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Afforestation's potential to help Cambridgeshire reach net-zero by 2050

Communication | Editorial | Invited contribution | Perspective | Report | Review

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Abstract

I present a preliminary assessment of afforestation's ability to help Cambridgeshire reach net zero emissions by 2050. Considering 7 different planting scenarios with different tree species over 3,000 hectares (about 1% of the county), I calculate a maximum cumulative net sequestration of 1.44 Mt CO_2 over the period 2020-2050, about 2.3% of the county's projected total emissions over that period under an ambitious decarbonisation strategy (or about double the county's projected emissions in the single year 2050). In addition, a methodology for calculating carbon sequestration and the associated abatement cost is presented, with sensitivity to land price and timber revenue explored. I calculate abatement costs of £20-50 per tonne CO_2, considerably less than those from bio-energy carbon capture and storage (BECCS) and direct air carbon capture and storage (DACCS), although it depends strongly on timber price. This suggests afforestation has the potential to be a cost-efficient method for contributing to Cambridgeshire's ambitious climate change strategy, but significantly larger areas would need to be planted if it were chosen to be a major driver in reducing net emissions.

Introduction

Reforestation and afforestation, the acts of replanting trees in deforested regions and in regions without previous tree cover respectively, have been identified as a key method for reducing net carbon dioxide emissions globally, a vital for mitigating climate change. A recent paper in *Science* stated that '*the restoration of trees remains among the most effective strategies for climate change mitigation*' [1] and the UK's Committee on Climate Change Net Zero report identified an afforestation target of 20,000 hectares per year increasing to 27,000 by 2025 [2]. In contrast to Direct Air Capture (DACCS) and Carbon Capture and Storage (CCS), afforestation does not require infrastructure to transport and store captured CO_2. In addition to sequestering CO_2, afforestation, when properly planned, can enhance biodiversity and inhibit soil erosion while also benefiting the public by providing places for exploration and recreation [3]. Programmes in Scotland increasing the public's interaction with woodland have been shown to help contribute to positive mental health in a cost-efficient manner [4]. Afforestation efforts have significant political support, appearing in the 2019 General Election manifestos of the Conservative, Labour and Liberal Democrats [5]. However, quantitative analysis of the amount of carbon sequestered by afforestation is less common but is crucial if countries are to continue to calculate accurate greenhouse gas emissions inventories and if afforestation is to be carried out efficiently as a mean of mitigating climate change.

A preliminary assessment of afforestation's potential to help Cambridgeshire reach net zero formed part of the report 'Net Zero Cambridgeshire' written in partnership with Cambridgeshire County Council (CCC) [6]. The report was presented to the CCC's General Purposes Committee and accepted as part of the evidence base for CCC's Climate Change and Environment Strategy. Here I describe the methodology for calculating the carbon sequestered by afforestation in brief and the respective results focusing on the extent of necessary afforestation, estimated abatement cost, and timescale of sequestration.

Cambridgeshire's Emissions

Cambridgeshire's total greenhouse emissions in 2016 were 6.1 Mt CO_2e (mega-tonne of carbon dioxide equivalent) [6]. Two scenarios, 'business as usual' (BAU) and 'ambitious' were considered for future emission projections. The BAU scenario considered only current or planned emission reduction policies, following the Steady Progression National Grid Electricity System Operator (ESO) Future Energy Scenario (FES) [7] for electricity and gas demand and decreases in the National Grid's carbon intensity following projections from the Department for Business Energy and Industrial Strategy [8]. In this scenario net annual emissions fall to 3.5 Mt CO_2e by 2050 (43% reduction). A major driver of this decrease is the decarbonisation of the national grid. In the 'ambitious' scenario, net annual emissions decrease by 90% to 0.6 Mt CO_2e with significant additional emission reductions predicted in the transport, domestic housing and commercial buildings sectors. This is driven in part by a significant decrease in gas demand due to adoption of low carbon heating, and transport emissions decline by 95% due to total electrification of cars and buses. However full decarbonisation is highly unlikely, as electricity generation in 2050 won't be zero-carbon intensive [8] and because decarbonising certain industries, such as agriculture, is challenging. In order to reach net-zero, there is a need to explore negative emission options such as afforestation.

