, reference carbon stocks, climate regions, soil types, and/or the land management classification system. This would allow to estimate country-specific carbon stock change factors.
Tier 3	Similar or more detailed data on the combinations of climate, soil, topographic and management data are needed, relative to the Tiers 1 and 2 methods, but the exact requirements will depend on the model or measurement design. Constant stock change rate factors per se are less likely to be estimated in favour of variable rates that more accurately capture land-use and management effects.

6 Estimates of planting of different crops

Crop diversification can be defined as the practise of cultivating more than one variety of crop belonging to the same or different species in a given area in the form of rotations and or intercropping. This is different to the planting of different crops, which refers to the replacement of current crops with different crops, and maintaining these new crops for long periods, e.g. the replacement of annual crops with perennial crops.

In Jersey's Rural Economy Strategy 2017-2021 (8), crop diversification is discussed in the context of moving away from producing traditionally farmed products in Jersey such as potatoes, to producing higher value goods and diversifying into niche markets. This is more akin to crop replacement.

Crop diversification generally has little effect on **soil carbon** but may result in a slight gain. Crop diversification and rotation delivers efficient nutrient cycling and soil quality improvement. In addition, including a rotation with leguminous crops reduces nitrogen fertiliser needs, field operations and N_2O emissions (9).

The impact of crop diversification or replacing current crops will not have a significant or long term impact in the GHG emissions inventory accounting of emission estimates, as the carbon stock changes in the different pools will not be captured, unless there is a conversion between land uses, e.g. cropland to forestland. The impact of crop replacements is determined by the change in **biomass and soil organic carbon**. In the case of biomass, the carbon stock change would be only significant if annual crops are substituted by perennial crops. A perennial crop, such as trees, is able to sequester carbon for a finite period of time before reaching maturity, until it is removed through harvest or reach a steady state where there is no net accumulation of carbon in biomass. To 'lock in' these gains in sequestered carbon, the harvested products (e.g. harvested wood products) would need to be used for building materials or as a fuel replacement for fossil fuels.

For a transition to perennial crops, the data required to quantify the carbon sequestration benefits would include the carbon in biomass at the maturity stage and the maturity cycle.

The replacement of an annual crop by another annual crop with higher biomass will only have an impact in the year of conversion, since annual crops (cereals, vegetables) are harvested each year, and so carbon stock reach equilibrium after the first year. Again however, additional benefits from sequestered carbon could be obtained through a use of the harvested products that releases the stored carbon much more slowly (e.g. as building materials) or replaces a more carbon intensive activity (e.g. biofuels).

For annual crops, to capture any benefit from carbon sequestered in the crop product use, the data required includes biomass harvested, biomass used in the products and the time carbon is held in products, that vary depending on the product and its uses.

The production and use of biofuels does not technically contribute to carbon sequestration as the carbon stored in the biomass will be released back to the atmosphere through combustion in a relatively short period of time. However, it can be considered a climate change mitigation action as it reduces the combustion of traditional fossil fuels.

The opportunities presented by crop replacement (annual and perennial) are discussed in more detail in the case studies (Section 8).

6.1 Estimates of biomass and dead organic carbon in croplands

For an explanation on soil organic carbon estimates refer to Section 5 Role of soil organic carbon in carbon sequestration and GHG inventories.

Cropland remaining Cropland

In the case of cropland remaining cropland, i.e. areas that have not undergone any land use conversion for a period of at least 20 years as a default period:

Biomass: Following the 2006 IPCC Guidelines Tier 1 approach, the change in biomass is only estimated for perennial woody crops. For annual crops, the increase in biomass stocks in a single year is assumed equal to the biomass losses from harvest and mortality in that same year - thus there is no net accumulation of biomass carbon stocks. Changes in carbon in cropland biomass may be estimated from: annual rates of biomass gain and loss or carbon stocks at two points in time. Default Tier 1 assumptions are: all carbon in perennial woody biomass removed (e.g., biomass cleared and replanted with a different crop) is emitted in the year of removal; and perennial woody crops accumulate carbon for an amount of time equal to a nominal harvest/maturity cycle. The 2006 IPCC Guidelines only provides one default value for woody biomass and harvest cycle in cropping systems containing perennial species in temperate climate.

Higher tiers develop estimates for the major woody crop types by climate zones, using country-specific carbon accumulation rates and stock losses where possible or country-specific estimates of carbon stocks at two points in time.

In the **UK NAEI** carbon stock changes in biomass due to cropland management activities are estimated using literature-derived Tier 2 stock change factors and activity data from agricultural surveys. Carbon stock changes in biomass can arise from changes between annual crops, orchards, and shrubby perennial crops. Biomass carbon stock change was assumed to occur in the year in which the change in crop type was reported. In the case of orchards, 10 tC/ha is the equilibrium carbon assumed, not differentiating between different tree types within orchards. This is a Tier 2 country specific value derived from literature.

Based on 2019 IPPC defaults[3], and just considering living biomass, the impact on carbon sequestered during the conversion from annual crops to orchards, for example, is:

- 5 tC/ha is lost in the year of conversion as the annual crop is harvested and not replanted.
- 8.5 tC/ha is gained over 20 years because 0.43 tC/ha are accumulated annually, during the first 20 years.
- Therefore, the first year of conversion: 4.57 tC/ha are lost. The following 19 years, 0.43 tC/ha are gained. After 20 years, there are no gains or losses of carbon, unless the land is converted to other uses and therefore trees are cut down.

