Options for carbon sequestration in the Solent Region

A University of Southampton Sustainability Implementation Group Discussion Paper

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Summary

Carbon sequestration is the removal of carbon from the atmosphere as a result of natural or man-made processes. Not all emissions will be able to be reduced to zero, therefore carbon sequestration will play a vital role in enabling countries and organizations to achieve *net zero* targets and potentially to become *net negative*. Carbon off-setting harnesses carbon sequestration by investing in projects which remove carbon from the atmosphere and so form 'carbon credits' for the investor. The aim of this study was to identify options for nature-based and non-nature based carbon sequestration in the Solent region.

Nature-based offsetting, which is likely to play the main role in the short term comprises ***Blue*** **carbon**, the sequestration of carbon via marine habitats such as sea grass and salt marsh, and the more familiar ***Green*** **carbon,** which refers to terrestrial habitats such as woodland or grassland.

Research suggests that ***blue carbon*** could have significant potential for carbon removal with sequestration rates that may exceed those of Green carbon. **However, Solent region specific research on the extent of current blue carbon habitats, their sequestration rates and the potential for restoring further habitat is currently missing.**

The Solent region contains a wide variety of ***green carbon*** habitats including woodland, grassland, heathland, peatland and hedgerows. Most of these habitats have been depleted by urbanisation or other land use change so that the scope for further land-use change or restoration is potentially limited. **Further research is therefore required to understand where green carbon habitats could be restored or created**.

Grey carbon or non-nature-based offsetting refers to sequestration via man-made technologies. At present, many grey carbon technologies are unproven at industrial scale but as their capacity comes to exceed available nature-based options, they are likely to be a vital component of long-term carbon removal and storage. **The recently announced Solent Cluster[1] could enable the University to build on its research capacity in this area but it should be mindful of the reputational risks of engaging with major fossil fuel producers or processors**.

Finally, it is recommended that **an offsetting plan is developed in case it is required as a last resort to achieve the University's 'Net zero Scope 1 and 2 emissions by 2030' target.** This should use accredited providers and could comprise a portfolio of blue and green carbon projects. This plan could align with the principles of the University's Civic Strategic Plan[2], its prioritised area of "Environment, Sustainability, Decarbonisation and Biodiversity". Accordingly, investing in local, regional and then UK based projects could be prioritised with international projects considered a last resort to ensure that the University invests as locally as possible, to the benefit of local communities and environments with available capacity.

[1] https://www.thesolentcluster.com/
[2] https://sotonac.sharepoint.com/:u:/r/teams/UniversityStrategy/SitePages/Civic-Strategic-Plan.aspx

Document history

- v1.0 for SIG comment
- v1.1 for external review by Professor P Anderson (Emeritus Professor, University of Liverpool, author of the 2021 Chartered Institute of Ecology and Environmental Management's report "Carbon and Ecosystems: Restoration and Creation to Capture Carbon"[3])
- v1.2 for UoS internal publication (intranet)
- v1.2_public for full release

Citation

Trewick, C., & Anderson, B. (2022) Options for carbon sequestration in the Solent Region. *University of Southampton Sustainability Implementation Group Discussion Paper*, University of Southampton: Southampton

[3] https://cieem.net/resource/carbon-and-ecosystems-restoration-and-creation-to-capture-carbon/

Contents

Introduction

The uncontrolled release of greenhouse gas (GHG) emissions since the industrial revolution has led to a global warming affect, with global temperatures rising by 1.1°C since pre-industrial levels. One of the biggest contributing greenhouse gases to global temperature rise is carbon dioxide (CO_2). In order to prevent further global temperature rise, the Intergovernmental Panel on Climate Change advised there must be a reduction in CO_2 emissions by 85% from levels seen in 2000 (IPCC 2007; Norris et al. 2021). Many countries and organisations around the world have set bold targets to reduce their CO_2 emissions to net zero by 2050. However, there will be cases where CO_2 emissions cannot be reduced to zero by 2050, because the infrastructure for that sector will take longer to decarbonise. Therefore, some emissions will have to be offset.

Carbon offsetting is a way for governments, organisations and individuals to compensate for unavoidable emissions by investing in the sequestration and storage of carbon elsewhere. In theory, the carbon removed by the project that has received investment offsets the carbon released within the government, organisation or individuals remit. The crucial factor in carbon offset projects is that *additional* carbon is sequestered to that which otherwise would have occurred. This sequestration of carbon from the atmosphere or process can take place through natural (biological) or man-made technological pathways CLEAR Center).

It is believed that up to 75% of all carbon offsets could come from both terrestrial and marine Nature-based Solutions (NbS) (Norris et al. 2021). There are many definitions for NbS, but in broad terms, NbS is when the restoration, sustainable management and protection of natural systems and habitats can also have positive benefits on societal issues such as climate change (Gregg et al. 2021).

However natural processes tend to be relatively slow and in the global context there is a clear requirement to reduce emissions as quickly as possible by 2030 if we are to divert current warming pathways. The remainder of the offset market and also the more rapid sequestration than NbS can provide will therefore have to come from carbon dioxide removal technologies, such as direct carbon capture and storage (CCS).

The aim of this study was to identify options for nature-based and non-nature based carbon sequestration in the Solent region.

Defining the Solent

The Solent region is located on the central south coast of the United Kingdom with Southampton at its coastal centre. For the purposes of this study the Solent region includes the County of Hampshire together with Southampton, Portsmouth and the Isle of Wight (see Figure 1). Due to its geography, the Solent region is an ideal location for an array of nature-based carbon sequestration projects because of the variation in both terrestrial and marine habitat found in the area.

