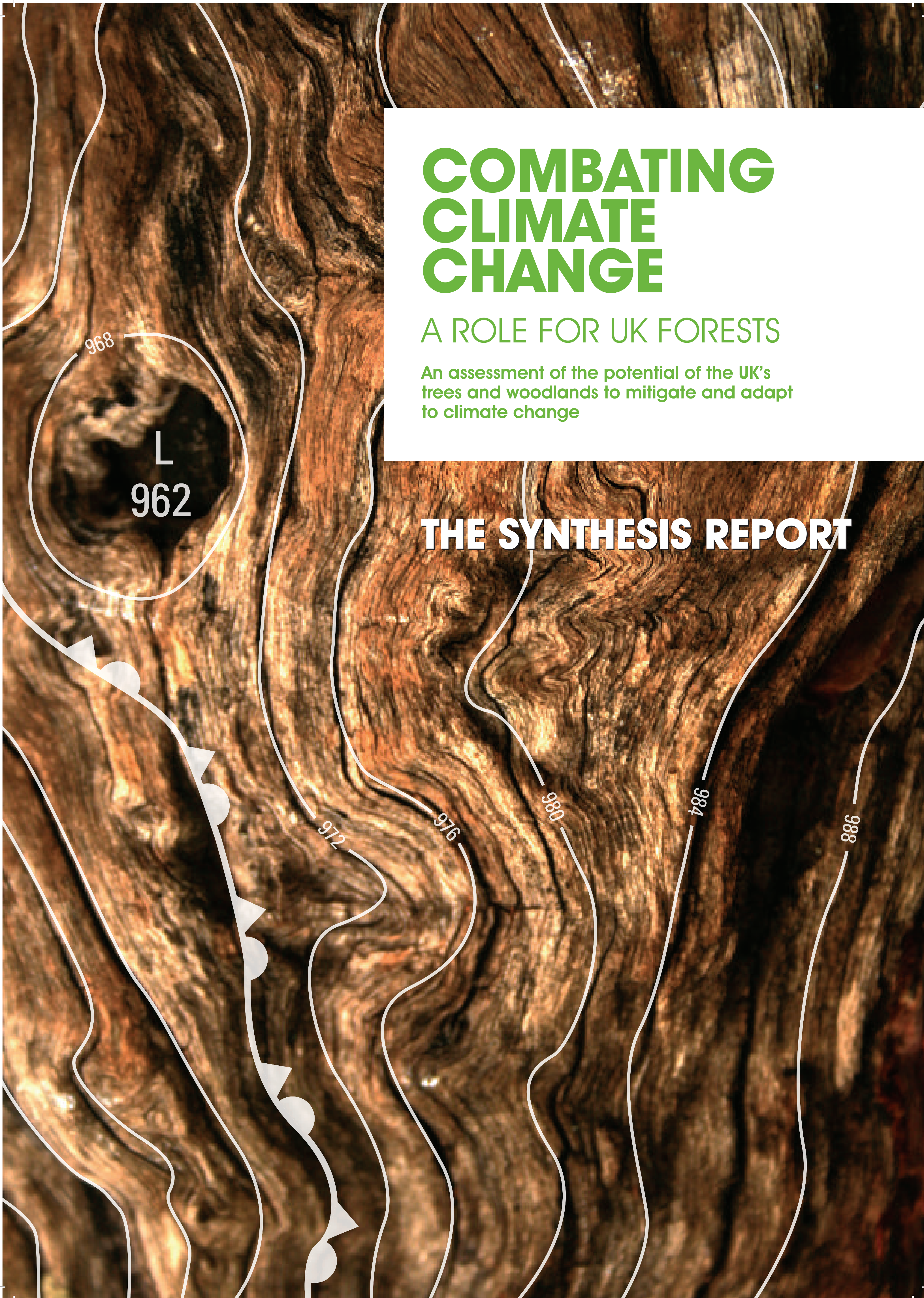
COMBATING CLIMATE CHANGE

A ROLE FOR UK FORESTS

An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change

THE SYNTHESIS REPORT



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The synthesis report

This report presents the key findings and synthesis of the first national assessment of UK forestry and climate change.

The independent assessment was commissioned by the Forestry Commission to examine the potential of the UK's trees and woodlands to mitigate and adapt to our changing climate. It forms part of the UK response to the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report published in 2007. The IPCC report provided authoritative evidence of how planting and managing woodland, avoiding deforestation, and replacing fossils fuels and carbon-intensive products with wood can make a major contribution to mitigating the effects of climate change. It also examined the impacts of climate change on forests, and the importance of adaptation to make forest ecosystems more resilient.

However, the IPCC report was global in scope and it highlighted a need to bring together information at the national level – to assess what climate change means for forests and woodlands in the UK, and to identify the gaps in our knowledge. For example:

- How are trees and woodlands in the UK currently responding to climate change and what is projected to happen in the future?
- Can more carbon dioxide be absorbed from the atmosphere by creating new woodlands, and by changing the ways we manage existing woodlands?
- What is the potential to use wood as a fuel for heat and power instead of fossil fuels?
- What is the scope to use more timber in place of other more fossil-fuel intensive materials?
- How can we adapt our woodlands to climate change?
- How can trees and woodlands improve our urban and rural environment to help us cope with climate change?

Combating Climate Change – A Role for UK Forests, the full report of the assessment, aims to provide a better understanding of how UK forestry can adapt to and improve its contribution to mitigation of climate change, with the following specific objectives:

- Review and synthesise existing knowledge on the impacts of climate change on UK trees, woodlands and forests.
- Provide a baseline of the current potential of different mitigation and adaptation actions.
- Identify gaps and weaknesses to help determine research priorities for the next five years.

The Assessment was compiled by a number of leading scientists co-ordinated by an independent steering group of forestry and climate change experts from the UK and overseas (see page 16), chaired by Professor Sir David Read, formerly Vice President of the Royal Society.

We hope that the contents of this synthesis, and the full assessment report, will inform policymakers, scientists, and all who have an interest in the future of our planet.