Carbon Sequestration

To calculate cumulative net sequestration of carbon dioxide over time for different combinations of tree species, data was used from the Woodland Carbon Code (WCC) [9], the UK standard for afforestation projects for climate change mitigation. An area of 3,000 hectares (ha, 11.7 sq. miles or 30 km^2, equivalent to about 1% of Cambridgeshire) was considered for these calculations, and seven different planting scenarios (Table 1) spanning coniferous and broadleaf species covered by the WCC data were investigated. Some of the species considered like Sitka Spruce are commonly used in afforestation while others like the native woodland mix would promote slower growing, more diverse woodland. Spacings on a range between 1.5 and 3 metres were considered, with 3m spacings resulting in about 1,100 trees per hectare. Thus 3,000 ha would result in 3-7 million trees being planted in Cambridgeshire, an order of magnitude greater than the total number planted since 2000.

Methodology and Assumptions

The cumulative net sequestration after a given period of time after planting is defined as the carbon dioxide sequestered by the trees and soil less the carbon emitted from soil disturbance and other establishment processes, calculated following WCC guidance [9]. Sequestration from the trees was calculated using inputs of tree species, tree spacing, yield class, and management regime. The yield class for the different species were determined using tools from the Forestry Commission (in line with WCC guidance) [10]. Yield class defined as the average volume (m^3) of wood produced by a tree species per hectare (ha) per year and it is a proxy for the suitability of a particular

