Carbon-Smart Forestry: What Could it Look Like?

Robert Matthews and **Carly Whittaker** introduce the concept of Carbon-Smart Forestry, which involves how forest management affects the carbon balance and encourages understanding of wider processes other than just carbon uptake in trees.

Carbon-Smart Forestry can be viewed as an important component of Climate-Smart Forestry. Carbon-Smart Forestry is defined as *the act of planning and carrying out forest management with awareness of potential impacts on the carbon balance*. Note that this does not place the consideration of forest carbon as the central or most important goal for forest management, given that in reality, forestry must meet multiple objectives.

This article sets out the principles of Carbon-Smart Forestry as of today, and how managing existing woodlands can help contribute towards carbon sequestration, alongside woodland creation activities.

Why think about carbon in woodlands?

Forest carbon is important because of its role in the global carbon balance and its contribution to aggravating or mitigating climate change. Ever since the rising level of carbon dioxide in the atmosphere has been identified as a significant driver of global warming, deforestation and the denuding of forest ecosystems (resulting in the release of forest carbon to the atmosphere) has been identified as the most important cause of carbon dioxide emissions after the burning of fossil fuels (Canadell et al., 2021). At the same time, the restoration of forest ecosystems, and actions to conserve and enhance the carbon retained in them, are recognised as important to efforts to reduce net emissions (IPCC, 2019).

In the UK, forests represent a relatively small part of the national emissions budget but are nevertheless important for achieving the UK's commitment to reach net zero emissions by and beyond 2050 (CCC, 2025). The Intergovernmental Panel on Climate Change (IPCC) has modelled options for socio-economic pathways to get to net zero emissions (Riahi et al., 2022) and highlights the vital role that 'carbon dioxide removal' (CDR) from the atmosphere has in getting to these targets. While industrial technologies can achieve CDR, none have been deployed at a large scale.

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By contrast, carbon sequestration in terrestrial vegetation and soil is a natural carbon capture process, and woodland carbon sequestration is the most important option. So, what can forestry practitioners do to deliver carbon sequestration on the ground in their woodlands?

The essential science of forest carbon

Most people working in the forestry sector will have heard of forest carbon sequestration and have some understanding of the concept. Growing trees capture carbon dioxide from the atmosphere during the process of photosynthesis, combining carbon with water to produce hydrocarbons that make up their tissues, while releasing oxygen. Carbon in plants is released again by the processes of respiration, mortality and decay, or through consumption of plant matter by animals, fungi and bacteria. Carbon is then transferred to other parts of

woodland ecosystems, such as deadwood, litter and soil, or immediately returned to the atmosphere. Trees may also be harvested, transferring some carbon into wood products. The unutilised material may be left behind as deadwood or may sometimes be disposed of by burning. If the inputs of carbon to the woodland from photosynthesis are greater than the losses from the various processes outlined above, then carbon is retained in the woodland. This process is referred to as *carbon sequestration,* and the total *carbon stock* is the result of carbon sequestration accumulated over time (Figure 1).

As forests grow older, eventually the rate of CO_2 removed from the atmosphere is balanced by the CO_2 returned to the atmosphere, and the forest will reach an equilibrium carbon stock (when averaged over a few years). The forest will then remain in balance unless there is some kind of disturbance, such as a harvesting event, or naturally occurring event such as a storm, fire, drought or disease outbreak (Forest Research, 2025).

Carbon sequestration as defined above is *not* simply the process of *carbon uptake*, which is more analogous to *forest (stemwood) increment*, a quantity more familiar to forestry practitioners. Results for carbon uptake and carbon sequestration in a woodland can be drastically different. For this reason, focusing on carbon uptake or increment when assessing woodland management options can lead to false conclusions about the effectiveness of strategies for maintaining or enhancing carbon sequestration.