Overview of contents of the full assessment report

The report comprises 14 chapters grouped into six main sections:

Section 1 provides the background for the report. It describes the structure of UK forests and reviews the policy framework. It then describes current trends and projections in our climate. The final part of this section explains the science behind the relationship between trees and forests (including soils) and greenhouse gases.

Section 2 assesses evidence of the impacts to date and of the likely impacts of climate change in the coming decades, using climate projections from the UK Climate Impacts Programme.

Section 3 focuses on the contribution of forests to mitigating climate change. It reviews the role of forest planting and management in absorbing and storing carbon, and examines the use of wood fuel and wood products in place of fossil fuels and products whose manufacture generates high levels of greenhouse gas emissions (i.e. substitution). It also assesses different scenarios for woodland creation and management in order to estimate the potential for forestry to abate greenhouse gases, taking account of a range of factors that determine the cost of mitigating carbon.

Section 4 reviews the scope to adapt our woodland resource to a changing climate and examines the role of trees, woods and forests in helping society adapt to the impacts of climate change.

Section 5 places forestry in a broader context of land use and sustainable development. It provides an economic perspective and considers what might affect people's behaviour in responding to climate change, and the role of institutions in assisting appropriate responses.

Section 6 summarises our conclusions and sets out future research needs.

To obtain a copy of the full assessment report, visit TSO (The Stationery Office) online at www.tsoshop.co.uk, or by using the contact details provided on the back cover of this synthesis report.

Combating Climate Change – A Role for UK Forests. An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change. (ISBN: 978-0-11-497351-3)

SYNTHESIS REPORT

Key Findings

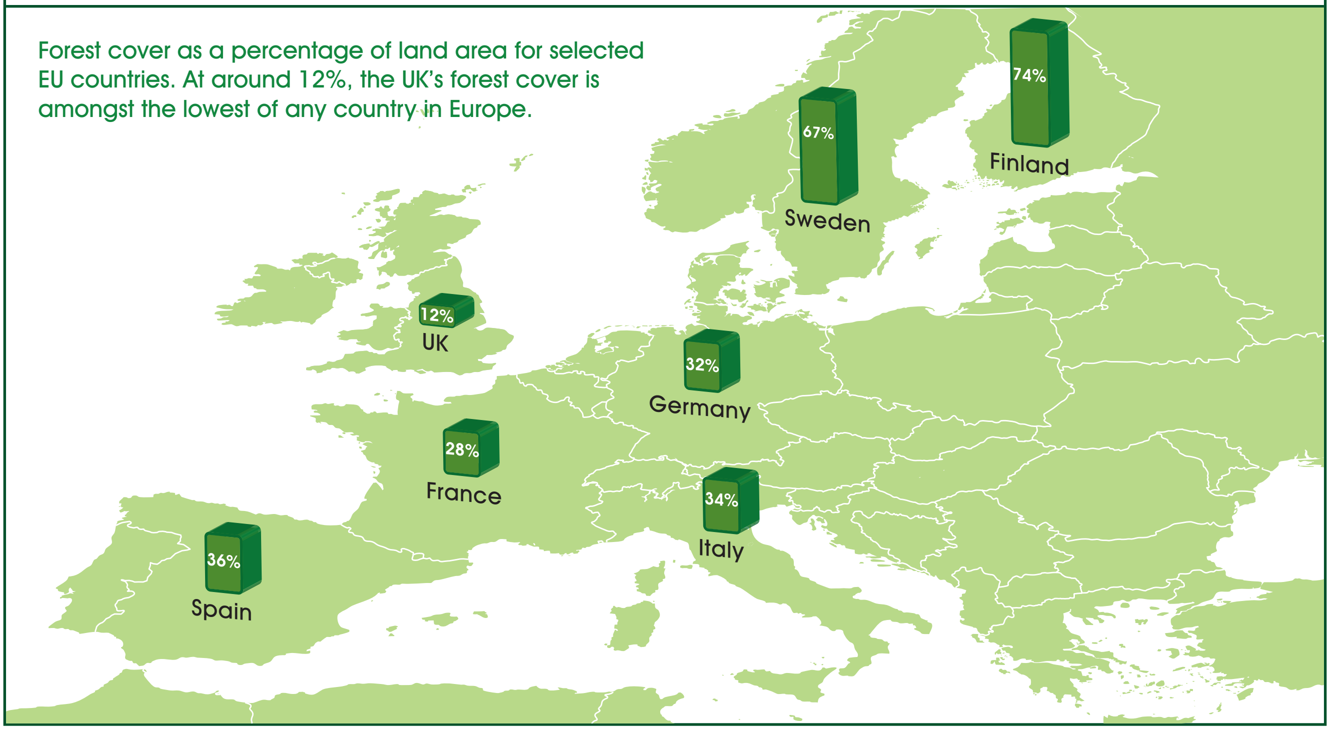
UK forests and trees have the potential to play an important role in the nation's response to the challenges of the changing climate. Substantial responses from the UK forestry sector will contribute both to mitigation by abatement of greenhouse gas (GHG) emissions and to adaptation, so ensuring that the multiple benefits of sustainable forestry continue to be provided in the UK.

A clear need for more woodlands

Forests remove CO_2 from the atmosphere through photosynthesis and, globally, could provide abatement equivalent to about 25% of current CO_2 emissions from fossil fuels by 2030, through a combination of reduced deforestation, forest management and afforestation. Analysis of woodland planting scenarios for the UK indicate that forestry could make a significant contribution to meeting the UK's challenging emissions reduction targets. Woodlands planted since 1990, coupled to an enhanced woodland creation programme of 23 200 ha per year (14 840 ha additional to the 8360 ha per year assumed in business as usual projections) over the next 40 years, could, by the 2050s, be delivering, on an annual basis, emissions abatement equivalent to 10% of total GHG emissions at that time. Such a programme would represent a 4% change in land cover and would bring UK forest area to 16% which would still be well below the European average (see map below).