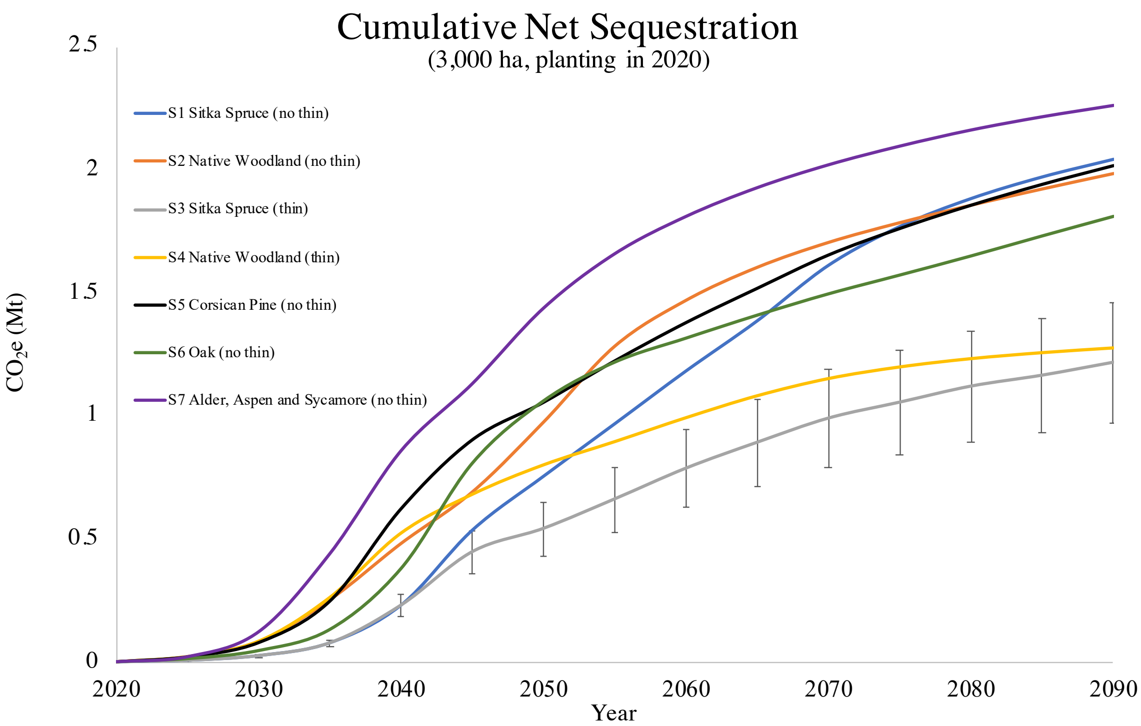

Figure 1: **Cumulative net sequestration with time.** The mixture of Alder, Aspen and Sycamore results in the greatest sequestration, while both simulated scenarios in which thinning occurs every 5 years ('thin') show substantially lower sequestration. Errors bars have been included for one scenario to provide an idea of the uncertainty in the model.

tree species for a certain location: a species of yield class 10 produces 10 m^3/ha/year of wood.

The yield class for a particular tree species is strongly dependent on the soil quality and species. Slow growing species such as Oak have yield classes between 4 and 10 while fast growing species such as Sitka Spruce and some pines have yield classes which can exceed 20 in the right conditions. Soil quality is parameterised using two metrics: Soil Moisture Regimes (SMR) and Soil Nutrient Regimes (SNR). These describe the level of moisture and nutrients in the soil respectively. SMR ranges from very moist (deep peat) to very dry (shingle), while SNR varies between very poor (deep peat) to very rich while also having the option of carbonate which restricts the species suitable for planting. In this study, values for SMR and SNR of 3 (very moist) and 5 (very rich) respectively were used as these conditions are found throughout Cambridgeshire and are suitable for a range of species. The management regimes considered were thinning once every 5 years or with no thinning at all; both were explored (Table 1). Finally, for each scenario, the carbon sequestered by trees was reduced by 20% in line with WCC guidance to account for uncertainty in the underlying data before calculating the cumulative net sequestration.

Soil carbon sequestration, which averages about 0.55 tCO_2 per ha per year, was also included for all scenarios which had no thinning following the WCC protocol. Disturbing the soil when planting can release carbon dioxide, and these emissions were included in the calculations. The quantity of CO_2 emitted depends on the soil type, previous land use, and level of soil disturbance. The soil type was assumed to be mineral, a fair assumption in Cambridgeshire; the chosen previous land use was arable given the dominance of crop agriculture for land in Cambridgeshire; and soil disturbance as low following the WCC's definitions. The validity of such assumptions will vary between planting locations, but they are not anticipated to have a significant effect on the cumulative sequestration after 20 years of growth. Additional establishment emissions from fuel used during ground preparation (0.06 tCO_2 per ha) and seedlings (0.38 tCO_2 per ha) were included in accordance with WCC guidance. Emissions from tree felling and processing of the timber was not included.

The plots of cumulative net sequestration with time (Figure 1) show that over the 30 years to 2050, the cumulative net sequestration varies considerably between scenarios with the mixture of Aspen, Alder and Sycamore (1.44 Mt CO_2e) sequestering well over twice as much as the thinned Sitka Spruce (0.54 Mt CO_2e). This highlights the importance of assessing potential carbon sequestration and planting the optimal mixture of trees when deciding on planting strategies. The increase of sequestration with time is also highly non-linear with a slow initial increase followed by a faster increase commencing at around 15 years of age. This illustrates an important feature of sequestration by afforestation: that of a time lag at the start where cumulative sequestration is small for several years. Thus, the sooner trees are planted, the better, particularly given the urgent requirement to reduce net carbon emissions. In the context of Cambridgeshire's emissions, planting 3,000 ha is predicted to sequester 0.9-2.3% of the county's total emissions between 2020-2050 (Table 1) or around 100-200% of the emissions predicted to occur in the year 2050.