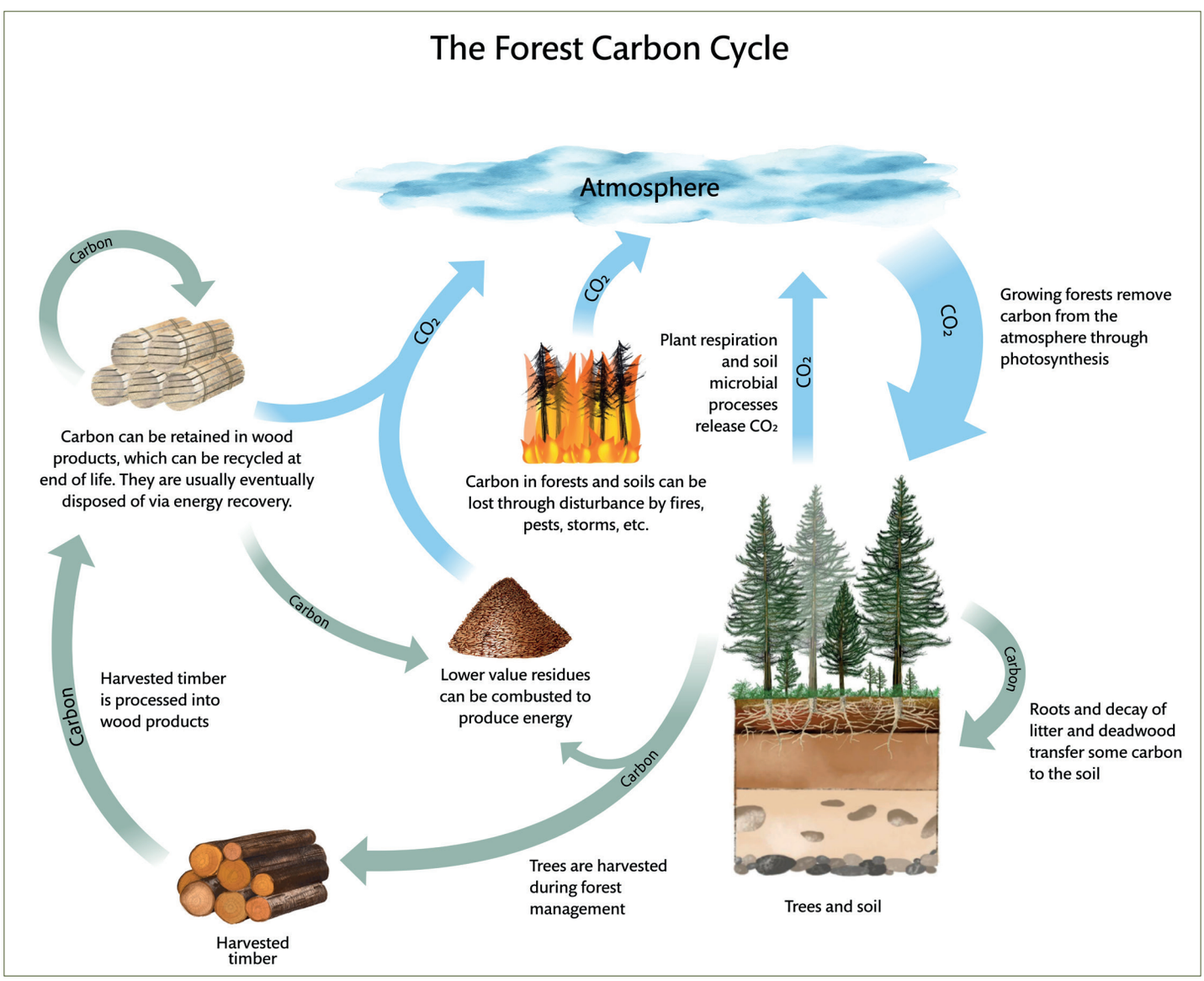

Figure 1. The Forest Carbon Cycle. An outline of the forest carbon cycle showing how forests provide a route to sequester carbon in land and soil, and that harvested wood products can be used to displace fossil fuels and provide a long-term carbon store until they are disposed of. Forests and soils can also be disturbed by human behaviour or natural disturbance which can release stored carbon back to the atmosphere. (Image: © Crown copyright, Forest Research)

How much carbon is there in woodlands?

The size of the carbon stock in woodlands depends on many factors such as tree species, soil type, climatic conditions and tree growth rate (yield class). The carbon stock in a stand of trees also varies considerably over time, depending on the age of the trees and how they are managed. With the exception of peatlands, woodlands typically have higher combined carbon stocks in trees and soil than any other vegetation type, as illustrated for England in Table 1.

At a UK national scale, soil carbon represents nearly 70% of the total stock in woodlands (Forest Research, 2025). This high proportion reflects large areas of woodlands on peaty soils in upland areas. A major survey of GB woodland sites (Vanguelova et al., 2013) has shown that soil carbon stocks can vary considerably depending on the soil type, with estimates to 1 m depth ranging from about 100 tonnes per hectare in shallow soils, to 150–200 tonnes per hectare in mineral soils, around 350 tonnes per hectare in peaty soils, and up to 500 tonnes per hectare and beyond in deep peats planted with woodland.