Woodland creation provides highly cost-effective and achievable abatement of GHG emissions when compared with potential abatement options across other sectors. The Committee on Climate Change considered that abatement costing less than £100 per tonne of CO_2 was cost-effective. All the woodland creation options evaluated here met this criterion including a range of broadleaved woodlands. The two most cost-effective options were conifer plantations and rapidly growing energy crops, but mixed woodlands managed for multiple objectives can also deliver abatement at less than £25 per tonne CO_2.

Forest cover as a percentage of land area for selected EU countries. At around 12%, the UK's forest cover is amongst the lowest of any country in Europe.



An enhanced woodland creation programme would help to reverse the decline in the rate of atmospheric CO_2 uptake by forests that is reported in the UK's Greenhouse Gas Inventory. From a maximum of 16 $MtCO_2$ per year in 2004, the strength of the 'forest carbon sink' is projected to fall to 4.6 $MtCO_2$ per year by 2020, largely because of the age structure of UK forests and the maturation and harvesting of the woodlands created as a result of the afforestation programmes of the 1950s to 1980s. The decline in planting rates since the 1980s also contributes to this serious projected decline in the sink strength of UK forests.

The new woodlands would also deliver a range of co-benefits but would need to respect a range of other land-use objectives including biodiversity, food security, landscape and water supply.

An asset to be managed wisely

Existing UK forests, including soils, are both a large store of carbon (estimated at around 790 MtC) and a system removing CO_2 from the atmosphere (about 15 $MtCO_2$ per year in 2007). Sustainable forest management can maintain the carbon store of a forest at a constant level while the trees continue to remove CO_2 from the atmosphere and transfer a proportion of the carbon into long-term storage in forest products. The total carbon stored in the forest and its associated 'wood chain' therefore increases over time under appropriate management systems.

Impacts of climate change are beginning to become apparent in the UK's woodlands, including effects on productivity, tree condition, woodland soil function, woodland fauna and flora and forest hydrology.

There is increasing concern over the number of outbreaks of novel pests and diseases in forestry and arboriculture. Forest pests and diseases could compromise the ability of woodlands to adapt and contribute to meeting the challenge of climate change.

The regulatory framework and sustainability standards for UK forestry will need to be maintained and, in some cases, adapted to address climate change. A similar approach should be put in place for the management of urban trees. This will ensure that trees continue to deliver a wide range of ecosystem services.

The status quo is not an option

Since tree crops take many years to mature, the planning horizons for forestry are inherently long. Actions taken now may only prove their worth in 50–100 years time and must be appropriate for both the current and future climates. A move towards planned rather than reactive adaptation in woodland creation and management is therefore preferable.

The creation of new woodlands and the restocking programmes of existing forests present major opportunities for adapting forests to future climate change. Changes to the selection of species and provenances for particular sites using the current range of species are required now. These choices can be accommodated using the range of species currently in use. Over longer timeframes, and if greenhouse gas emissions do not decline, we will need to consider the introduction of new species, including those from continental Europe. However, further research is urgently needed to establish which species will be best suited to the changed environmental conditions. The preference for use of native tree species and local provenances under all circumstances will need to be reconsidered.

The changing climate raises difficult questions for conservation of woodland biodiversity. Current descriptions of native woodland communities based on species composition are unlikely to remain valid because some native members of the flora and fauna may struggle to survive.

Harvesting and use of wood increases forestry's mitigation potential

Harvesting of trees leads to transfers of their carbon into wood products where it is stored, often over long periods. These can be used to substitute for those materials the production of which involves high emissions of GHG. Wood products can also be used directly as sources of energy to replace fossil fuels.

Forests achieve their considerable productivities largely in the absence of nitrogen (N) fertilisation, thus avoiding the high fossil fuel costs of N fertiliser production, direct losses of the greenhouse gas nitrous oxide (N_2O) and the risk of pollutant-N loss to the environment as nitrate to water catchments.

Within the next five years sustainably-produced wood fuel has the potential to save the equivalent of approximately 7 $MtCO_2$ emissions per year by replacing fossil fuels in the UK. This contribution could be increased further as bioenergy, including energy derived from woody biomass, makes an increasing contribution to UK targets for renewable heat, power and liquid fuels. The use of biomass for heating provides one of the most cost-effective and environmentally acceptable ways of decreasing UK GHG emissions.

The estimated total quantity of carbon stored in wood-based construction products in the UK housing stock in 2009 is 19 Mt (equivalent to 70 $MtCO_2e$). If the market for wood construction products continues to grow at its current rate over the next 10 years there is the potential to store an estimated additional 10 Mt of carbon (equivalent to 36.7 $MtCO_2e$) in the UK's new and refurbished homes by 2019.

Part of the current failure to accept wood products for use in construction arises from conservatism in the construction industry. Outmoded attitudes need to be robustly challenged by drawing on the evidence and promoting the technical properties of wood.

Trees help people adapt

Trees have an important role in helping society to adapt to climate change, particularly in the urban environment, through providing shelter, cooling, shade and runoff control. Tree and woodland planting should be targeted to: (a) places where people live, especially the most vulnerable members of society, and (b) places where people gather (such as town and local centres) which currently have low tree cover.

Forestry practitioners should engage with the public to contribute to societal understanding and responses to climate change. The changes required will challenge both policy makers and managers to adopt a more flexible approach in response to the emerging body of evidence.

Policy incentives need to be re-designed so that adequate reward is given to the provision of the non-market benefits of forests, especially those relating to the climate change mitigation and adaptation functions of forests.

We conclude that further scientific and socio-economic analysis is required to enable the UK to achieve the full adaptation and mitigation potential of forestry that is identified in this first national assessment. Clear, robust, research programmes will be needed to underpin the changes of forestry policy and practice which are required to meet the new and challenging circumstances.

Synthesis of evidence

Forests are a multiple-purpose resource which make up almost a third of the Earth's land surface. Through their photosynthetic and respiratory activities they play a critical role in the global carbon cycle. While there have been numerous global- and continental-scale determinations of the contributions of forests to the planetary carbon cycle, few have considered these issues in depth at the national scale. Here we present a synthesis of a scientifically-based analysis of the potential of UK forests and trees to play a role in the nation's response to the challenges of the changing climate.