[3] 2019 IPCC Refinement present specific parameters for orchards, while 2006 IPCC defaults did not differentiate between different perennial woody crops.

However, in the case of **Jersey** it is assumed that there is no carbon stock change in biomass in cropland remaining cropland.

Dead organic matter: The 2006 IPCC Guidelines Tier 1 methodology assumes that the dead wood and litter stocks are not present in cropland or are at equilibrium as in agroforestry systems and orchards; while higher Tiers allow for calculation of changes in dead wood and litter carbon due to management practices.

The **UK NAEI, including Jersey**, reports that carbon stock change in dead organic matter in cropland remaining cropland does not occur.

New Cropland

In the case of new croplands, aged less than 20 years that were Grasslands previously:

Biomass: The **UK NAEI, including estimates for Jersey,** follows the 2006 IPCC Guidelines approach where the amount of biomass that is cleared for cropland is estimated by multiplying the area converted in one year by the average carbon stock in biomass in the Grassland prior to conversion. Changes between these equilibrium biomass carbon densities are assumed to happen in a single year. For **Jersey,** the UK stock change factors are applied as a close geographical proxy. Grassland converted to Cropland is considered a conversion from non-shrubby grass to crop, with a carbon stock change value of 2.2 tC/ha, i.e. the conversion produces carbon gains in the year of conversion (there are net removals).

Dead organic matter: The 2006 IPCC Guidelines Tier 1 methodology assumes that the dead wood and litter Carbon stocks in lands converted to Cropland are all lost during the conversion and that there is no accumulation of new dead organic matter in the Cropland after conversion. It also assumes that dead organic matter in Grassland is zero.

> Currently, carbon stock change in biomass due to planting of different crops is not estimated in Jersey´s GHG inventory. Carbon change in biomass could be estimated in changes between annual and perennial crops.

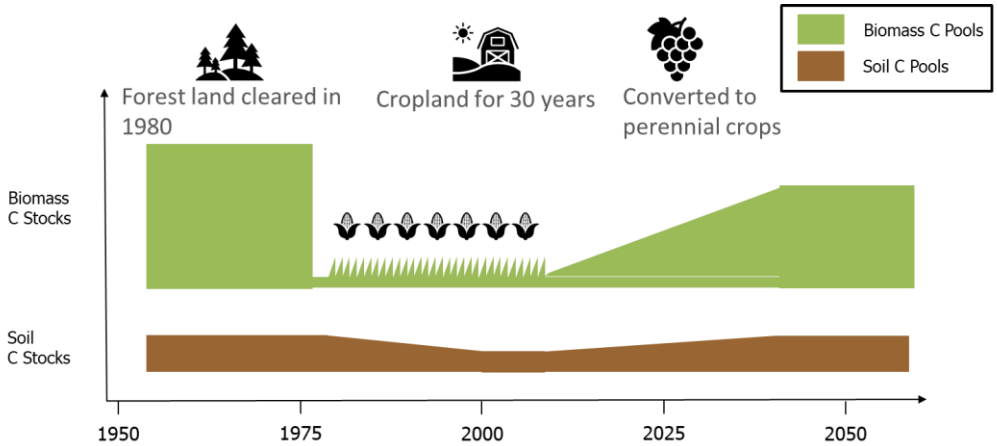

Figure 7. Cropland management and conversion and carbon stocks. Source: presentation of the Land use technical working of the GHG Protocol.

For **Jersey**, no carbon stock change in dead organic matter is reported, following Tier 1 assumptions. Figure 7 illustrates cropland management practices and the impact on biomass and soil carbon stocks.

6.2 Data requirements for the estimate of carbon sequestration in cropland biomass

Values for carbon stocks in living biomass and dead organic matter in different crops will be needed to estimate the impact of the crop change. Different information would be needed depending on the Tier level approach to apply.

Table 4 Data requirements and availability for estimating carbon impact of planting different crops.

Tier level	Data required
Tier 1	Annual area of crops and conversion between different crops. National data on above-ground woody biomass growth rate, and maturity cycle.
Tier 2	Annual area of crops and conversion between different crops. Annual woody biomass growth rate, including below ground biomass, losses from removal, fuel wood and disturbance. Data can be based on national data sources for different cropping and agroforestry systems.
Tier 3	Highly disaggregated factors for biomass accumulation, including below ground biomass, losses from removal, fuel wood and disturbance, are needed, that can include categorisation of species, specific for growth models incorporating management effects.

7 Estimates of carbon in forestlands

According to the definition in the 2006 IPCC Guidelines, forestlands include all land with woody vegetation consistent with these threshold as defined in the national inventory. In the UK NAEI, the thresholds for defining land use areas as forestland are:

- A minimum area of 0.1 hectares;
- A minimum width of 20 metres;
- Tree crown cover of at least 20 per cent, or the potential to achieve it;
- Minimum height of 2 metres, or the potential to achieve it.

Therefore, areas of trees not reaching the above thresholds will not be accounted as forestlands. Any land converted to forestland must meet these criteria to be included in the inventory.

7.1 Forestlands remaining forestlands

Biomass: The 2006 IPCC Guidelines provides two methods: The annual change in carbon stocks in biomass can be estimated using the gain-loss method, where the annual increase in carbon stocks due to biomass growth and annual decrease in carbon stocks due to biomass losses are estimated. Data on species and growing stock is needed to be used with default parameters to estimate growth and data on harvest rates or volume and loss of biomass dues to disturbances is needed for the estimates of losses. Tier 2 uses country-specific values for of emission/removal factors.