After soil, trees represent the next biggest component of carbon stocks in woodlands. In general, for woodland-grown trees, the stem is the largest component of the tree carbon stock, at 50–65%, while roots make up 20–30%. Tree carbon stocks range from 0 for a new planting site up to a maximum of approximately 200–300 tonnes carbon per hectare (Broadmeadow and Matthews, 2003; Morison and Matthews, 2023).

Table 1. Estimates of carbon stocks in different vegetation types and their soils (England only).

	Carbon stocks (tC ha^{-1})		
Vegetation/soil type	**Soil**	**Vegetation**	**Total**
Woodland (mean for England)	274	86	394
Improved grassland	72-229	4	76-233
Unimproved grassland	274	4	278
Upland and lowland heathland	280-381	2-9	282-390
Hedgerows	67-176	25-46	92-222
Arable and horticultural	120	4	124

Notes:
1. Total carbon stocks for woodland also includes contributions from deadwood and litter.
2. Estimates in the table are based on a synthesis of available published evidence, with results selected to ensure comparability of results for different vegetation types as far as possible. Sources: Gregg et al. (2021), Vanguelova et al. (2019), Chapman et al. (2013), Zerva and Mencuccini (2005), Forest Research (2025).

Additional small components of total UK woodland carbon stocks are contributed by deadwood and litter, estimated at 3.9% and 4.7% respectively, though variability in these carbon stocks can be very high.

At UK scale, broadleaved and conifer woodlands make roughly equal contributions to tree carbon stocks (240 million tonnes carbon), but the importance of broadleaves and conifers varies with country. According to National Forest Inventory statistics for the year 2020 quoted by the JNCC (2025), broadleaved woodland trees contribute most of the tree carbon stocks in England (73%), with conifers making the bigger contribution in Scotland and Northern Ireland (78% and 66% respectively). The contributions are roughly equal in Wales (52% broadleaves, 48% conifers). On the whole, these results reflect the relative areas of broadleaves and conifers in the four countries.

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Forest Research applied a forest carbon model to produce consistent estimates of woodland carbon sequestration potential for a wide range of broadleaved and conifer woodland types (Matthews et al., 2022). The results suggest that both types of woodland can sequester similar amounts of carbon, given the site types and climatic conditions present in the UK. The main distinction is that broadleaved woodlands usually take longer to accumulate high carbon stocks, but these stocks may be more enduring than in faster growing conifer woodlands that are managed on commercial rotations for wood production.

To put the above estimates of UK woodland carbon stocks into perspective, in 2024, total greenhouse gas emissions were estimated to be equivalent to 371 million tonnes of carbon dioxide (DESNZ, 2025). The entire UK woodland carbon stock is thus holding slightly less than three years of emissions at current rates out of the atmosphere, although a large part of this stock is in woodland soils, which will have accumulated carbon over very long timescales. This stresses the importance of reducing emissions across the wider economy if woodland carbon sequestration is going to help with achieving net zero emissions.

The principles of Carbon-Smart Forestry

If we focus on what is within the power of woodland planners and managers to influence in terms of carbon in their woodlands, there are several opportunities to act. These have been the subject of many reviews (Schelhaas et al., 2006; Schlamadinger et al., 2007; Nabuurs et al., 2007; Mason et al., 2009; Standing Forestry Committee, 2010; Matthews et al., 2017; Matthews, 2020; Verkerk et al., 2022; Strengers et al., 2024) and are generally grouped into:

- Creation of new woodland areas (afforestation).
- Prevention of woodland loss (avoidance of deforestation).
- Conservation or enhancement of carbon in existing woodlands, including protection against disturbances and extreme events such as fires, storms and disease outbreaks.
- Enhancing wood production in existing woodlands, to achieve substitution benefits in other sectors.

The respective carbon sequestration and conservation benefits of woodland creation and preventing forest loss are relatively well understood, so the next two sections focus on the two latter categories.