To date the primary scientific input to global climate change negotiations is the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) published in 2007, and a summary of more recent developments was published in 2009. Chapter 9 of the Working Group 3 report on mitigation of the Fourth Assessment concluded that forestry could make a very significant contribution to a low-cost global mitigation portfolio that provided synergies with adaptation and sustainable development. The Stern Review commissioned by the UK Government in 2006 similarly concluded that curbing deforestation was a highly cost-effective way of reducing greenhouse gas (GHG) emissions and that action to preserve forest areas was urgently needed. In response to these two reviews the Forestry Commission (FC) hosted a meeting of all interested parties in London (November 2007) to consider the UK response and produced a climate change action plan. One of the four key actions identified was a national assessment of UK forestry's contribution to mitigating and adapting to climate change, to be published prior to the UNFCCC meeting in Copenhagen in December 2009. To achieve this the present independent expert assessment was commissioned with the remit to provide a better understanding of how UK forestry can adapt to and improve its contribution to mitigation of climate change, with the following specific objectives:

- review and synthesise existing knowledge on the impacts of climate change on UK trees, woodlands and forests;
- provide a baseline of the current potential of different mitigation and adaptation actions;
- identify gaps and weaknesses to help determine research priorities for the next five years.

The UK Government has taken a lead in climate change policy development and, while the current assessment was in progress, set challenging and legally binding targets leading to an emissions reduction of 80% of 1990 GHG emissions by 2050. A contribution to the targeted reductions in atmospheric GHG concentrations can be achieved by increasing the rates at which the gases are removed from the atmosphere through biological uptake. In its White Paper, the UK Low Carbon Transition Plan (2009), the Government identified woodland creation as a cost-effective way of fighting climate change and recognised the urgency of action to support tree-planting initiatives. This pressure to act is further accentuated by the climate change projections (UKCP 2009) which use model simulations to provide probabilistic estimates of future climate. These indicate that the UK climate will continue to warm substantially through this century; that there will be changes in rainfall patterns and its seasonal distribution; and that considerable regional variations can be expected. These projections are timely since they provide the essential physical background needed to inform those adjustments of forestry policy and practice that will be required both to mitigate the impacts of the projected changes and to tailor adaptation measures to local conditions.

The science reviewed here and the general implications for policy advice which arise from it are thus presented at a critical time in the development of UK policies on woodland creation and of other actions designed to achieve adaptation and mitigation through UK forestry. Our assessment has yielded the overarching and strongly-held conviction that, confronted by climate change, substantial responses are required of the forestry sector.

This evaluation of the science shows that the UK forestry sector can contribute significantly both to the abatement of emissions and to ensuring, through effective adaptation, that the multiple benefits of sustainable forest management continue to be provided.

Forests and atmospheric carbon

The largest impact of forests on atmosphere/land surface exchange arises through the net ecosystem exchange of carbon (Figure 1). Woodlands and forests are a net sink of CO_2, i.e. they remove CO_2 from the atmosphere, except during tree harvesting and for a relatively short period thereafter (the duration depending on soil type and other site factors). The strength of this sink (i.e. the rate of removal) has been quantified for general UK forest types (coniferous and broadleaved woodlands) and the impact of some management activities on CO_2 emissions and removal are known. While there are gaps in understanding, sufficient is known for the overall GHG balance to be calculated and for projections to be provided for both the existing UK forest cover and for a range of alternative forest management scenarios.

Measurements made over several years in a coniferous forest in Scotland show average annual removal from the atmosphere of around 24 tonnes of CO_2 per hectare per year ($tCO_2\ ha^{-1}\ yr^{-1}$). Comparable measurements made in an oak forest in southern England indicate that it removes *c.* 15 $tCO_2\ ha^{-1}\ yr^{-1}$ (Figures 2a and 2b). Analysis shows that the rate at which carbon accumulates in forest stands from one crop of trees ('rotation') to the next rotation is influenced by site (particularly soil type), forest operations and by the extent of soil disturbance at planting and harvest. In considering emissions abatement it is important to note that, while forest carbon stocks will reach upper limits, the total abatement can continue to rise over successive rotations because of carbon storage in wood products and the substitution of wood for fossil fuel. The dynamics of the current and projected UK forest carbon sink are largely determined by historic planting patterns which involved extensive afforestation, mostly in the uplands, through the 1950s to 1980s. The *c.* 1 million hectares of coniferous forest planted in the UK, mainly on marginal land, over this period represents a major resource as both a carbon store and a carbon 'sink'. In contrast to agricultural crops, such forests achieve their considerable

Figure 1
The major pathways of carbon uptake, storage and release in forest ecosystems.