Stock difference method requires the measured of biomass in two points in time, that is usually based on forest inventory measures.

The biomass gain-loss method is applicable for all Tiers although the stock-difference method is more suited to Tiers 2 and 3. This is because the stock-difference method will provide more reliable estimates for relatively large increases or decreases of biomass or where very accurate forest inventories are carried out.

Dead organic matter: The 2006 IPCC Guidelines Tier 1 method assumes that the dead wood and litter carbon stocks are in equilibrium so that the changes in carbon stock in the dead organic matter pools are assumed to be zero. Countries experiencing significant changes in forest types, disturbance or management regimes in their forests are encouraged to develop domestic data to quantify the impacts from these changes using Tier 2 or 3, applying gain-loss or stock difference method.

7.2 New forestlands

Biomass: Following the 2006 IPCC Guidelines, the gain-loss method is applied. Losses are due to biomass removal for land preparation before trees planting. Gains are the result of biomass growth in the new forestlands (that also needs to consider losses due to harvest or disturbances). Tier 2 uses nationally derived data and more disaggregated activity data and allows for more precise estimates of changes in carbon stocks in biomass.

Dead organic matter: The 2006 IPCC Guidelines Tier 1 assumption is that dead wood and litter pools increase linearly from zero (in the non-forest land-use category) to the default values for the climate region over a period of T years (the current default is 20 years for both litter and dead wood carbon pools). For Tier 2 country-specific dead wood and litter values are used instead of the 2006 IPCC Guidelines[4].

Harvested wood products (HWP): The estimates are based on the inflow and outflow of carbon into/from this pool, on the basis of the change of the carbon in paper, wood panels and sawn wood. Annual harvested biomass used to their production is needed to calculate the inflow into HWP pool (how much carbon is locked in annually). Then default half-life values for these three products can be used to estimate the outflow (carbon released annually from the HWP pool). Following the production approach, as in the UK NAEI, only wood from Jersey´s forest would be accounted for (not imported wood).

The **UK NAEI** CARBINE model includes the estimates of carbon stock changes in all pools of land converted to forestland.

It should be noted that the UK NAEI, submission 2020, indicates that net emissions from forest land in all Overseas Territories and Crown Dependencies will be calculated using the Tier 1 method in the next submission, and that there will be improvements to the land use matrix to ensure consistency in total areas and land use transitions.

[4] Note that default values for dead wood carbon stocks in forests are not available in IPCC 2006.

8 Case studies

8.1 Introduction

The case studies below consider the opportunities for enhanced carbon sequestration in Jersey through the promotion of better soil management practices and the replacement of current crops with alternative vegetation cover. The GoJ requested an investigation into 'crop diversification' as a route to increasing carbon sequestration. In this report, crop diversification is taken to mean the replacement of current crops by other types of crops. These case studies will discuss the concept of crop replacement and the diversification of Jersey's agricultural outputs. In addition, the data that is needed to estimate GHG emissions/removals with a Tier 1 approach are presented. It should be noted that total emissions from LULUCF and agriculture represent approximately 0.2% and 5% of Jersey's total GHG emissions in 2018 respectively. Therefore, there is relatively limited scope for impacting on Jersey's total GHG emissions through the activities discussed below. However, these activities contribute towards Jersey's aim to be carbon neutral by 2030 and they also have other co-benefits that are important to consider.

8.2 Scope

The first consideration for evaluating soil management and crop replacement practices as an opportunity for carbon sequestration is the land area available for implementing any changes in land use or land management. The primary land area considered for these activities is the land already in use for traditional cultivation purposes (potatoes and dairy). The table below outlines the approximate breakdown of agricultural land use in Jersey between 2007 and 2017. The total area farmed has decreased by 5% between 2007 and 2017, although the area of both fruit and potato farming increased over the same period. However, unpublished data suggests that the area used for potato farming has decreased in the last three years (2017 – 2020) (10). The size of the cattle herd has decreased by approximately 34% between 2007 and 2017. If these trends continue, there may be scope for planting additional crop variations on unused land, as well as for replacing existing crops.

Table 5 Agricultural statistics in Jersey, 2007 - 2017 (11)

Land use or crop	2007	2017	% change
Total area farmed (ha)	6,320	5,994	-5%
Potato crops (ha)	2,440	2,909	19%
Fruit (ha)	16.2	46.6	188%
Total cattle (number of animals)	7,315	4,842	-34%

It is worth noting that there are also areas of cropland of low productivity that could be included in the scope of these case studies. These areas are currently less productive in terms of crop productivity than they could be if soil management practices were adopted and the appropriate crops were planted. These areas include:

- Marginal unenclosed coastline areas, historically used for grazing
- Woodland areas in the valleyed interior of the island
- Wet meadows in the valleyed interior of the island

However, it is important to note that any proposed changes to these areas should consider both the existing carbon sequestration potential (of unmanaged woodland areas, for example) and of the significance for biodiversity and ecosystem services that these areas represent.

Additionally, there is a significant portion of land not currently regulated under Jersey's Agricultural Land Law of 1974 (ALL). This is land that has not been traded since 1974 and as such does not fall under the remit and regulation of the ALL. The implication of this is that there are large areas of land that are not commercially farmed or mandated for specific activities. This presents an opportunity, through policy reform, to mandate land use change, or the adoption of specific agricultural practices, that sequester carbon at a higher rate on a significant portion of land previously unmanaged. The area of land managed under greenhouses has not been considered in this report.