Conservation or enhancement of carbon in existing woodlands

The conservation or enhancement of carbon in existing woodlands may require a holistic assessment of numerous factors, including site conditions, potential productivity, vulnerability to natural events and proximity to point of use of wood products. It may not be realistic to expect forestry practitioners to carry out in-depth evaluations of these factors in the routine planning and management of woodland, but decisions could be based on a common set of high-level principles (distilled from a combination of Broadmeadow and Matthews, 2003; Verkerk et al., 2022; Matthews, 2020; Matthews et al., 2022) as set out below:

Soil and litter – conserve carbon stocks

When creating new woodlands, aim to conserve carbon stocks in soil and litter by avoiding creating woodlands on highly organic soils. During woodland creation, keep soil cultivation to the minimum needed to ensure effective tree establishment and growth, while avoiding soil carbon loss as far as possible.

Figure 2. Conserve existing carbon stocks during harvesting operations by avoiding ground disturbance and soil compaction wherever possible. (Photo: © Crown copyright, Forest Research)

While soil carbon stocks in existing woodlands are usually significant, the rate of accumulation can be slow, and soils can lose carbon quite quickly if disturbed by excessive ground preparation during woodland creation or during harvesting and restocking of woodland. The first priority for management of woodland litter and soil carbon is therefore to ensure conservation of the existing carbon stocks, by avoiding ground disturbance and soil compaction wherever possible during silvicultural and harvesting operations (Figure 2).

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Deadwood – conserve or manage carbon stocks

Conserve or manage carbon stocks in deadwood, litter and soil. On occasion, if your management plan considers impacts on woodland carbon and other ecosystem services (such as habitats, flood risk and fire risk), a proportion of deadwood arising from harvesting operations (forestry residues) may provide a resource of wood energy or biomass feedstock.

Trees – conserve, enhance and manage carbon stocks

Conserve or enhance carbon stocks in trees, at the scale of the woodland, depending on local circumstances and wider objectives. This could be achieved by extending rotations in even-aged managed stands or avoiding clearfelling through adoption of continuous cover forestry. More extreme actions

might involve strict limits on wood harvesting in managed stands and supporting transformation to intact high conservation value ecosystems with high carbon stocks.

One common feature for all actions, however, is that any carbon sequestration will eventually saturate in the long term. There may be trade-offs between prioritising the conservation of woodland carbon stocks and wood production. Sites and climates that can support very fast-growing trees provide opportunities to manage woodlands for commercial wood production, either involving clearfelling or continuous cover management practices, and can support greenhouse gas emissions mitigation through a combination of enhanced carbon stocks and increased timber and wood energy supply. On the other hand, sites and climates where trees are likely to grow slowly may be suited to the creation of woodland reserves and semi-natural woodlands, by establishing enduring broadleaved tree species and managing them for high carbon stocks.

Building resilience into forest planning, by considering how to mitigate risks from environmental threats, will help ensure conservation of carbon stocks and maintenance of carbon sequestration. Avoid creating and restocking woodlands with stands of only a few tree species, and consider whether developing multi-species mixtures within stands can support resilience.

Forest operations – keep emissions to a minimum

Aim to minimise greenhouse gas emissions during forestry operations. Although not a major part of the carbon story, reducing the use of fossil fuels during site preparation and harvesting operations, and for timber transport, will help. Make only essential use of fertilisers.