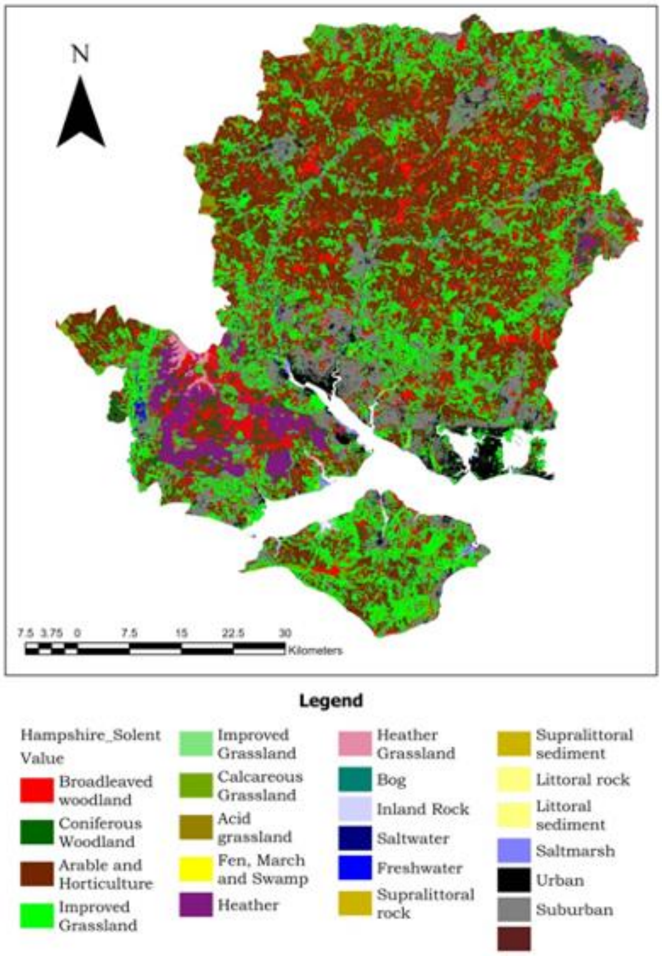

Figure 1: 'Solent' region as defined in this report with terrestrial habitats shown (source: CEH Land cover map 2020 Morton et al, 2020)

As one of four Universities in the Solent region, the University of Southampton aims to achieve net zero across Scope 1 and Scope 2 emissions by 2030. However, it is unlikely to be possible to reduce **all** emissions to zero, therefore there may be a need for the university to offset any remaining unavoidable Scope 1 and 2 emissions from 2030. Further ambition to reduce Scope 3 emissions is particularly difficult with a study by Arup, CenSA and De Monfort University (2021) estimating that around 60 percent of GHG emissions from higher education institutions come from Scope 3. This was confirmed by SIG's analysis suggesting that Scope 3 emissions comprise at least 80% of the University's total (Anderson, 2020). Although the University of Southampton has not yet set a target for Scope 3 emissions reductions, it is possible that offsets will need to be used for residual Scope 3 emissions from, for example, upstream energy use, waste and business travel.

The aim of this study was to

1. Identify options for carbon sequestration in the Solent region that could be used to offset unavoidable emissions produced by the University of Southampton;
2. Estimate the potential annual sequestration capacity of these options.

To do this, the report discusses Blue (marine), Green (terrestrial) and Grey (non-nature based or technological) sequestration in turn.

Blue carbon

Blue carbon is defined as the carbon that becomes stored in marine and coastal ecosystems through natural processes (Norris et al. 2021). Carbon may be stored in the biomass of marine fauna and flora, or in the marine sediment (Mcleod et al. 2011; Norris et al. 2021).

Plant dominated coastal ecosystems such as seagrass and saltmarsh habitats sequester carbon through their below and above ground biomass, sediments and non-living biomass (Norris et al. 2021). Carbon sequestered in biomass is generally stored over a decennial timescale, whilst sediment sequestered carbon is stored over millennial timescales and can therefore be viewed as permanent if undisturbed (Duarte et al. 2005a; Lo lacono et al. 2008; Mcleod et al. 2011; Norris et al. 2021).

Seagrass restoration

Seagrass is not just excellent at carbon sequestration, there are also many other benefits to restoring seagrass such as increased biodiversity, sediment stabilisation, catching ocean plastics, providing fish nurseries, improving nutrient cycling and reducing coastal erosion (Nordlund et al. 2016; Green et al. 2021).

Estimated seagrass carbon storage in the Solent region vary in the literature with values ranging from 33.8 +/- 18.5 Mg C ha^{-1} for the top 30cm of sediment (Lima et al. 2020) to 141 +/- 74 Mg C ha^{-1} within the top 1m of sediment in the seagrass meadows (Green et al. 2018; Green et al. 2021). Carbon sequestration rates are more difficult to estimate than storage because there are many different factors that influence the rate such as hydrology, sediment type and seagrass species. A review by Gouldsmith and Cooper (2022) suggested the per ha rate may range from 16.1-20.2 tCO_2e ha^{-1} $year^{-1}$.

According to the Blue Marine Foundation, 317 hectares of seagrass across the Solent have been found to be in poor condition (Norris et al. 2021) and, partly in response, Hampshire and Isle of Wight wildlife trust are working to restore seagrass habitat across the Solent region[4].

In addition, ongoing University research is mapping areas of seagrass in the Studland Bay area of the Solent to help with restoration projects[5]. However, this research has been limited by funding constraints and they have so far been unable to map the full extent of both the existing habitat and areas where it could potentially be restored.

Saltmarsh restoration

Saltmarsh is another blue carbon habitat that can sequester and, as with sea grass derived sediment, store carbon for long time periods when undisturbed. Saltmarsh is one of the best habitats in the UK for sequestering carbon, with yearly sequestration rates around 1.20-2.2 tC ha^{-1} yr^{-1} (Burden et al. 2019; Armstrong et al. 2020; Parry and Hendy 2022). A study by Armstrong et al. (2020) also found that sequestration rates on non-sandy sediments were 30% greater than that recorded for saltmarsh growing on sandy sediment. Gregg et al. (2021) suggest restoration of high salt marsh can be slow in accumulating

[4] See https://saveourseabed.co.uk/

[5] https://www.southampton.ac.uk/research/projects/making-sense-of-state-of-the-art-geospatial-data-to-explore-opportunities-for

carbon, whilst the accumulated carbon in low restored shore sites were not significantly different from the natural ones after 15 years. Other studies found sequestration rates were high (averaging 1.04 tC/ha/yr in the first 20 years after restoration) before dropping to around 0.65 tC/ha/yr thereafter. There is a suggestion that it could take around 100 years for a restored salt marsh to gain the equivalent carbon stocks to a natural site.

According to the Blue Marine Foundation (2021), over half of the Solent's saltmarsh has been lost in the last few decades due to land conversion, meaning vital carbon stores have been lost (Norris et al. 2021). Even so, current estimates suggest the Saltmarsh in the Solent stores around 75,000 tonnes of carbon, but this could double if the saltmarsh is restored to its original size (Parry and Hendy 2022). Further, the current extent of saltmarsh in the Solent is believed to sequester around 4673.2 - 5841.5 $tCO_2e\ yr^{-1}$ (Parry and Hendy 2022, see also Table 2). Therefore, it is not only important to restore the saltmarsh to increase carbon sequestration but also to protect current saltmarsh to prevent the further loss of carbon stores.