Case study 1: Exploring soil management practices in cropland

An increasingly important and relevant discussion surrounding carbon sequestration practises and reducing the impact of the agriculture sector on GHG emissions focusses on soil management practices, sometimes called **regenerative agriculture**. The primary purpose of regenerative agriculture is to boost soil health which is reported to have many beneficial impacts including improvement of plant health and crop yields, increase of water retention and infiltration, prevention of soil erosion, improvement of water quality, improvement of biodiversity and habitats and the sequestration of carbon and the reduction in GHG emissions (12).

The importance of carbon storage in soils is increasingly discussed in the context of GHG mitigation strategies for agricultural systems. Policy based solutions have been adopted globally including the "4 per 1000" Initiative[5], an international programme to promote action on soil health and soil carbon, and the State of California's Healthy Soils Program (HSP) and HSP Incentives Program[6] which offers financial incentives to farmers to implement conservation management practices that sequester carbon, reduce atmospheric greenhouse gases (GHGs), and improve soil health. Practices cited by the program as improving soil health and carbon sequestration potential include cover cropping, no-till, reduced-till, mulching, compost application, and conservation plantings. The sections below present a short summary of the research and evidence relevant for considering how best to allocate resources effectively to improve carbon sequestration in Jersey's agricultural sector.

In EU Member States a range of mitigation measures exist to increase the carbon stocks in mineral soils (13). These measures can be categorised in two main groups:

- Restrict the breakdown of organic matter (e.g. zero or reduced tillage)
- Ensure supply of organic matter: on the field (e.g. cover crops, incorporate crop residues) or of external organic matter (e.g. manure, compost and other organic material).

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[5] https://www.4p1000.org/
[6] https://www.cdfa.ca.gov/oefi/healthysoils/

Restrict the breakdown of organic matter: Tillage regime

The tillage or the amount the soil disrupted in the process of planting and harvesting crops can have an impact on the storage and release of GHGs from the soil. No tillage or minimum tillage induces changes in the soil structure and in the location of soil organic matter and crop residues (9). Conventional tillage regimes can weaken the soil structure and reduce the stability of soil aggregates. Reduced tillage or no-tillage can help to maintain soil quality and avoid further soil degradation. The combination of all these modifications has an important impact on carbon and nitrate transformation in soil and leads to a more intact soil structure.

Research shows that reduced tillage regimes can increased soil organic carbon in surface layers of the soil (14). However, knowledge about carbon stored in the deeper layers is particularly important, because these management practices may also actually reduce carbon storage at deeper layers (by reducing the incorporation and decomposition of plant materials and subsequent root growth), leading to no net difference in stored carbon between management practices (15). In summary, the evidence base is inconclusive of the overall net benefits of reduced tillage regimes for carbon storage in soils. This uncertainty in the literature highlights the need for country specific research and the collection of local/regional data.

In addition to the uncertainty surrounding positive benefits of reduced tillage regimes, there is also an issue of whether altering the tillage regime is practical for maintaining agricultural yields. A recent study investigating the impact of reduced tillage on organic potato crops in the Netherlands highlighted that reducing the tillage reduced the potato yield by approximately 13% compared to standard tillage due to lower average tuber size. However, the reduced tillage regime also increased the quality of the crop (in terms of specific gravity, dry matter and starch contents) (16).

However, reduced tillage regimes can provide some positive impacts on biodiversity and ecosystem services including: enhancement of soil drainage and improvement in food supplies for insects, birds and small mammals, due to more availability of crop residues and weed seeds. No or minimum tillage also improves ecosystem services, such as water regulation, carbon storage, soil stability, protection of surface soils from erosion, enhanced water infiltration, increased soil fertility through enhanced nitrogen stocks (in the long term), improved soil, water and air quality, reduced soil erosion and reduced fuel use in tilling machinery. However, a no tillage regime can also lead to an increased need for either pesticides or alternative pest control (e.g. integrated pest control management).

Ensure supply of organic matter

Ensuring soils have a good supply of organic matter is a well documented method of increasing carbon stores in soils. A supply of organic matter is provided either on the field through **cover crops**, **artificial soil covers** or **crop residues**, or through external sources such as the addition of **compost** or **manure**.

The use of manure over inorganic fertilisers has been shown to increase soil organic carbon levels in top soil and there are numerous studies indicating that manure application is the best method for incorporating organic matter into soils and storing carbon (17) (18). However, this relies on a significant source of manure and, therefore, a sufficiently large cattle herd. Nonetheless, input from manure and/or compost is a positive measure that promotes soil health and carbon storage and therefore should be considered as part of the soil management 'menu' of options.

Evidence suggests crop residue management also has a role to play in carbon sequestration strategies. Despite providing a significant carbon input, however, crop residues alone may not be adequate to maintain soil organic carbon levels in soils with a higher clay content such as in Jersey (19).

Cover crops provide temporary or permanent surface cover on agricultural fields. A cover crop is a fast-growing plant grown at the same time or between plantings of a main crop. Alternative cover can be created by using bio-plastic films that are compostable. Most studies have found that cover crops can increase soil organic carbon concentrations in the long term. Cover crops and artificial soil covers can also reduce carbon loss due to soil erosion (20) (21) (22). However, a consideration of carbon and nitrogen dynamics and balance (input vs. output) is needed to better understand the effects on GHG fluxes. Cover crop effects depend on management factors including nitrogen fertilization, tillage system, cover crops species, and irrigation management. Common cover crop species include black oats (winter hardy, sown later than other species and produces large amounts of biomass) and mustard (very fast growing, used as a control for Potato Cyst Nematode in rotation with potato crops).