Cost of the intervention

In addition to the net sequestration of carbon, the associated costs were estimated to allow for calculation of the abatement cost (AC) which is defined as the cost per tonne of CO_2 sequestered. The major costs were taken to be cost of trees, planting, purchase or rental of land, and the cost of managing the land. Financial support from the Government and revenue from timber sales were considered as means to reduce the abatement cost. The cumulative net CO_2 sequestration over a 30-year period (2020-2050) was considered assuming planting in 2020. The abatement cost is described by the following Equation:

$$AC = \frac{(\mathrm{T} + \mathrm{P} + \mathrm{L} + \mathrm{M}) - (\mathrm{G} + \mathrm{S})}{\mathrm{CO}_2^{\mathrm{seq}}} \qquad (1)$$

where T is the purchase cost for the trees, P is the planting cost, L is the land cost, M is the management cost, G is the government support, S is the sales from timber, and CO_2^{seq} is the cumulative net CO_2 sequestration.

Methodology and Assumptions

The cost of land was the most dominant factor, and four scenarios were considered: renting land from either the 12,000 ha Rural Estate (RE) owned by CCC at £327 per ha per year (strictly an opportunity cost in the case of the CCC using their own land for afforestation), renting land at the East of England (EoE) average rate of £240 per ha per year on Full Agricultural Tenancy [11], or purchasing Grade 3 farmland (£7,500 per acre [12]) or grazing land (£4,500 per acre [12]).

Wholesale purchase of trees of £0.40 per tree[1], planting costs of £1,250 per ha [13], management costs £150 per ha per year without thinning (thinning scenarios had an additional £1000 per ha every 5 years) and staffing costs (£75,000 per year) were included. Financial support from the UK Government for purchasing trees, in the form of the TE4 Capital Grants scheme (£1.28 per tree) [14], was also included.

Revenue from timber sales was estimated. Multiplying the duration of tree growth by the yield class gives the volume of wood per hectare. While timber prices are a source of considerable uncertainty, they have shown long-term growth [15], increasing by 130% over the last 20 years (coniferous wood, sold standing) and a drive to use more sustainable materials in construction such as wood over concrete is expected to increase demand in the future. Data for softwood prices (pine, spruce etc.) were used for all species due to a lack of reliable data for other species. This means that the calculated abatement costs calculated are likely to be lower bounds. To account for this uncertainty as well as for other unforeseen costs, the total wood yield was halved to produce a more conservative estimate. In addition, the AC shown in Table 1 also includes the scenario where there is no revenue from wood sales. It is also assumed that the wood sold is not combusted (but is instead used in construction, paper, or other applications that do not release the stored CO_2).

[1] Price determined from a wholesale tree supplier (April 2020).

Table 1: **Scenario Details, Net Cumulative Sequestration (2020-2050) and Abatement Cost.** YC: yield class [m^3/ha/year], CO_2^{seq}: cumulative net CO_2 sequestration, AC: abatement cost, *Assuming 5% year-on-year drop in emissions (~80% reduction by 2050), ** Assuming planting on Rural Estate, *** Native Woodland: 20% Oak , YC 8; 20% Sycamore, YC 10; 20% Birch, YC 4; 8% Aspen, YC 10; 10% Alder, YC 6; 10% Rowan, YC 4; 12% Willow, YC 4; all spacings 2.5m, except for Oak at 2m (WCC Standard Example 2).

Scenario	**Scenario Description**	**CO_2^{seq}(% of total 2020-2050 emissions*) [Mt CO_2]**	**AC** with and (without) timber sales [£ per tCO_2]**
S1	Sitka Spruce, 2 m, YC 12	0.76 (1.2%)	34 (57)
S2	Native Woodland***	0.98 (1.6%)	35 (44)
S3	Sitka Spruce, 2 m, YC 12, thinned	0.54 (0.9%)	80 (112)
S4	Native Woodland,*** thinned	0.75 (1.2%)	65 (76)
S5	Corsican Pine, 1.5 m, YC 14	1.06 (1.7%)	22 (41)
S6	Oak, 3 m, YC 6	1.06 (1.7%)	32 (40)
S7	Alder YC 6, Aspen YC 10, Sycamore YC 10, spacing 3m (equal fractions)	1.44 (2.3%)	20 (30)