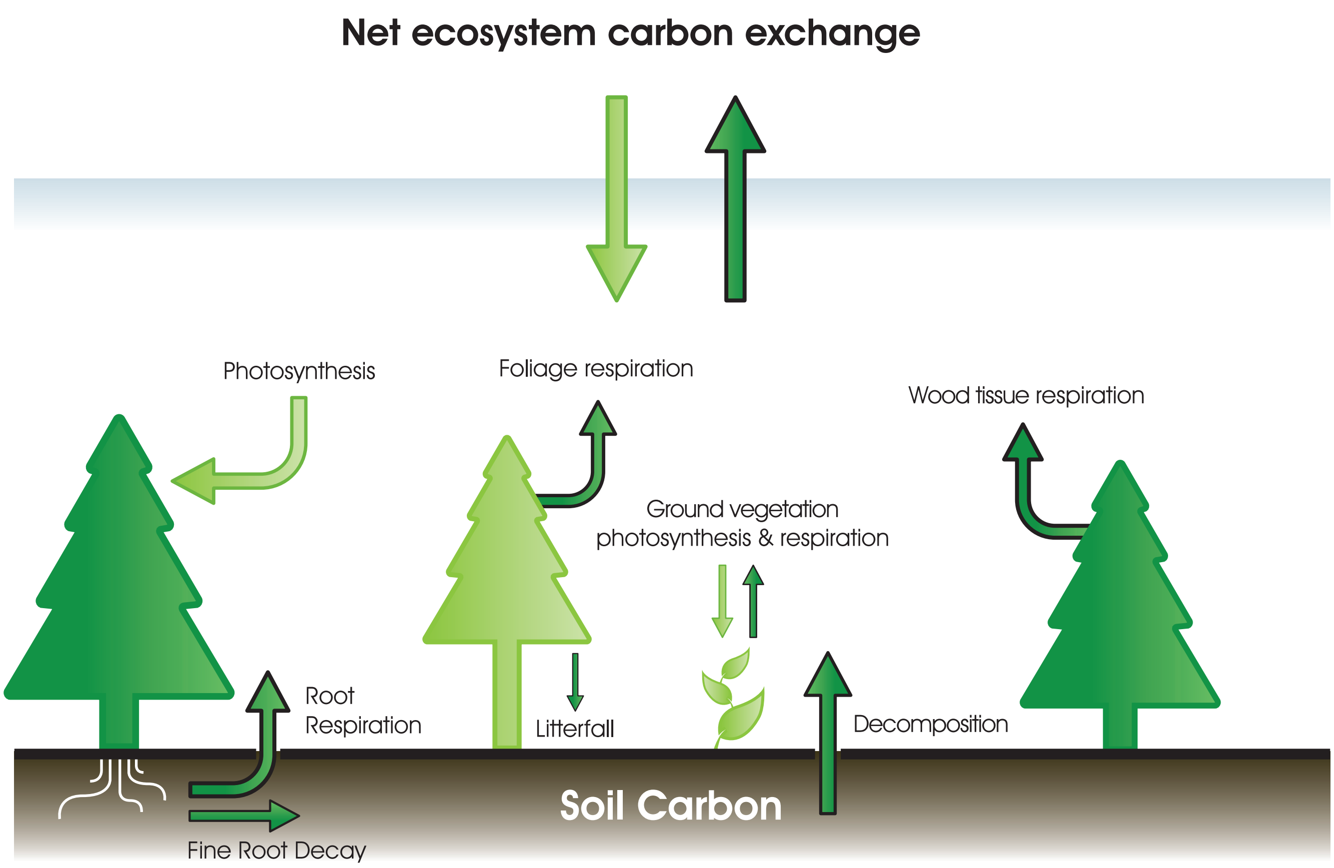


Figure 2a
The daily average (over 5 years) net removal (positive) or release (negative) of CO_2 from (to) the atmosphere by a 17 to 21 year-old stand of Sitka spruce at Griffin Forest, Scotland between 1997 and 2001. Values are expressed as kg CO_2 per hectare per hour, i.e. Net Ecosystem Productivity (NEP). The vertical columns show the daily (24 hour) net CO_2 fluxes for every day of the year. The columns above the zero line show the net 24h removals from the atmosphere and gains by the forest, while those below the line indicate the net daily emissions from the forest to the atmosphere. The solid line shows the five-year-average of accumulated removals from the atmosphere.