Furthermore, the use of cover crops can reduce N_2O emissions by extracting nitrogen unused by precedent crops and decreasing nitrate leaching. This contributes to a diversified agricultural system, the co-benefits of which include a range of ecosystem services such as: efficient nutrient cycling and conservation of biodiversity, soil quality improvement, increased water holding capacity in surface soil, control of weeds, diseases, and arthropod pests, pollination service, reduction in erosion and water requirements, reduction of nitrogen and other fossil-fuel-intensive inputs (9).

Scope for implementation in Jersey

Modification in tillage regime has limited scope in Jersey (23) . In the case of Jersey Royal production, there has been an increase of mechanisation as growers shift to nematicide control products that prohibit hand planting. There is a trade-off regarding hand and mechanised planting. On the one hand, according to the Rural Economy Strategy 2017-2021, "hand planting of chitted potato seed is preferable to current automatic methods which damages shoots, delays maturity and reduces yields". However, mechanical planting in contrast produces less soil disturbance than hand planting, because when using automatic planters the field is ploughed, power harrowed and then planted and closed in a final pass whereas with hand planting, the field is ploughed, harrowed, opened with a crawler and closed with a covering frame after planting. As such, purely in terms of soil carbon retention, mechanical planting is preferable. Based on the health warnings linked to current nematicide application, it is unlikely that any change in planting methods is likely.

The choices around automatic vs. hand planting of potato crops are also affected by the increasing cost of labour, staff availability (being dependant on domestic population policy and the impact of Brexit) and retention issues, the minimum wage and the price pressure within the UK market place.

The future trend of manure input is uncertain since it depends on several linked factors: the decrease of cattle numbers might lead to a decrease of manure applied to agricultural soils; however, excretion rates by head can increase as bigger and more productive cattle are bred.

A limited crop residue removal strategy could provide additional benefits for carbon sequestration in Jersey alongside other techniques such as cover crops, or in the short term before activities of a larger undertaking such as crop replacement.

Finally, cover crops and incorporation of crop residues might be a suitable way to increase organic matter input to soils. Cover crops can offer an integrated pest management system alongside more traditional crops as well as enhancing the soil organic carbon and reducing N_2O emissions. This would also address one of the key concerns flagged in the Rural Economy Strategy 2017-2021 document (para 2.156). Evidence indicates that the periodical planting of mustard in rotation with potato crops can offer the benefit of controlling Potato Cyst Nematode whilst also improving carbon stocks. However, when using cover crops it is important to evaluate the impacts that the management needs of the cover crops might have, such as the need for mechanical treatment of mustard plants that increase soil compaction. Local growers have used mustard (including so-called 'hot' mustards) as cover crops and for Potato Cyst Nematode control for many years, and are familiar with the use of other cover crops such as phacelia, Solanum sisymbriifolium, cereals such as barley, and other brassicas such as rape and turnips.

All of these approaches could also be incentivised by following in the footsteps of the State of California's HSP Incentives Program and adopting a similar program. An existing mechanism already exists in Jersey in the Rural Support Scheme (Rural Economy Strategy 2017-2021) which could offer a policy pathway if adapted to promote activities that successfully sequester carbon. More work would be required to define eligible activities and monitoring and evaluation tools, further developing on an existing policy identified in the Rural Economy Strategy – 'GSA22 Soil Nutrient Calculator', the development of an island-wide soil nutrient calculator. Businesses in Jersey have also expressed interest in a locally sourced carbon offsetting scheme (24). However, further work would be needed to determine whether the limited land mass of Jersey means that establishing and managing a locally sourced carbon offsetting scheme is a viable option.

Estimating carbon sequestration due to soil management practices that increase carbon in soils

This section refers to the data required to reflect the impact on GHG emissions from changes to soil management practices in the emissions inventory, and provide an estimation of the scale of the impact. This includes a consideration of switching tillage regimes, increasing carbon inputs (such as growing cover crops and increasing the input of fertilisers, manure, or compost). In that respect, the focus is on 'croplands remaining croplands' in IPCC Guideline terms.

Although the carbon sequestration potential of soil management practices is still uncertain and more studies are needed, the 2006 IPCC Guidance provides a method and the parameters required for estimating soil organic carbon changes due to changes in practices (see Section 5):

Data needed to estimate carbon sequestration due to change in soil management practices in cropland:

- Annual area of land remaining in the same use (cropland).
- Annual information on areas under different management systems (type of crop, tillage regime and organic matter input). To allow selection of Tier 1 parameters.

These data may be collected based on surveys, remote sensing imagery or other data providing not only the total areas for each land management system, but also the specific transitions in land use and management over time on individual parcels of land. For an improved estimate, it is important to track the management systems in the same area over the years, since the return to a less effective soil conservation practice in just one year of the timeseries will cause a loss in soil organic carbon.

Based on Tier 1 default parameters, these changes in management practices would be reflected as carbon sequestration to be reflected in the GHG inventory:

Table 6. Carbon sequestration due to soil management practices.