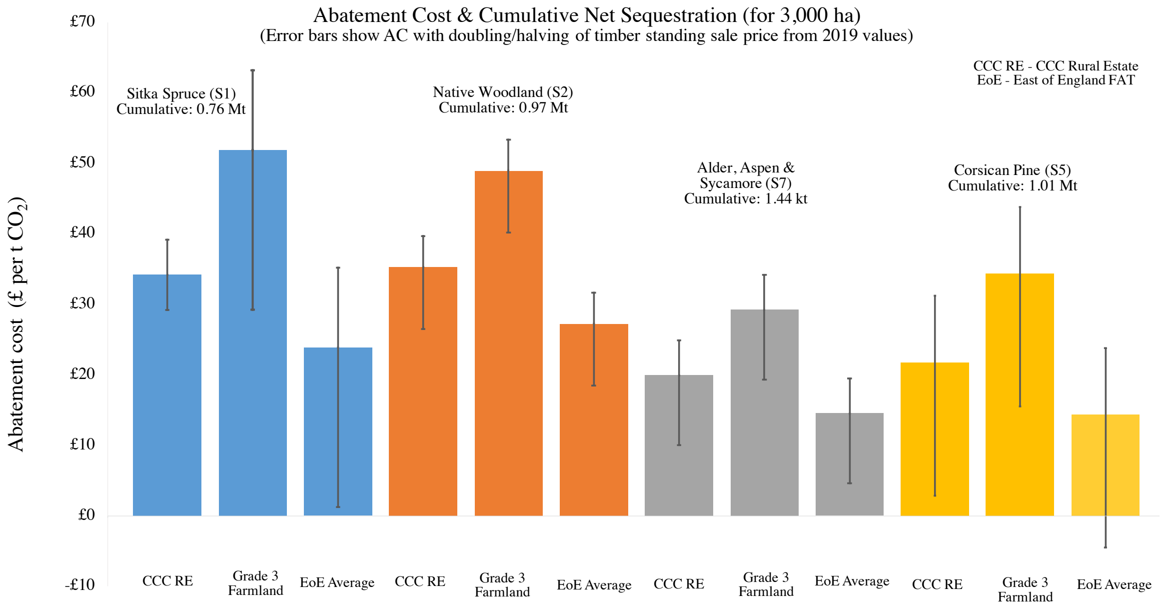

Figure 2: Abatement cost and Cumulative Net Sequestration for 4 planting scenarios in 3 different land scenarios: CCC Rural Estate (RE), Grade 3 Farmland [12], and East of England Full Agricultural Tenancy [11]. Sensitivity to the timber price [15] indicated by the doubling/halving the value (indicated by error bars) is shown to be a major driver of the calculated AC, particularly for the plantings that rely on high timber yield. Therefore, consideration of future timber price is important for more comprehensive afforestation studies.

To understand the influence of the timber price on the predicted AC, the AC was calculated with no timber revenue (Table 1) and under situations where the timber price was doubled and halved (relative to 2019 value) on RE, EoE and Grade 3 farmland. These changes resulting in average AC changes of -£15 and +£8 per tCO_2 respectively across the scenarios (Figure 2). The EoE and GZ option had ACs as low as £16 per tCO_2 for Scenarios 5 and 7. The magnitude of this uncertainty means that any plans for afforestation should consider timber price projections carefully and account for potential fluctuations.