Saltmarshes also provided other benefits such as flood protection by acting as natural sea barriers (Chmura 2013; Norris et al. 2021). Saltmarshes located at the mouths of estuaries create a pollutant barrier, helping to filter out pollutants being carried downstream (Norris et al. 2021). They can also act as nutrient sinks, reducing the risk of nutrient blooms which lead to the spread of toxic algae and marine dead zones (Chmura 2013; Norris et al. 2021). Finally, they are important habitats for fish and crustaceans of economic value (Baker et al. 2020; Norris et al. 2021), helping to stabilise fish stocks.

Macroalgae

Macroalgae such as seaweeds and kelp are recognised as possible blue carbon habitats. The sequestration of carbon in macroalgae is through the storage of carbon in the aquatic plant's biomass, which is then stored when the plant dies and sinks to the shelf and deep ocean sediments (Norris et al. 2021). According to the Blue Marine Foundations blue carbon report, it is likely that macroalgae could be added into the blue carbon offset market in the near future (Norris et al. 2021).

There are also co-benefits to macroalgae restoration, one of which is seaweed aquaculture. Not only does seaweed aquaculture contribute to carbon sequestration, but it also provides a sustainable food source (Hoegh-Guldberg 2019; Norris et al. 2021). A recent review by Gao et al 2022 suggests possible sequestration rates of 8.65 $tC0_2e$/ha for cultured macro-algae, nevertheless carbon sequestration via macroalgae is still considered controversial (Hill et al. 2015).

There are currently no major macroalgae restoration projects in the Solent, however nearby projects such as the Sussex Wildlife Trust kelp restoration project have so far proven successful in expanding seaweed beds.

Marine Sediment

The unvegetated areas of tidal zones are known as the intertidal sediments, including mudflats and sandflats (Gregg et al. 2021). Different sediment types can store different amounts of organic carbon, with sandy sediments storing the least amount of organic carbon compared to muddy sediments (Smeaton et al. 2021). It is important to note, however, that within these sediment classes there can be even more differentiation between carbon sequestration rates (Smeaton and Austin 2019). According to the Southern Inshore Fisheries and Conservation Authority, the marine sediment within the Solent region includes coarse, sand and muddy sand, mud and mixed sediment.

Available information on the carbon sequestration rates of different sediment types around the UK is limited, however a review by Armstrong et al. (2020) found the carbon sequestration rate of sediment in Welsh marine habitats varied from 0.4-1.36 tCO_2e ha^{-1} yr^{-1}. Another study by Adams et al. (2012), which focused on mudflats, found managed, realigned mudflats sequestered around 2.68 tCO_2e ha^{-1} yr^{-1} and natural mudflats sequestered 3.48 tCO_2e ha^{-1} yr^{-1}.

Oyster farming

There is emerging research to suggest that well established oyster reefs become carbon sinks (NORA 2020). Oysters take in particles from the water column and release these particles into the seabed as faeces, which become trapped in the sediment over time (NORA 2020). The carbon in those particles is subsequently stored in the sediment in a process known as bio-deposition (Fodrie et al. 2017). If the amount of carbon stored in the sediment outweighs the amount of carbon the oysters respire, then there is a net carbon store.

The Solent Oyster restoration project[6], run by the Blue Marine Foundation, is currently underway and may be able to offer further insights into the potential for this process.

Blue carbon: the current picture

Using values provided in the literature on carbon sequestration rates and habitat data, it has been possible to estimate the possible total carbon sequestered per year for each habitat (Table 1). Unfortunately, sufficient data on carbon sequestration rate for macroalgae in the UK could not be found at this time.

Habitat	**Carbon sequestration rate (tCO_2e ha^{-1} $year^{-1}$)**	**Source**
Seagrass	16.1-20.2	Gouldsmith and Cooper 2022
Saltmarsh	2.35-8.04	Beaumont et al. 2014; Gregg et al. 2021
Restored saltmarsh	3.81	Burden et al. 2013; Gregg et al. 2021
Macroalgae	8.65	Gao et al, 2022
Marine sediment	0.4-1.36	Armstrong et al. 2020
Mudflats	2.68-3.48	Adams et al. s2012

Table 1: The carbon sequestration rate (tCO_2e ha^{-1} yr^{-1}) from blue carbon habitats

By combining these rates with Land Cover data (Morton et al, 2020) on the area in hectares (ha) of saltmarsh in the Solent region (Hampshire, Isle of Wight and Southampton) the possible yearly carbon sequestration rate could be calculated for saltmarsh and seagrass habitats in the Solent region (Table 2). Unfortunately, at the time of analysis, data on the extent of seagrass around England, and the Solent in particular, was not available[7]. For the purposes of comparison we therefore use the 317 ha of degraded seagrass reported above which appears broadly similar in extent to the habitat maps available from the ReMEDIES project[8].

[6] https://www.bluemarinefoundation.com/projects/solent/
[7] Data for England now available at https://naturalengland-defra.opendata.arcgis.com/maps/e009f2adbc9b4028a34842b133c6636b/about
[8] https://saveourseabed.co.uk/about-our-seabed/habitat-maps/

To put the sequestration estimates reported in Table 2 in context, the University's Scope 1, 2 and 3 emissions were estimated to be around 120,000 T CO_2e in 2018/19.

Habitat	Land Cover area (ha)	Carbon sequestration rate (low) (T CO_2e)	Carbon sequestration rate (high) (T CO_2e)	Minimum yearly sequestration (T CO_2e)	Maximum yearly sequestration (T CO_2e)
Saltmarsh	1705	2.35	8.04	4,007	13,708
Seagrass	317	16.1	20.2	5,100	6,400

Table 2: The minimum and maximum carbon sequestration rate for the area of saltmarsh and degraded seagrass in the Solent region, T CO2e

Importantly, some blue carbon habitats have a greater carbon burial rate than some terrestrial habitats (Gregg et al. 2021,) and if restored and protected on a larger scale, could make a significant contribution to carbon capture. Carbon trapped in sediment can accumulate rapidly as restoration commences, rather than the delayed response seen in most tree planting, although saltmarsh restoration can take longer to achieve a more positive carbon balance. This means that blue carbon habitats may not take as long as some terrestrial habitats to build up carbon stores once they have been restored. Given that they also sequester 'permanently' on the scale of millennia via sedimentation (provided this is not disturbed), blue carbon habitats are therefore likely to be important contributors to offsetting schemes as rapid sequestration, ideally in the year of emission, is crucial to mitigate current warming pathways.