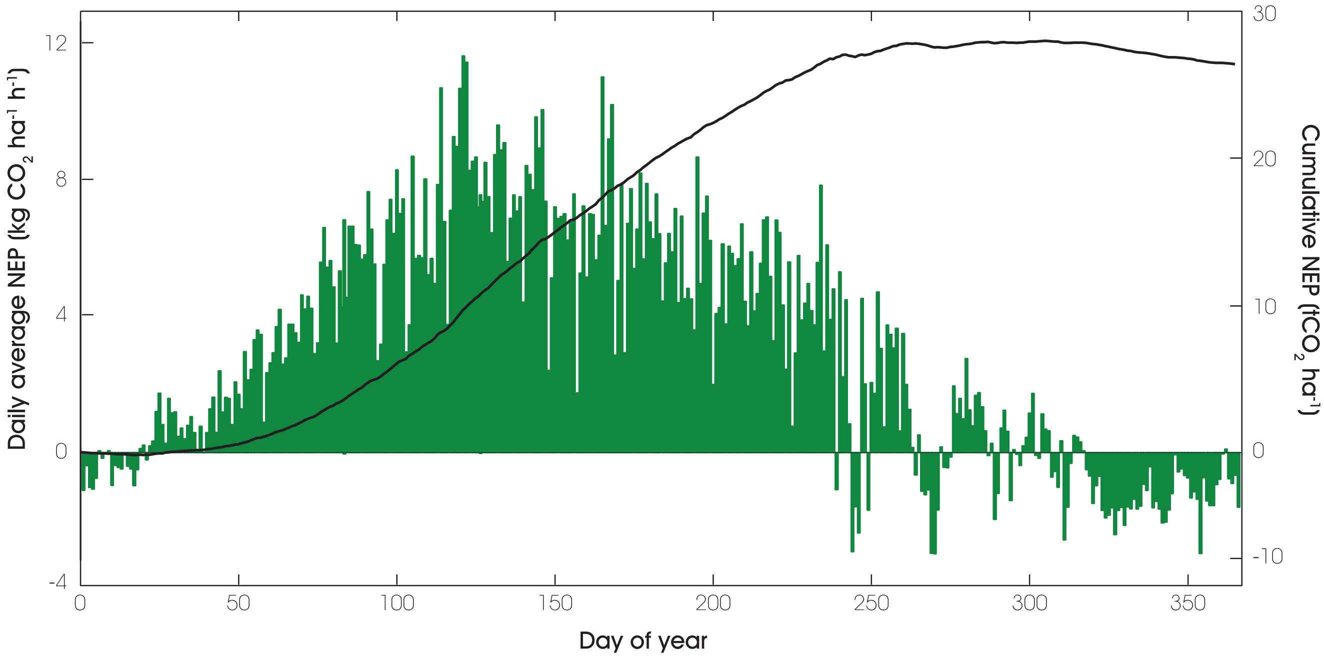
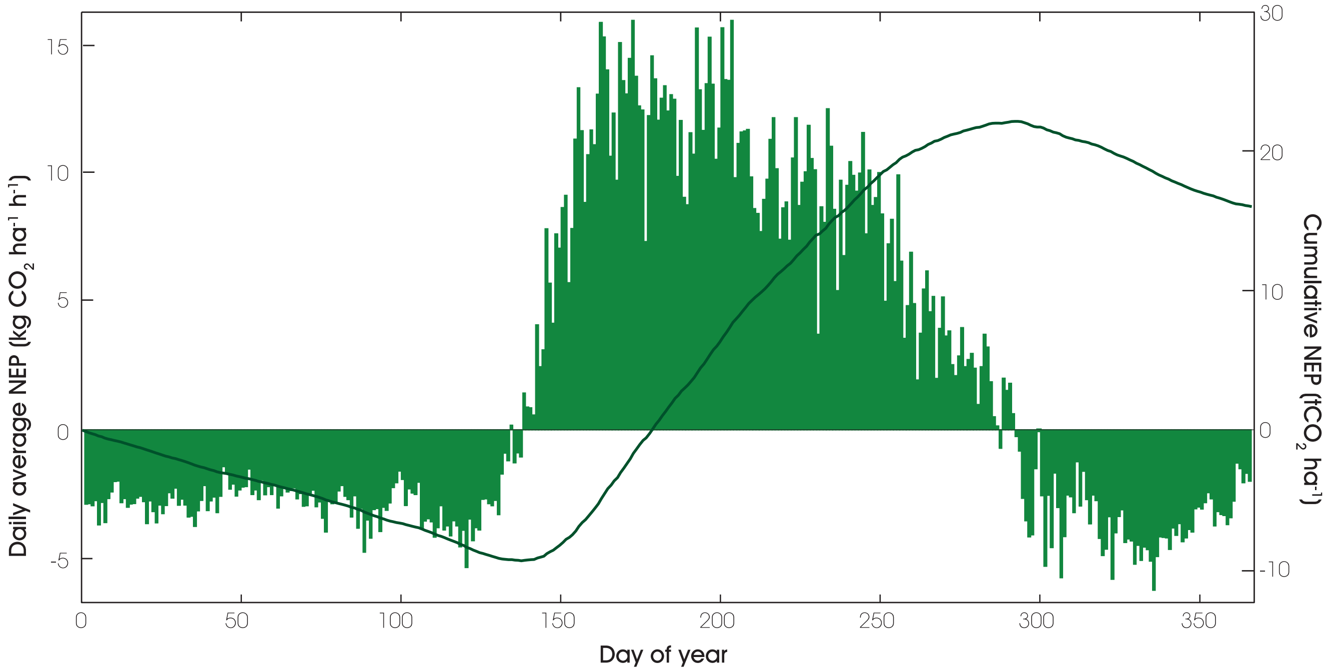


Figure 2b
The daily average (over 8 years) net removal (or release) of CO_2 from the atmosphere by a 72 to 80 year old mixed oak–deciduous woodland at the Straits Enclosure, Alice Holt, England between 1999 and 2006. Other details as in (a) above.



productivities largely without the application of nitrogen (N) fertilisers, thus avoiding the high fossil fuel costs of N fertiliser production, direct losses of the greenhouse gas nitrous oxide (N_2O) and the risk of nitrate (NO_3^-) pollution of water resources.

Although the UK's existing forest area has more than doubled over the past 80 years, at around 12% it is amongst the lowest of any country in Europe. Further, annual areas of new planting have declined sharply since 1989 (Figure 3) and this has important consequences for the potential contribution that UK forests can make to mitigation of climate change. Current estimates show that, largely as a result of the earlier planting activities, the strength of the UK carbon sink increased from 12 $MtCO_2$ yr^{-1} in 1990 to a peak of 16 $MtCO_2$ yr^{-1} in 2004. In Scotland, where woodland cover is higher than in the rest of the UK and the population density is smaller, the removal of CO_2 by forests currently accounts for around 12% of emissions. However, the situation is very different in England, where the forest carbon sink equates to less than 1% of total GHG emissions.

Because of the age structure created by the planting history in UK forestry, as the harvesting of the forests created in the last century continues, falls in net CO_2 uptake by UK forests are expected even though harvesting is usually followed by restocking. Significantly, the afforestation rates of the post-war years have subsequently been greatly reduced, so the projected CO_2 uptake by UK forests shows a marked decline to as little as 4.6 $MtCO_2$ yr^{-1} by 2020 (Figure 4). Such declines, which are reported as part of the UK's GHG inventory to the UNFCCC, have serious implications for our ability to meet the challenging targets for emission reductions outlined in the Climate Change Act and the UK Low Carbon Transition Plan. The rapid diminution of the carbon sink provides both a challenge and an opportunity for the forestry sector. By making provision for reversal of this trend it has the potential to significantly increase its total contribution to climate change mitigation (see below).

Baseline and potential for mitigation in UK forests

The total carbon stock in UK forests (including their soils) is approximately 790 MtC and the stock in timber and wood products outside forests is estimated to be a further 80 MtC. Changes to the large forest carbon stocks can be

Figure 3
Areas of new forest planting in the UK between 1975 and 2009. The progressive decline in total UK planting in recent years is striking.