Original practice	New practice	Total carbon sequestered until equilibrium (tonnes C/ha)*	Total increase in soil organic carbon until equilibrium (%)*
Full tillage	Reduced	7.6	8%
Full tillage	Non tillage	14.25	15%
Medium input	High input (without manure)	10.45**	11%
Medium input	High input (with manure)	41.80**	44%

** Default is 20 years*

*** Note that soil management practices are defined based on average results from a global dataset of experimental results and that the actual amount of input is not considered in the calculations. These increases will be accompanied by an increase in nitrogen input to soils, leading to N_2O emissions, that are estimated based on the corresponding amount of nitrogen input to soils from fertiliser, crop residue, manure, or compost.*

To put the figures in the table above into context, applying 14.25 plus 41.80 tonnes C/ha over 2,909 ha of Jersey's potato growing crop assuming all is converted from full tillage and medium input to no-tillage and high input with manure (not a feasible solution but serves as an example for the top range of possible impact), would equate to an approximate total of 8 kt of carbon sequestered annually for 20 years. Once converted to CO_2eq (multiply by -44/12), this equals an addition sink of approximately -30kt CO_2eq per year for 20 years. This represents roughly 7% of Jersey total GHG emissions from 2018. This is without consideration for the increase in N_2O emissions associated with increased input of organic matter which will offset the additional carbon sequestered by a small amount.

Case study 2: Exploring crop replacement activities

The process of diversifying Jersey's annual crop is in line with broader strategic aims of Jersey's agricultural sector that look to promote the cultivation of high value agricultural products for niche markets as a replacement for traditional potato or dairy farming (Jersey's Rural Economy Strategy 2017-2021). To date, Jersey has seen limited implementation of this strategy (6). Whilst the Rural Economy Strategy references high value pharmaceutical crops, this case study discusses the possible scope for replacing traditional annual crops in Jersey with alternatives that have potential for enhanced carbon storage. This section includes a discussion of the potential impacts on GHG emissions and the data requirements for highlighting these changes in the GHG inventory, and broader considerations for biodiversity.

In considering crop replacements, it is important to understand the processes by which carbon sinks can be increased, as discussed in detail in the report above. Thus, this case study is primarily focussed on the replacement of traditional crops and farming practices (including dairy farming) already in place with crop alternatives that have the potential to sequester additional carbon and provide additional ecosystem and socio-economic benefits. For an annual crop replacement, this means either another annual crop that has a higher biomass and the impact on carbon sequestered is registered in the year of conversion (short term impact), a woody perennial crop that sequester carbon for a finite period of time until reaching maturity (medium/long term impact), new woodlands or the production of harvested products that release stored carbon much more slowly (e.g. as building materials) or replace a carbon intensive activity, for example biofuels (medium/long term impact). Section 6 above provides more details on these aspects.

In terms of carbon sequestration potential, tree planting (not considering orchards) is the most effective solution. This approach benefits from increasing the amount of carbon stored in the woody biomass of the tree and through carbon sequestered in the soil with limited disturbance; dead organic matter and litter can be also significant in forest areas. The impacts on carbon emissions can be magnified further with effective management of the harvested wood products (HWPs). For example, harvesting the timber for building materials would store and lock in the biomass. Through this process of growing forestland, harvesting, and storing carbon in HWPs and re-growing the forestland, carbon sequestration can be maximised on an area of land.

The replacement of annual crops with perennial crops such as fruit trees and vines is another alternative to increase the carbon storage potential of the agricultural sector. Whilst this would represent a smaller carbon storage sink than converting to forestland, it has increased storage potential compared to annual crops.

In both cases, the replacement of annual crops to woody perennial crops and to woodlands would have a positive impact on the soil carbon stock.

A recent development, in part a result of the alternative crops strategy in the Rural Economy Strategy, has seen the promotion of industrial hemp as a potential agricultural product with a Jersey based company, Jersey Hemp, having been awarded the first contract to grow cultivate industrial hemp for three growing seasons in May 2018 (24). Scientific evidence on the carbon sequestration potential of hemp is currently limited. A recent policy briefing document 'The Role of Industrial Hemp in Carbon Farming' published by Hemp Alliance for the Government of Australia (25) suggests that industrial hemp has significant carbon sequestration potential. The data presented in this report suggests that the composition of the crop allows hemp to absorb more atmospheric carbon per kg than other crops. The fast rate of growth for hemp allows two crops to be grown a year which also increases the potential for carbon storage.

The key factor in storing the carbon however is the end use of the product and its application for sustainable building materials, such as 'hempcrete' which are likely to release carbon much more slowly than other crop products (such as foodstuffs).

Studies on the potential of hemp as an effective carbon sequestration practise are scant, particularly in relation to national level GHG accounting. However, initial reports suggest positive outcomes for hemp farming in relation to carbon sequestration and other soil health co-benefits. Country specific research and data will be required for a better understanding of the impacts on carbon storage, particularly in relation to the end usage of hemp products.

Scope for implementation in Jersey

A maximum of approximately 1000 ha are available for crop replacement strategies or changes in land-use across Jersey (10).

The division of this land between different crops / land uses will depend on a number of factors including economic and biodiversity implications. The additional benefits for sequestered carbon in the long-term with perennial crop or woodlands must be weighed against the loss of short-term income from annual crop products. However, these solutions also offer other co-benefits including improving landscape connectivity through biodiversity corridors. The 'Jersey multi-species distribution, habitat suitability & connectivity modelling' study (26) highlights the importance of woodlands as wildlife corridors, particularly in the west and southwest areas of the island. Any future planning for woodland conversion should consider the recommendations from this report which include the protection and restoration of unprotected and degraded habitats, and of wildlife corridors, across the island.