Blue carbon: Issues

One of the biggest issues facing restoration projects is that the historical habitats were lost due to urbanisation, therefore they cannot be restored to match the historical locations of the habitat. This is especially true for saltmarsh, in which habitat has been lost by the expansion of the ports in Southampton (Parry and Hendy 2022). Therefore, more research is needed to find areas that could be restored to saltmarsh or where saltmarsh could be created.

A better understanding of the factors that affect carbon sequestration rates in blue carbon habitats is also needed (McLeod et al. 2011). Factors that can impact the carbon sequestration rate include sediment type, sedimentation rate, species type, hydrology, nutrient cycles, flow rate and changes in sea level (Middleton and McKee 2001; Kristensen et al. 2008; McLeod et al 2011). One particular area that needs research is the impact of climate change on carbon sequestration rates and carbon storage in blue carbon habitats, as this could impact the future success of natural offset projects (McLeod et al. 2011). The effect of these factors would need to be understood before a costly and time consuming restoration project begins, especially where it is 'guaranteeing' a certain level of sequestration credits.

On a global scale it has been estimated that macroalgae could sequester 174 Mt C yr^{-1}, suggesting there is significant potential (Krause-Jensen and Duarte 2016). However, at present, there is very limited data on the carbon sequestration rate of macroalgae in the UK. A UK focus is needed as many factors affect the rate at which macroalgae can sequester carbon, similar to seagrass. Further research is therefore necessary to determine whether or not there is scope for a macroalgae restoration project in the Solent, which species would be appropriate and how much carbon this would sequester.

More research is also needed to understand the extent of seagrass in the Solent, including the new seagrass beds being planted as part of the Hampshire and Isle of Wight programme. Coupled with research on the carbon sequestration rate of the seagrass in the Solent, a more accurate estimate could be then calculated for the specific species types under local conditions. This could then provide input to a 'Blue Carbon Potential' model for the Solent which would be able to make estimates of the potential maximum sequestration per year if all available area was used to implement nature-based services.

Green carbon

Green carbon is the carbon stored in terrestrial habitats, including in living organisms. Many habitats across the UK have the capacity to store carbon in both their biomass and in the soil. Whilst forestry is the most frequently cited example, other options exist. In each case we need to distinguish between the amount of carbon that can be stored long term and the rate at which carbon can be sequestered. These vary by habitat and impact the opportunity to increase sequestration via land-use change alongside emissions reducing management of existing or re-established habitats.

Peatland and heathland

Heathland and peatland are two habitats that store significant amounts of carbon in the UK (Gregg et al. 2021). The New Forest, located to the west of the Solent region, contains both heathland and peatland habitats.

In heathlands, the majority of carbon is stored in the soils and a small amount is stored in the vegetation (Gregg et al. 2021). Carbon stores in organic-rich soils under heathland can be high (up to about 211tC/ha, Alonso et al, 2012) and need to be protected to maintain these stocks. The amount of carbon in the usually woody, shrubby vegetation varies from 2-9tC/ha. Heathland sequestration rates can reach a high 12.65 $tCO_2e\ ha^{-1}\ yr^{-1}$, but only when the dwarf shrubs (mostly heather, *Calluna vulgaris*) are growing strongly. More typical rates are 3.34 $tCO_2e\ ha^{-1}\ yr^{-1}$ (Quin et al. 2015). Heathlands may be intensively managed, either through grazing or by removing invading trees. These can result in soil disturbance and the release of carbon. It is believed that intensive management could reduce carbon sequestration, but further research is needed to understand the extent of this impact (Gregg et al. 2021). There could be opportunities for restoring acid grassland to heathland or to re-create heathland on suitable soils in low-value agriculture which could contribute to carbon capture in the region.

In terms of peatland, the New Forest is a hot spot with 75% of the valley mires within Western Europe found in the New Forest[9]. The sequestration rate of peatland habitats is generally low, but they have an excellent ability to store large amounts of carbon over a long period of time, as long as the peatland is not disturbed. Much peat across the country is in poor condition after damage through drainage, wildfire and erosion, being particularly high where peatlands have been reclaimed as farmland (Gregg et al. 2021). This results in carbon loss as peat is oxygenated by lowered water tables. Avoiding further losses through better management is therefore crucial in reducing the contribution peatlands make to atmospheric carbon dioxide levels. Restoration of peatlands is essential in order to slow carbon loss to the atmosphere (CCC 2020). Their low sequestration rates are partly compensated by the very extensive area of this habitat across the country as a whole. Restoration of valley mires is part of the New Forest Higher Level Stewardship (HLS) scheme[10].

[9] https://www.newforestnpa.gov.uk/app/uploads/2018/03/wildlife1_habitats.pdf
[10] https://www.hlsnewforest.org.uk/projects/wetland-restoration/

Tree planting

Tree planting is one of the most well-known methods of carbon sequestration. Trees are a reliable source of carbon storage, as well as providing other ecosystem benefits and services (Gregg et al. 2021). The ability of trees to sequester carbon is impacted by different factors such as age, species, soil type and climate (Gregg et al. 2021), therefore site-specific consideration needs to be taken when planting trees for carbon sequestration.

Carbon is sequestered by trees as they grow; whilst some carbon is stored in the tree's biomass, around 70% is stored in the soils (Anderson 2021). As trees take a number of years to produce an effective canopy, it also takes time to accumulate leaf litter and to start to capture carbon significantly, varying with species and situation. At the same time, establishing trees, particularly if significant ground preparation is undertaken, can result in the loss of existing carbon in the soils. Therefore, the carbon sequestration potential of trees can take a few decades to produce a carbon positive balance sheet. Additionally, maximum sequestration rates are reached whilst trees are growing strongly, which peaks at different times depending on the species. This lag in sequestration potential needs to be considered when evaluating tree planting as an offsetting mechanism (Gregg et al. 2021).