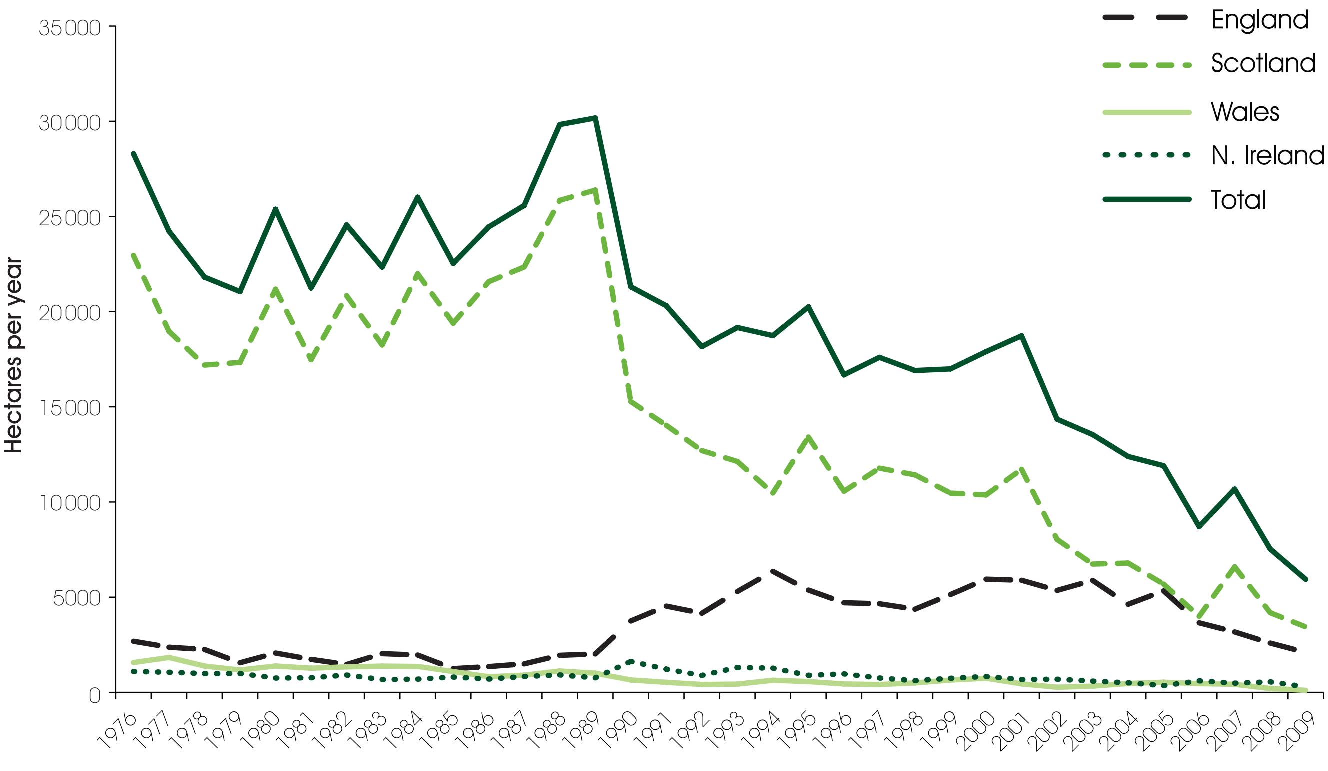
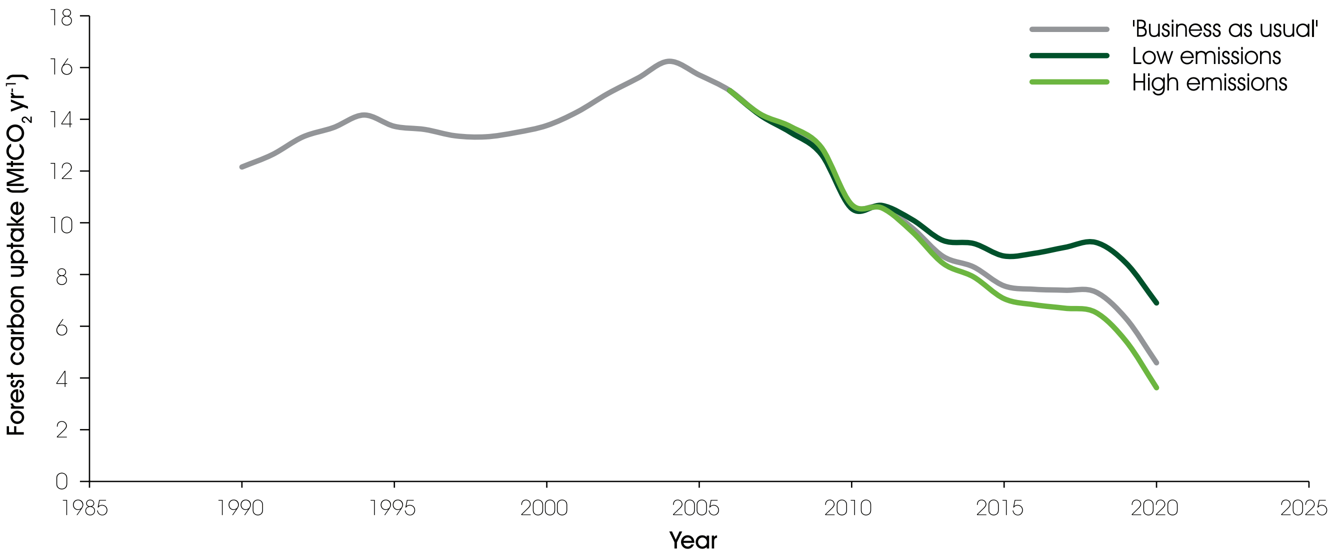


Figure 4
The estimated net greenhouse gas (GHG) uptake by UK forests projected to 2020. Values are presented as net CO_2 equivalent uptake from the atmosphere, under three different assumed scenarios viz: afforestation continues at its present (i.e. declining) rate - referred to as 'business as usual' (grey line), increased rates of afforestation, i.e. 25 000 ha per year – referred to as 'low emissions' (dark green line), and uptake assuming no further afforestation – referred to as 'high emissions' (light green line). These estimates comprise the forestry component of the UK Land Use, Land Use Change and Forestry (LULUCF) GHG inventory.