Conclusion

This preliminary investigation suggests afforestation in Cambridgeshire could have an abatement cost of £20-50 per tonne CO_2 evaluated over a 30-year period and play an important role in helping the county reach the target of net-zero emissions by 2050. However, if afforestation is to be employed as major driver for reducing net carbon emissions in Cambridgeshire, an area fraction considerably larger than 1% of the county would be needed; even afforesting 10% of the county would not be sufficient on its own to reduce the county's emissions to net zero. Decarbonisation of energy generation, a reduction in private car usage and electrification of transport, a transition away from gas for heating, and a reduction in meat and dairy consumption are all necessary actions. Nevertheless, several important conclusions about afforestation can be drawn.

Sequestration varies significant between different planting scenarios, with the most efficient scenario examined here sequestering 2.6 times more CO_2 than the least efficient. This highlights the critical importance of quantifying the carbon sequestration of planting strategies if afforestation is to be performed efficiently. Of the scenarios considered, an Alder/Aspen/Sycamore mix is predicted to result in the highest sequestration with 3,000 ha (about 1% of county's area) sequestering, over a 30-year period, around 1.4 Mt CO_2e. If the county follows an ambitious decarbonisation strategy [6], such a level of sequestration is likely to amount to more than 2% of the county's cumulative emissions over that time and, after 2050, a considerably greater fraction as forest sequestration rises and anthropogenic emissions continue to fall. Sitka Spruce and other coniferous species delivered lower cumulative sequestration but are likely to be important to ensure a supply of softwood, a commodity in higher demand, and thus increase the financial return and lower abatement costs. Native woodland would also lead to significant sequestration and, if properly managed, help promote biodiversity by ensuring a mixture of species.

The abatement costs calculated in this work are higher than the nation-wide average value of £12 per tCO_2 suggested by the Committee on Climate Change [2]. One reason for this difference is likely to be to higher land costs in England with the Committee on Climate Change considering afforestation on a national scale including regions of Scotland where agriculture is not as efficient and thus land prices are lower. Furthermore, the abatement costs are significantly lower than the marginal abatement costs predicted for Bioenergy with CCS (£158 per tCO_2) or DACCS (£300 per tCO_2) [2], suggesting afforestation is still a cost-efficient method for removing CO_2.

The abatement costs calculated here also showed significant dependence on timber prices, highlighting the importance of future timber demand in the viability of any project. Therefore, afforestation on a commercial scale is likely to be much more feasible if more policies are introduced which incentivise the use of timber in construction and other industries. Such policies would have a dual environmental benefit of promoting the safe, reliable removal of carbon dioxide from the atmosphere as well as reducing the usage of energy and carbon intensive materials of concrete and steel. In addition, well-regulated markets for timber, tied into sequestration verifying bodies like the WCC, would also help promote sustainable practices by both foresters and purchasers, aiding the industry.

The modelling presented in this work is a first step but provides a strong basis for further planning of afforestation projects. Such projects should include a thorough consultation with an ecologist to consider the effects on biodiversity; maximising carbon sequestration should not come at the expense of all other environmental concerns. The effect on the water table (an important issue in Cambridgeshire [16]) should also be considered along with the development of an efficient business plan to maximise revenue from wood sales. Furthermore, other stakeholders, such as farmers, should be consulted to ensure afforestation brings them benefits to them as well; for example, selecting trees that will return more nutrients to the soil or reduce soil erosion. It should also be noted that afforestation will need to compete with other land uses [17]. Future climate change is likely to make land less productive, and increasing population will place a higher demand on land for agricultural output.

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About the Author

James Weber read Natural Sciences (Chemistry) at the University of Cambridge before starting a PhD in the Department of Chemistry in atmospheric modelling and climate change. His research focuses on the interactions between the biosphere and climate, mediated via the chemical oxidation of biogenic volatile organic compounds, and how these processes will influence future climate. He has also been involved in the 6th Coupled Model Intercomparison Project (CMIP6) looking at biogeochemcial feedbacks which will contribute to the evidence base used by the Intergovernmental Panel on Climate Change (IPCC).

Conflict of interest The Author declares no conflict of interest.

Data availability All data is available upon request from James Weber.