The value of trees for carbon sequestration also depends on their management. Trees planted for timber maintain their carbon after harvest only if used for long-lived purposes such as construction or furniture, whilst use for eg. paper or cardboard results in loss of the carbon fairly quickly. Trees planted as semi-natural woodlands with little management, particularly if established on ex-arable or disturbed land where carbon loss is minimised, and using natural regeneration rather than planting, can continue to sequestrate carbon at reasonable rates (8.43-33.0 tCO_2e ha^{-1} yr^{-1}) for many years. Old growth forest and ancient broadleaved woodlands are known to still be sequestrating carbon at rates between 4.77-17.97 tCO_2e ha^{-1} yr^{-1} up to 600 years of non-intervention. These are good rates compared with other habitats, and useful for long-term carbon capture.

In Southampton, it was estimated that 100,600 tonnes of carbon are stored in trees in the city and 2,700 tonnes is sequestered each year (Mutch et al. 2017). The study found that one of the major limiting factors for improving tree planting in the city of Southampton was urbanisation (Mutch et al. 2017). Therefore, as suggested by the Climate Change Committee (CCC), the conversion of low yield arable land to woodland in the Solent region could be a viable option (CCC 2018). If this is achieved through natural colonisation plus adding any missing species, this would achieve the best carbon capture results, especially on clay-rich soils.

Grasslands

Grasslands make up around 40 percent of land cover within the UK (ONS 2015; Gregg et al. 2021) and are diverse including different types of habitats such as semi-natural and agricultural grassland. This section focuses on semi-natural grasslands due to the absence of data on the sequestration rates of agricultural grassland.

Semi-natural grasslands comprise three main types; neutral, acid and calcareous and are biodiversity rich habitats, typically managed using low-intensity, organic management practices such as low input grazing. Semi-natural grasslands have decreased across the UK over the past century due to conversion to agricultural land. (Ridding et al. 2015; Greggs et al. 2021). However, floristically diverse grasslands have been shown to hold significant stocks of carbon, particularly on clay-rich soils, which can exceed that found below woodlands in the full depth of the soil profile (Soussana et al. 2010). Even under intensive stock farming, levels can reach high levels. Tuohy et al. (2021), for example, reported levels of 170.9-459.3tC/ha in surface water gleys and 254.6-645.0tC/ha on alluvial soils in Ireland, which the authors considered was well below their maximum capacity based on their soil texture.

Unfortunately, carbon sequestration rates for semi-natural grasslands are not as well researched compared to their carbon storage ability, and it is difficult to find data on UK based carbon sequestration across the different types of semi-natural grasslands. However, favourable rates of sequestration have been demonstrated for a neutral grassland overlying calcareous rocks where diversification plus the addition of red clover (*Trifolium pratense*) was found to achieve levels of a high 11.62 $tCO_2e\ ha^{-1}\ yr^{-1}$ (de Deyn et al. 2010). Carbon loss was found on plots where inorganic fertilisers were still applied with no red clover. Other studies have also shown that diverse grasslands can sequestrate up to five times more carbon than monocultures. A recent study in urban Berlin (Schittko et al. 2022), found that soil organic carbon was positively associated with plant diversity reaching 83.5tC/ha (to 0.3m depth – over 60% of a grassland soil's carbon will potentially be below this). This is similar to woodland soil storage and important within an urban context.

For the purposes of this study, a generalised value for grasslands in the UK of 0.18-1.78 $tCO_2e\ ha^{-1}\ yr^{-1}$ from Janssens et al. (2015) has been used, although this is low compared with some studies and may underestimate totals. Although this value is comparatively low compared to some other green carbon habitats, because grasslands make up such a large part of UK land cover, the impact of restoring flower-rich grasslands with deep-rooted legumes from net emitting arable land-use (when regularly tilled) could be quite substantial. Opportunities within the urban portfolio could be explored and would have multiple benefits for people's health and wellbeing as well as other ecosystem services. It also needs to be borne in mind that grasslands need regular management, either by grazing or mowing with the cut material removed to maintain diversity. These both have carbon implications as stock give off different amounts of methane and carbon dioxide and mowing may use fossil fuels. The overall carbon balance has to be considered, as with woodland management and harvesting. Research into grasslands across Europe from Ireland to Hungary (Soussana et al. 2010) has suggested that stock grazing plus hay removal might only reduce carbon sequestration by some 19%, although more investigations in different climates, management systems and soils are still needed.

Changes to agricultural practices

Compared to semi-natural grasslands, agricultural topsoil is commonly very poor in terms of carbon storage due to modifications such as fertilisation, tillage and drainage (Emmett et al. 2010; Gregg et al. 2021). However, carbon sequestration can be improved in farmland through floristic diversification and cessation of the use of inorganic fertilisers in grasslands, agroforestry, wood pasture, hedgerow restoration and changing farming methods to reduce soil disturbance and aid with carbon storage (Gregg et al. 2021).

Conversion of poor-quality arable land to low input grasslands is recommended by the CCC, as the benefit of carbon sequestration outweighs the poor yield from degraded arable land (CCC 2018). Low input grassland can also support livestock, so that agricultural output is not lost (Anderson 2021).

Understanding the potential of carbon sequestration through changes in agricultural land use or improvements in agricultural practices is nuanced as there are many other economic and social factors to be considered. However, the CCC have outlined in multiple reports on land use change that change in agricultural practices and conversion of some agricultural land is needed in the coming years to help the UK meet net zero targets (CCC 2018, 2020b). This implies that there may be scope to invest in land-use change or improvements in agricultural practices in the Solent region which would not compete with food production.

Green Carbon: the current picture

Using values provided in the literature on carbon sequestration rates and habitat data, it is possible to estimate the current total carbon sequestered per year for each habitat (Table 3), although some of these figures apply to only short periods of the life cycle such as for conifer plantations and depend on how the timber is harvested and used, and in grasslands some suggest that there is a carrying capacity for mineral-associated organic carbon which could take up to 100 years (depending on the starting condition) to reach. There could also be higher levels of sequestration in floristically diverse grasslands with good deep-rooted legume cover than the figures used below.