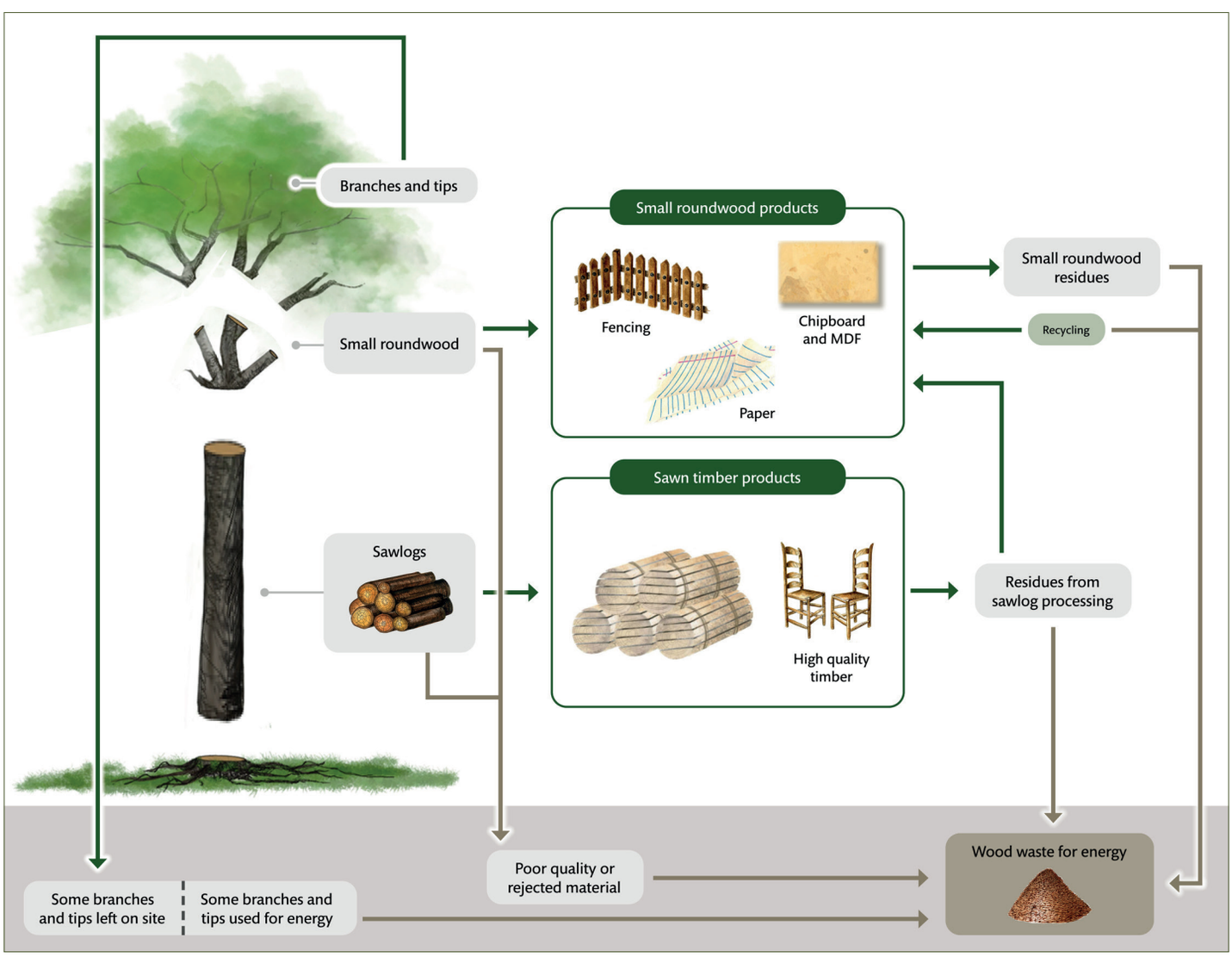

Figure 3. The Wood Product Carbon Pool. The carbon in harvested wood leaves the forest carbon stock and enters various wood-based product pathways, where carbon will be retained until processing residues and final waste products are disposed of. (Image: © Crown copyright, Forest Research)

Enhancing wood production in existing woodlands

Enhancing wood production in existing woodlands can be achieved by adjusting rotations so they are closer to the productive maximum, 'mobilising' production from previously undermanaged woodlands, and promoting innovative uses of timber offcuts and branchwood, where suitable markets can be found.

Although wood is a renewable resource, it is also a scarce resource. Ensuring its most effective and efficient use as a carbon mitigation tool could involve aiming to:

- Make best use of wood in enduring wood products or in end uses that will help avoid consumption of fossil fuels or high-emissions materials.
- Using wood-based products according to the principles of a 'circular economy': reuse, repurpose, recycle, recycle again, and dispose by burning with energy recovery in preference to landfilling (Figure 3).

Strictly, activities in the wood processing and end-use sectors are outside the scope of woodland planning and management. But it is worth noting that a joined-up approach across the wood supply chain and wider economy could lead to synergies that maximise emissions reductions and support the achievement of net zero emissions.

Carbon-Smart Forestry: just another factor in design planning

In conclusion, while the concept of Carbon-Smart Forestry is understandable, this article hopefully demonstrates that forestry practitioners can avoid focusing on woodland management for carbon as an end in itself and instead think about how to harmonise woodland carbon with management for other objectives and with practical constraints.

It may be difficult to apply Carbon-Smart Forestry to individual stands or very small woodlands, because of challenges in balancing trade-offs and synergies at small scales. Woodland carbon stocks can also vary significantly over time at smaller scales, making it harder to verify benefits of any management interventions aimed at carbon conservation or sequestration. The exception is when creating new woodlands, where the changes in vegetation carbon stocks compared to the previous land cover are usually easier to distinguish.