Historically, the area of fruit tree crops has increased since 2007, however in recent years has stabilised. Jersey's most common perennial crop is currently the apple tree. Switching to perennial crops can provide a range of ecological and socio-economic benefits that could overlap with some of Jersey's national agricultural and biodiversity strategies (27), summarised below:

- **Ecological benefits** include many advantages over annual crops in terms of maintaining ecosystem functions. This includes the maintenance of soil cover, soil structure and biota as well as providing soil stability and enhancing soil health through deeper root systems.
- **Socio-economic benefits** include a reduction in financial investment as a result of reduced fertilizer and energy inputs. Perennial crops can also offer solutions for soils considered marginal in terms of output for annual crops.

There is an opportunity to reverse the falling trend of value of other exported produce with the work on alternative crops, such the planation of circa 47 ha (260 vergées) of hemp in 2017 destined for culinary oil and fibre production (28). For this to be an effective strategy for increasing carbon storage however, the industrial hemp crop would need to be used in products with demonstrable carbon sequestration potential over a longer period such as building materials. Hemp can be grown on existing agricultural land (unlike most forestry projects), with the possibility of growing fibres on nutrient poor soil (29), and can be included as part of a farm's crop rotation with positive effects on overall yields of follow on crops. Hemp grown on Jersey has also been used as a carbon rich ingredient for biologically complete compost, promoting regenerative farming approaches (24). Further research is required to develop a country-specific methodology that would be needed to account for this data in the national GHG inventory.

Estimating carbon sequestration due to crop replacements: living biomass, soil organic carbon and biomass products

Carbon sequestration from the crop replacement strategies discussed in this case study is calculated using different methods depending on whether the annual crop is replaced by an alternative annual crop, a perennial crop or woodland. For each conversion, the change in carbon can be registered in the soil organic carbon, living biomass, biomass of harvested products or dead organic matter in situ. Each of these methods derives its methodology from the 2006 IPCC Guidelines where possible, and will have different data needs. Tables 7 and 8 below summarise the data needed to estimate the impact of crop replacement strategies on carbon stores.

Table 7. Data requirements for crop replacement strategies

<table>
<tr><th rowspan="2">Crop replacement</th><th colspan="4">Data needed to calculate impact</th></tr>
<tr><th>Soil organic carbon</th><th>Living biomass</th><th>Biomass in harvested products</th><th>Dead organic matter</th></tr>
<tr><td>Annual with harvested product (e.g. hemp)</td><td>• Annual area of crops converted (ha)
• Soil organic carbon in the annual cropland (tC/ha)
• Soil organic carbon in the harvested product (tC/ha)*</td><td>No defined methodology exists but would require annual rates of biomass gain and loss or carbon stocks at two points in time. I.e. % carbon in living biomass of crops before and after conversion.</td><td>• Annual living biomass removed that is contained in annual produced harvest products
• Half-life (years): number of years until half of the amount goes out of use.*</td><td>Not calculated under Tier 1; for higher tiers, depends on the method of calculation (gain-loss or stock-difference) but requires data on total quantities of dead wood and litter.</td></tr>
<tr><td>Perennial (e.g. orchard or vines)</td><td>• Annual area of crops converted (ha)
• Soil organic carbon in the annual cropland (tC/ha)
• Soil organic carbon in the perennial crop (tC/ha)</td><td>• Annual area of annual crops converted to perennial crops (ha)
• Annual area of perennial woody crops that have not reached the maturity age (ha)
• Living biomass in the vegetation cleared before planting the new crop
• Peak/growth biomass of the perennial woody crops (tonnes C/ha)
• Years needed for the fruit crop to reach maturity (years).</td><td>• NA</td><td>Not calculated under Tier 1; for higher tiers, depends on the method of calculation (gain-loss or stock-difference) but requires data on total quantities of dead wood and litter.</td></tr>
<tr><td>Woodland</td><td>• Annual area of crops converted to woodlands (ha)
• Soil organic carbon in the annual cropland (tC/ha)
• Soil organic carbon in the woodland (tC/ha)</td><td>• Annual area of crops converted to woodlands (ha)
• Species planted
• C stock change in woodlands (based annual growth and losses, sourced from field measurement or calculated with allometric functions and management information as cuts and disturbances) (tonnes C/ha)</td><td>• Annual living biomass removed that is contained in annual produced harvest products
• Half-life (years): number of years until half of the amount goes out of use.</td><td>• Annual area of crops converted to woodlands (ha)
• Dead organic matter in forestland (tC/ha).</td></tr>
</table>

**A specific carbon sequestration factor would need to be developed for this calculation*

Based on **Tier 1** default parameters, the change in soil organic carbon due to replacement of annual crop to annual with harvested product (e.g. hemp), perennial woody crop (without including change in tillage regime or organic matter inputs) or forestland would be reflected as carbon sequestration in the GHG inventory as per the table below.

Table 8. Calculating carbon sequestration due to crop replacement. These values do not consider management or input factors in perennial crops. Only the land use factor is considered

Original land use	New land use**	Total soil carbon sequestered until equilibrium* (tonnes C/ha)	Total increase in soil organic carbon until equilibrium* (%)	Total living biomass carbon sequestered until equilibrium* (tonnes C/ha)	Total biomass in harvested products carbon sequestered until equilibrium* (tonnes C/ha)	Total dead organic matter carbon sequestered until equilibrium* (tonnes C/ha)
Annual crop	Annual with harvested product (e.g. hemp)	NA (species specific research required)	No change	NA (no defined methodology)	NA (no defined methodology)	NA (no defined methodology)
Annual crop	Perennial woody crop	29.45	45%	63***	NA	NA (no defined methodology)
Annual crop	Forest	29.45	45%	120****	Dependent on harvesting rates and product use	Dependent on the type of forest for litter, default deadwood values are not available