Habitat	**Carbon sequestration rate (t CO_2e ha^{-1} year^{-1})**	**Source**
Mixed broadleaved woodland up to 30 years	7-14.5	Gregg et al. 2021
Natural woodland generation on former arable soils	7.3-14.3	Poulton et al. 2003; Anderson 2021
Conifer plantation (Sitka spruce)	11-20.5	Dewar and Cannell 1992; Anderson 2021
Old growth forest and ancient broadleaved woodland	4.77-17.97	Anderson, 2021
Hedgerows	0.47-23.36	Gregg et al. 2021
Heathlands	3.34-12.65	Alonso et al. 2012; Quin et al. 2015; Anderson 2021
Improved grassland	0.18 - 1.78	Janssens et al. 2005
Reversion of arable land to low input grassland	1.59	Warner et al. 2020; Gregg et al. 2021
Peatlands	0.18-3.70	Artz et al. 2013; Anderson 2021
Restored peatlands	3.23-25.41*	Artz et al. 2013; Anderson 2021

*Table 3: Carbon sequestration rates of different green carbon habitats * = mostly a reduction of loss of carbon rather than sequestration.*

As with the Blue carbon examples in Table 2, the area in hectares (ha) of different terrestrial habitats in the Solent region (Hampshire, Isle of Wight, Portsmouth and Southampton) was estimated using recent Land Cover data (Morton et al, 2020) (Table 4). The current annual carbon sequestration was then estimated for the Solent region for each of the specified green carbon habitats using the rate ranges reported in Table 3. Arable and horticultural land, which comprises most of the remaining non-urban/suburban land use (28% pf total) was excluded as it is a net emitter (see 'Cropland' in Table 4).

Habitat	Land Cover area (ha)	% of Solent area	Carbon sequestration rate (T CO2e/year)		Estimated annual sequestration (kT CO_2e)	
			low	*high*	*Minimum*	*Maximum*
Broadleaved woodland	60533.5	14.6	7	14.5	423.7	877.7
Coniferous woodland	15698.8	3.8	11	20.5	172.7	321.8
Improved grassland	111624.1	26.9	0.18	1.78	20	198.7
Peatland	783.5	0.2%	0.18	3.7	1.41	2.9
Heathland	21574.3	5.2%	3.34	12.65	72.1	272.9
Totals					**692.7**	**1,687.8**

Table 4: Minimum and maximum potential carbon sequestration for the area of different habitats across the Solent region

In order to assess the validity of these carbon sequestration values, the minimum and maximum sequestration rates for woodland (Broadleaf and coniferous) and improved grassland were compared to the sum of the relevant Land Use, Land Use Change net emission data from the BEIS 2020 district level GHG emissions inventory data for the Solent region (Table 5).

2020	Cropland (kT CO2e)	Forest land (kT CO2e)	Grassland (kT CO2e)	Settlements (kT CO2e)	Wetlands (kT CO2e)
Total kt CO2e	130.6	-491.3	-107.1	79.8	-0.3

Table 5: Net emissions due to land use in different land use types across the Solent region (Source: BEIS, 2022)[11]

As the table shows, the BEIS value for all-forestry sequestration (491 kT CO_2e) was slightly lower than the estimated low – high range for sequestration across broadleaved and coniferous habitats shown in Table 4 (596 - 1,200 kT CO_2e). However, the BEIS value for grassland (107 kT CO_2e) was roughly central to the equivalent estimated value (20 – 200 kT CO_2e) shown in Table 4. This suggests that the habitat-based analysis of carbon sequestration in the Solent region shown in Table 4 is within expected orders of magnitude.

In this context, offsetting all estimated annual University Scope 1, 2 and 3 emissions of ~120 kT CO_2e would require adding 25% extra **new** forestry (~19,000 ha) to the Solent's woodland according to the BEIS data. Were we to restrict this to the current Scope 1 and 2 emissions (~ 25 kT CO_2e) then the value would be closer to 5% (~4,000 ha). If we only wanted to offset our staff Business Travel emissions (~ 6 kT CO2e) then this would 'only' require 930 ha. Of course, the University will not be the only Solent region organisation seeking to offset future residual emissions through green carbon and newly planted woodland would not reach these sequestration rates for some time as discussed below. In contrast, most of the blue carbon options appear able to sequester or trap carbon (in sediments) relatively quickly and could be functional within a few years.

[11] https://www.gov.uk/government/collections/uk-local-authority-and-regional-greenhouse-gas-emissions-national-statistics

Green carbon: issues

Comparing the low and high total sequestration estimates from Table 4 with gross Solent region emissions from the BEIS data (8,864 kT CO_2e including CO_2, CH_4 and N_2O) suggests that sequestration due to existing land-use could be 'removing' 8 - 18% of current emissions. Without detailed land-cover and potential land-cover (and land use) change modelling it is not currently possible to estimate the extent to which the future residual emissions from the Solent region's current gross annual emissions could be offset by additional local NbS (Fryer & Williams, 2021). However, even if we were to assume that 'only' 500 kT CO2e of residual emissions remained in 2050, this would still require a *doubling* of the Solent forested land area according to the BEIS data. Further, woodland habitats can take 10-20 years to reach maximum carbon sequestration rate, therefore woodland restoration cannot be relied upon as the only option for offsetting current- year emissions. As with Blue carbon, there is therefore a need to model land-cover change in the Solent to understand the potential for 'Green Carbon' nature-based services to offset regional residual emissions. This could build on similar models developed at the University which focused on the New Forest National Park (Fryer & Williams, 2021).

Some of the Green Carbon options would sequestrate carbon relatively rapidly, particularly diversification of grasslands, restoration of flower-rich swards on poor agricultural land and creation of well vegetated ponds (although the latter would be small in terms of total area), but tree planting schemes could only become carbon positive over 5-40 years depending on the initial conditions. The latter could be part of a long term portfolio but would need to be supplemented by more immediate solutions. Tree planting in urban areas also have other ecosystem benefits, particularly in terms of temperature modification and shade for people and buildings.

The conversion of poor-quality arable land may be difficult, especially where there is multiple land ownership (such as the New Forest) or if the farm is solely arable based and does not yet have the capacity for grazing livestock on converted arable land. There is currently little funding available from the government to promote conversion of poor-quality arable land, despite the CCC emphasising the importance of land-use change if the UK is to reach net zero by 2050 (CCC 2018). However, this may change under the future Environmental Land Management Scheme (ELMS) and there are emerging signs of increasing flow of private capital into this area which sees both carbon and biodiversity credits as future income streams[12]. Soil Carbon and Marine Carbon Codes, for example, are being developed and a feasibility study into a Farm and Soil Carbon code is underway as part of the Yorkshire Integrated Catchment Solutions Programme[13] which may have wide relevance.