The size of the challenge of meeting net zero emissions means we need every tool in the box to help get there. Carbon-Smart Forestry represents a way of thinking, and an approach to practice, whereby woodland owners, planners and managers can contribute towards this goal, within the well-understood context of multipurpose forestry.

You can find out more about key carbon topics in the Forest Research Climate Change Hub (Figure 4).

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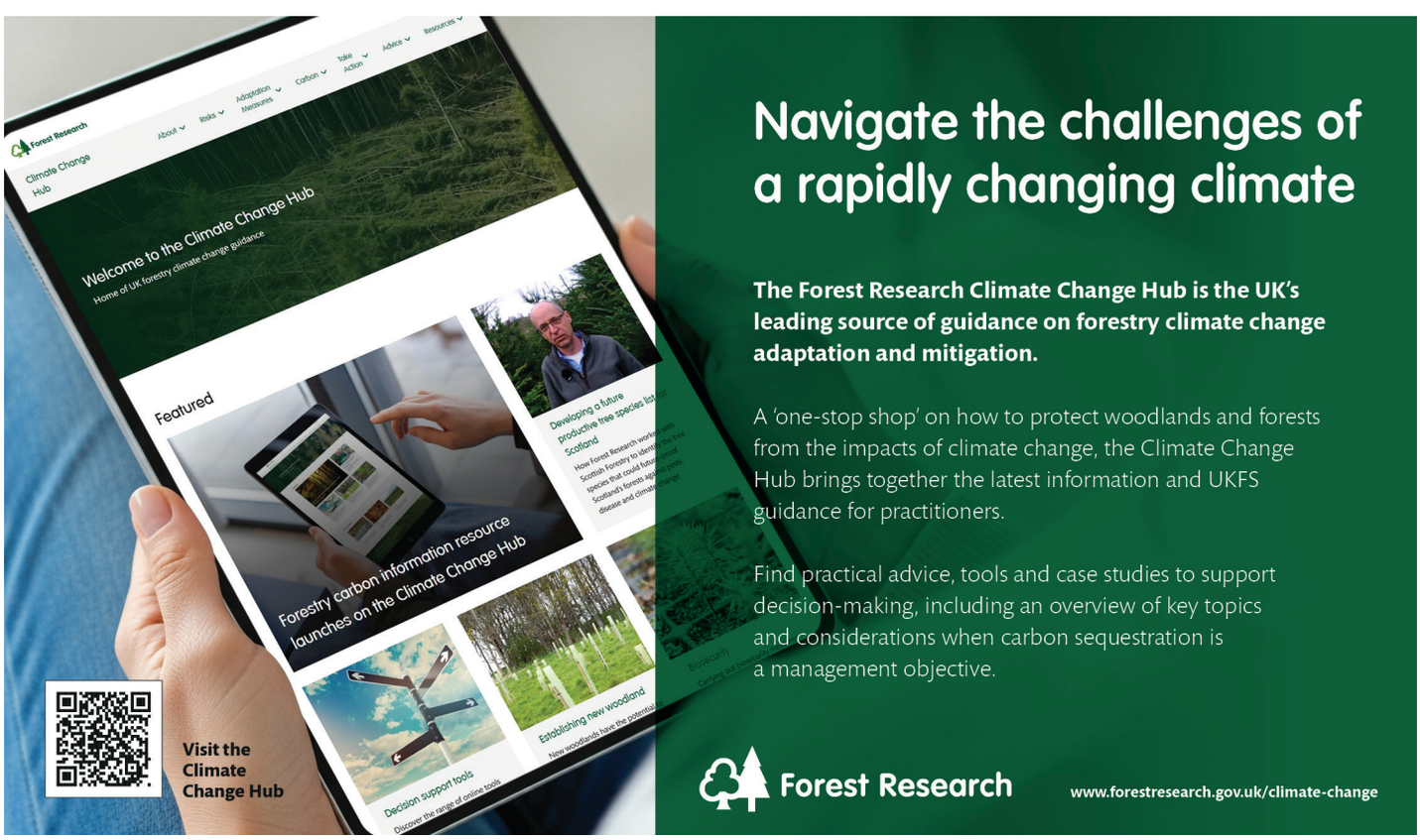

Figure 4. The Forest Research Climate Change Hub is the home of UK forestry climate change information and guidance.