** Default is 20 years*

*** Note that management and input factors in perennial crops are not considered and the land use factor is 1, the soil organic carbon in perennial woody crops is equal to soil organic carbon reference. Also, Tier 1 assumed soil organic carbon in forestland is equal to soil organic carbon reference.*

**** Default value for temperate perennial crop systems (IPCC 2006, Volume 4, Chapter 5, Table 5.1). It is assumed that the biomass in annual crops is in equilibrium and therefore a percentage change cannot be calculated*

***** Default value for temperate Oceanic forest, Europe (IPCC 2006, Volume 4, Chapter 4, Table 4.7). It is assumed that the biomass in annual crops is in equilibrium and therefore a percentage change cannot be calculated.*

To put these figures into context, applying 29.45 plus 120 tonnes C/ha across 1,000 ha available for land use change across Jersey assuming all are converted from annual crops to forestland, equals an approximate total of 7 kt of carbon sequestered per year for 20 years. This equates to an addition sink of approximately -27kt CO_2eq per year for 20 years. This represents roughly 6% of Jersey total GHG emissions from 2018. This is without consideration for biomass in HWPs or dead organic matter.

9 Recommendations

Considering the actual status of the GHG inventory for Jersey and the interest of GoJ to further improve them and assess carbon sequestration potential, the following activities are recommended as next steps:

Current used land use areas:

- Discuss with the UK Centre for Ecology & Hydrology (CEH) the data to gain a better understanding of where land area data comes from, how it is used and how it changes each year to gain a better understanding of the inventory.

Croplands:

- Collect data about management practices for different land uses, in terms of crop type, management and input.
- Track areas of different crop types and management practices over time. Analyse trends to assess the importance of practices change.
- Further analyse the potential for cropland type changes and management practices change, and which particular crop types and practices can be used in Jersey. Assess the potential of carbon stock increase impact of these crop types and practices (beyond IPCC defaults).
- Further investigate the benefits and trade-offs involved in the use of cover crop such as radish or mustard.
- Assess and further research Jersey-specific data on industrial hemp agriculture with respect to carbon content, planting schedule and harvested product uses to develop a Jersey-specific methodology for calculating the enhanced carbon storage.

Forestlands:

- Investigate what particular information CEH will use/need for Jersey estimates.
- Further analyse the potential area that can be dedicated to forestlands. Identify and map land parcels that are eligible for conversion to forestland.
- Assess the potential for harvested wood products (production and market).

Other seminatural ecosystems:

- Assess the potential of enhanced management practices in seminatural ecosystems, for example moving from unmanaged to managed grassland.

Cross-cutting policy and stakeholder engagement activities:

- Explore expansion of the Rural Support Scheme to promote soil management and crop replacement practices, including the development of a Monitoring and Evaluation framework that will require enhanced tools for monitoring soil health such as the Soil Nutrient Calculator discussed in Jersey's 2017 - 2021 Rural Economy Strategy.
- Explore wider engagement of local business community to support and promote a local carbon offsetting scheme.
- Review and update the Agricultural Land Law of 1974 to include all relevant land parcels on the island, not only those that have been traded since 1974.

- Engage farmers in the discussion of which land management and crop replacement strategies are practicable and appropriate for deployment across the island.

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Annex I

Table A.1. Relative stock change factors (FLU, FMG and FI) (over 20 years) for different management activities on cropland (Table 5.5 IPCC 2006, Volume 4, Chapter 5).

Management systems characteristics	Value	Error	Definition
Land use			
Long term cultivated	0.69	±9%	Represents area that has been continuously managed for over 20 years, to predominantly annual crops. Input and tillage factors are also applied to estimate carbon stock changes.
Perennial/ Tree crop	1	±50%	Long-term perennial tree crops such as fruit and nut trees, coffee, and cacao.
Set aside (<20 years)	0.82	±17%	Represents temporary set aside of annually cropland (e.g., conservation reserves) or other idle cropland that has been revegetated with perennial grasses.
Management			
Full tillage	1	NA	Full tillage, Substantial soil disturbance with full inversion and/or frequent (within year) tillage operations. At planting time, little (e.g., <30%) of the surface is covered by residues.
Reduced tillage	1.08	±5%	Primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion). Normally leaves surface with >30% coverage by residues at planting.
No tillage	1.15	±4%	Direct seeding without primary tillage, with only minimal soil disturbance in the seeding zone. Herbicides are typically used for weed control.
Input			
Low	0.92	±14	Low residue return occurs when there is due to removal of residues (via collection or burning), frequent bare fallowing, production of crops yielding low residues (e.g., vegetables, tobacco, cotton), no mineral fertilization or nitrogen fixing crops.
Medium	1.00	NA	Representative for annual cropping with cereals where all crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g., manure) is added. Also requires mineral fertilization or N-fixing crop in rotation.
High - without manure	1.04	±13%	Represents significantly greater crop residue inputs over medium carbon input cropping systems due to additional practices, such as production of high residue yielding crops, use of green manures, cover crops, improved vegetated fallows, irrigation, frequent use of perennial grasses in annual crop rotations, but without manure applied (see row below).
High – with manure	1.44	±13%	Represents significantly higher carbon input over medium C input cropping systems due to an additional practice of regular addition of animal manure.

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Aether provides world experts in environmental data analysis and interpretation, and is at the forefront of greenhouse gas and air quality pollutant emissions calculation and review

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