Nevertheless, given that nature-based services may be slow acting processes with limits to capacity the potential for grey carbon must be considered.

Grey carbon

Grey carbon is defined as carbon dioxide removal technologies, which are man-made technologies that remove carbon dioxide from the atmosphere. These technologies may also be called negative emission technologies (NETs).

[12] See https://www.nattergal.co.uk/ as an example
[13] https://icasp.org.uk/projects-2-2/uk-farm-and-soil-carbon-code-a-feasibility-study/

The Climate Change Committee (CCC) and the IPCC state that carbon removal technologies will be necessary to meet net zero targets (Ricardo Energy & Environment 2020). These technologies will be vital for sectors which are difficult to decarbonise before 2050. Conceptually these can be separated into carbon capture – where the emissions are removed from waste gases or the atmosphere, and storage – where the CO_2 is then permanently stored. There are a number of different approaches to each of these stages with carbon capture tending to involve energy intensive industrial processes and storage requiring a suitable geological formation ideally located close to the point of carbon capture.

Direct carbon capture and storage (CCS)

CCS is most effective when the carbon is captured directly from the source before it is released to the atmosphere, with the greatest impacts of direct CCS so far being seen on power plants (Sood and Vyas 2017). The Solent region is home to the UK's largest petrochemical complex, ExxonMobil Fawley, which produces an array of energy products, lubricants and chemicals and is known to be active in CCS development. However, there are currently no known local geological formations that can be used for CO_2 storage, and so the infrastructure for the transport of CO_2 needs to be developed[14]. The recently announced Solent Cluster[15], in which both ExxonMobil and the University are partners, will enable the University to build on its research capacity in this area but it should be mindful of the reputational risks of close engagement with major fossil fuel producers or processors especially if fugitive emissions remain substantial and the permanence of the CO_2 storage cannot be assured.

Bioenergy carbon capture and storage (BECCS)

One particularly interesting example of CCS is Bioenergy carbon capture and storage (BECCS). BECCS involves the cultivation of bioenergy crops to naturally sequester carbon and then the use of CCS when they are combusted to permanently capture and store the carbon that was sequestered. If successful it is thought that BECCS could be used to permanently remove atmospheric carbon but the technologies are in very early stages of commercial development. As before, the success of this approach depends on the assured permanence of the storage.

The University is active in this area with Professor Gail Taylor from the School of Biological Sciences looking to identify optimal sites for BECCS. However, one of the major issues is ensuring the environmental impact of growing plant biomass for BECCS, such as via land-use competition with food crops, does not outweigh the benefit of carbon capture directly after burning biomass. Recent University research modelling the environmental and social implications of BECCS at regional scales suggests that an increased number of smaller BECCS deployments will be needed to ensure a win–win for energy, negative emissions and ecosystem services (Donnison et al, 2020). There could therefore be the potential for such developments in the Solent region.

Microalgae as a form of CCS

Microalgae such as diatoms, cyanobacteria and blue, green, and red algae also have the potential to sequester carbon enzymatically (Gayathri et al. 2021). The microalgae use CO_2 to create biomass and bioenergy; with studies suggesting that 1kg of microalgae can sequester 1.84kg of CO_2 (Chen et al. 2009; Gayathri et al. 2021). It has been found that growing microalgae in close proximity to a carbon source can help to reduce CO_2 levels in that area (Cheah et al. 2015; Gayathri et al. 2021). The microalgae can also be

[14] [14] https://idric.org/project/mip-2-2-co2ports-to-pipelines-co2p2p/
[15] https://www.thesolentcluster.com/

collected and used to produce bioenergy, as well as other useful industrial chemicals (Onyeaka et al. 2021). Given the fact that much of the Solent's coastline is occupied by industrial installations, this may be one option worth exploring for tackling direct emissions.

Grey carbon: the potential

The potential of carbon removal technologies varies depending on the type and scale of the technology.

Unlike carbon sequestration via natural habitats, which is prone to fluctuations, grey carbon technologies should sequester a known value each year.

The difficultly with understanding the potential for grey carbon technologies, especially within the Solent region, is that many of these technologies are still in the research phase and are yet to be scaled up to industrial level. Robust estimates of potential are therefore difficult to source. This issue is discussed in more detail in the section below.

Grey carbon technologies: issues

Many grey carbon technologies require large amounts of energy and resources to set up and run. On a whole lifecycle basis, this means that they may not be the most suitable method for carbon sequestration given the emissions that could be produced in the manufacture and production of the grey carbon technology (Climate Change Committee 2020b). In addition, as with Blue and Green carbon it is important to ensure that the storage of CO_2 after it has been captured is secure and permanent. In response to thus, recent research at the University has contributed to at least two emerging start-ups who have patented methods for accelerating the rate at which captured carbon can be permanently stored as deep-crust carbonated minerals[16]. Whilst in the early stages of development these approaches have the potential to permanently store significant levels of emissions albeit at costs that are currently at least 10 times higher than those reported for green carbon. These companies are explicitly partnering with large emitters at point sources who capture their emitted carbon dioxide through energy intensive methods and then pay for it to be used as a feed stock for the mineralisation process. This may also be a solution for emitters with no local permanent storage potential[17].

Currently, the proven scale of CCS does not meet demand when it comes to grey carbon technologies. As of 2020, it was reported that globally there are only 21 large-scale CCS plants in operation on an industrial scale (Global CCS Institute 2020). One possibility could be to work with local industry in order to research, develop and implement carbon capture technologies in which the university could invest. However, it is also important to consider that in order to make use of the resulting carbon offset services, the projects would need to have already reached the operational phase. It is therefore no surprise that within the UK Voluntary Carbon Market, (see below) grey carbon technologies are not commonly used compared to woodland and peatland restoration for offsetting.

Making offsetting pay: Voluntary carbon markets

Having considered the potential processes and mechanisms for carbon sequestration, the report now considers how these 'services' can be packaged as carbon market offerings.

[16] See https://www.southampton.ac.uk/blog/sussed-news/2022/12/05/university-scientist-helps-company-win-earthshot-prize/ (Carbfix; 40.01)
[17] See e.g. https://climeworks.com/

In contrast to compulsory carbon markets (CCM) as implemented through emissions trading schemes which cover specific industrial sectors, unavoidable carbon emissions from other sectors may be offset using carbon credits purchased via a voluntary carbon market (VCM) (Norris et al. 2021). A VCM enables governments, businesses or individuals to offset emissions through financing the removal of carbon through technological and natural solutions. As the name implies, the VCM is a voluntary system in which organisations can chose to offset their unavoidable emissions. Although voluntary, the demand for carbon offsets via the VCM is predicted to grow substantially as governments and organisations aim to reach net zero targets in the coming years. This means that the underlying assets providing the sequestration will also grow substantially in value.

Current options: Blue

According to a report by the Blue Marine Foundation, a UK based voluntary blue carbon market is currently under development (Norris et al. 2021). This would ensure the standardisation of using blue carbon projects as carbon offsets across the UK. However, the UK based voluntary blue carbon market is still in the research phase and therefore unlikely to be ready for a few years. As an example, Plymouth City Council are currently piloting a Seagrass Carbon Code[18].

Current options: Green

In contrast a Green carbon based VCM is emerging quite rapidly but only for specific habitats currently. Although it is likely to be formalised in the future, action will still need to be taken to offset unavoidable emissions before this point. Therefore, it is recommended that the University should look into high quality systems that are already in place.

Two current quality standards are:

- The **Woodland Carbon Code** (WCC): a quality assurance standard which produces independently verified carbon credits for UK based afforestation projects (Koronka et al. 2022).
- The **Peatland Code**: quality assurance standard for peatland restoration projects that also provides verified carbon credits (IUCN 2022).

In addition, the Wildlife Trusts' Wilder Carbon scheme combines carbon sequestration with biodiversity restoration via a not-for-profit operation. The scheme is standardised via the Trusts' wilder carbon standards[19] and already has a seagrass restoration project running in the Solent which could potentially be expanded with regional 'offsetting' investment. In addition, the Wilder Carbon scheme offers a service to develop new projects, which could be a further option for the University should there be capacity to invest locally.

Discussion

The University has committed to net-zero Scope 1 and 2 emissions by 2030 which is likely to require offsetting residual Scope 1 and 2 emissions from this date. Depending on ambition this may also need to be extended to include some aspects of residual Scope 3 emissions, such as those from unavoidable business travel. In order to achieve this, the magnitude of unavoidable emissions for the University of Southampton will need to be estimated and a carbon offset plan formulated. This will need to ensure the

[18] See https://www.greenfinanceinstitute.co.uk/gfihive/neirf/
[19] https://www.wildercarbon.com/publications/the-wilder-carbon-standard/

carbon sequestered by projects meets the value of unavoidable emissions alongside other strategic objectives such as local community and regional investment and local biodiversity gain.

Clearly the university should aim to use an accredited carbon offset scheme to ensure the carbon credits are legitimate, additional and meet a high standard of quality. Once the UK voluntary market becomes standardised, there may be more options available for acquiring carbon offsets, but until then it is recommended that an accredited offset provider is used. A better understanding is needed of the Voluntary Carbon Market in the UK and the quality of accredited carbon offset schemes already available. This should be considered in a future research project.

A focus on investing in local, regional or at least UK based projects should be a priority in order to align with the principles of the University's Civic Strategic Plan's prioritised area of "Environment, Sustainability, Decarbonisation and Biodiversity" [20]. Accordingly, investing in local, regional and then UK based projects should be prioritised with international projects considered a last resort to ensure that the University invests as locally as possible, to the benefit of local communities and environments with available capacity. However, given the potentially limited capacity and high demand for sequestration in the Solent region it is likely that UK wide projects will need to be considered.

Although it would be better to sequester all residual emissions in the year they are emitted, a balance between different carbon sequestration projects is more likely given the limited capacity of fast-acting nature-based services. This might mean a mixture of those with the most immediate effect such as seagrass restoration and grey carbon and those with long-term impact such as tree planting or peatland restoration.

More generally, additional research is urgently needed into the potential for grey carbon sequestration in the Solent region, by combining university and industry research. There is scope for carbon capture technologies given the amount of industry in the Solent region, however a better understanding of the potential industry partnerships is needed. It is hard to understand the potential of grey carbon technologies without having an understanding of which technologies may be suitable in the Solent region and how the resulting CO_2 can be permanently stored.

From the blue carbon perspective, the carbon sequestration rate of seagrass and macroalgae in the Solent region needs urgent research. Currently, data is lacking for both blue carbon habitats. First, a better understanding of the extent of seagrass habitats in the Solent region is needed in order to understand the potential of carbon sequestration of this habitat. Secondly, it is suggested that further research is conducted to determine the carbon sequestration rate of both seagrass and macroalgal habitats, in order to understand their potential.

Conclusion

The potential for carbon sequestration in the Solent region is varied, with natural offsets spanning both marine and terrestrial habitats.

In terms of green carbon, there are different options given the variation in terrestrial habitats across the Solent region. Some of these options could be used relatively rapidly should offsetting of emissions be needed in the near term.

[20] https://sotonac.sharepoint.com/:u:/r/teams/UniversityStrategy/SitePages/Civic-Strategic-Plan.aspx

Due to the availability and sequestration potential of blue carbon habitats in the Solent region, the potential of these habitats should be further explored as a priority. This is especially relevant as a project to restore seagrass beds in the Solent is already underway and this activity could be up-scaled and collaborate with the work on the development of a Seagrass Carbon Code currently being undertaken by Plymouth City Council.

There are also a range of options for grey carbon technologies, however the potential of these technologies in the Solent region is harder to assess given that many of these technologies are not currently operational on an industrial scale. Therefore, further research should be undertaken to create a clearer picture of which grey carbon technologies may be appropriate in the Solent region.

Overall, although there are clear options for nature-based carbon sequestration in the Solent region, in the absence of significant grey carbon development it is likely that these options alone may not meet the scale required to offset the University of Southampton's unavoidable emissions. This will be increasingly the case as more organisations compete for 'offsets' via the VCM. Therefore, it is recommended that the University develop an offsetting framework that could be deployed if required.

In order to align with the University's Civic Strategic Plan[21], and especially the prioritised area of "Environment, Sustainability, Decarbonisation and Biodiversity", local, regional and then UK based projects could be prioritised with international projects considered a last resort. This would ensure that the University invests as locally as possible, to the benefit of local communities and environments with available capacity. Further research is therefore needed to provide a better understanding of available accredited carbon offset schemes at the local and national levels.

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[21] https://sotonac.sharepoint.com/:u:/r/teams/UniversityStrategy/SitePages/Civic-Strategic-Plan.aspx

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