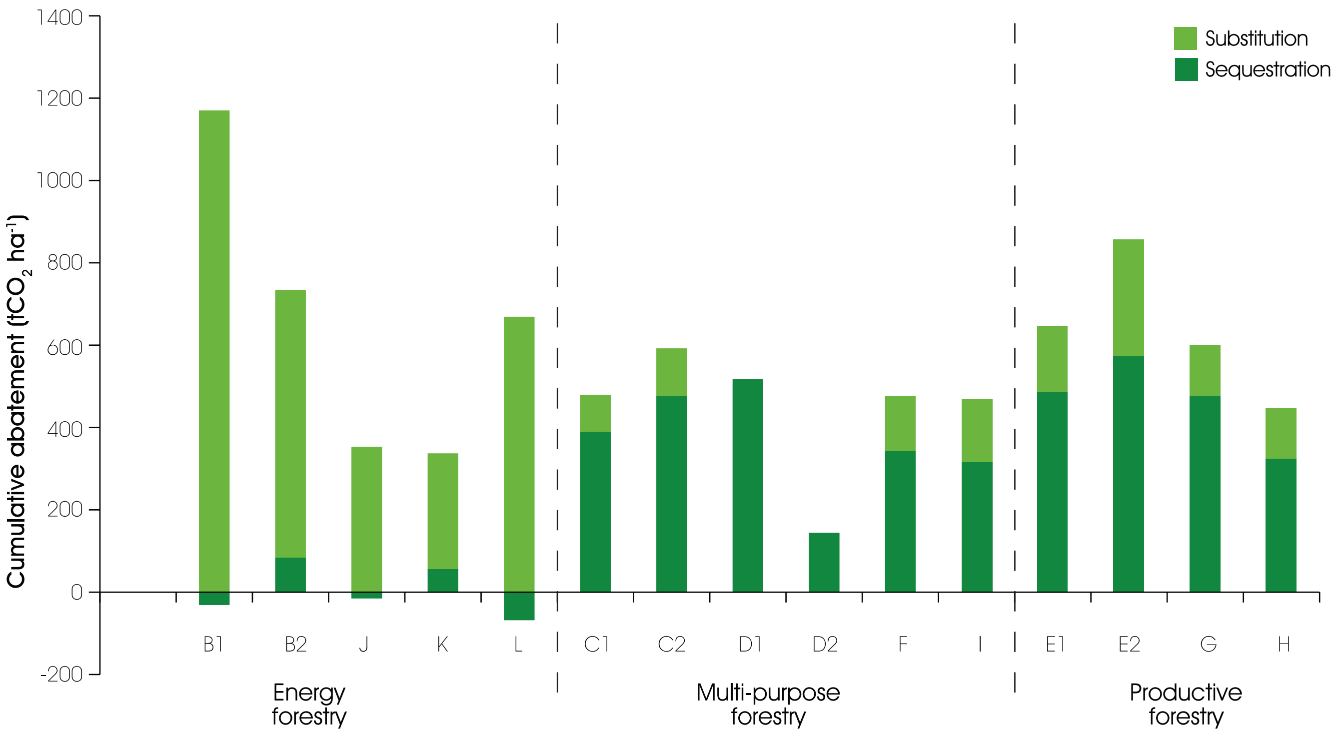
achieved through management practices. More intensive Forest Management Alternatives (FMAs – see Table 1) have the lowest standing carbon stocks, but by far the highest annual rates of carbon sequestration (uptake). Since these estimates consider only carbon in the forest, they do not include the further potential of wood to provide abatement of GHG emissions by substituting for fossil fuels as well as for materials which cause large GHG emissions in their production.

Models have been developed which simulate the full life cycle of carbon, including that retained in forest products and fossil fuel emissions avoided by the use of forest products. These enable us to provide, for the first time, a comprehensive evaluation of the abatement potential of UK forests. These model calculations demonstrate that a combination of increased new planting and the substitution benefits of wood fuel and wood products for fossil fuel intensive materials, has the potential to deliver significant abatement (i.e. reduction in net GHG emissions). New woodlands can be planted to deliver a range of forestry and other objectives. Different options for planting provide the potential for significant abatement either as sequestration or substitution, particularly over the longer term (Figure 5). Energy forestry, in contrast to multi-purpose and conifer/mixed forestry, shows a larger contribution to abatement through substitution than through sequestration in the forest stand and soil.

Table 1
Estimates of whole-tree carbon stocks (expressed as tonnes of CO_2 equivalents per hectare) and annual mid-rotation rates of carbon sequestration (expressed as tonnes of CO_2 equivalents per hectare per year) in conifer stands subject to each of five Forest Management Alternatives (FMAs 1–5) representative of European Forests (for full details see the main report). Values in brackets have higher uncertainty.

Forest Management Alternative					
	Unmanaged forest nature reserve FMA 1	Close to nature forestry FMA 2	Combined objective forestry FMA 3	Intensive even-aged forestry FMA 4	Wood biomass production FMA 5
Carbon stocks	800	500	(450)	400	(200)
Annual rates	(6)	(11)	(16)	22	29

Figure 5
Projected cumulative emissions abatement in 2050 for a range of different woodland creation options planted in 2010, grouped by principal objective. In each case, the contribution to abatement from sequestration in biomass and soils is shown separately from substitution for fossil fuels and energy-intensive materials. Energy forestry options include short rotation forestry (both native 'K' and non-native species options 'B1', 'B2', 'L') and short rotation coppice 'J'; multi-purpose forestry options include farm woodlands ' C1', 'C2', native woodlands managed primarily for biodiversity objectives 'D1', 'D2' and mixed woodlands managed on a 'close-to-nature' basis 'F', 'I'; productive forestry options include conifer and mixed woodlands, managed on a rotational clearfell 'E1', 'E2', 'G', or continuous cover basis 'H', but with timber production as an important objective.



Clearly, the extent to which abatement can be achieved will be directly proportional both to the increases in area over which the new planting takes place and the extent of fossil fuel substitution that can be gained. For example, woodlands planted since 1990, coupled to an enhanced woodland creation programme involving planting 23 200 ha (14 840 ha over and above the business as usual assumption of 8360 ha per year) of forest per year over the next 40 years, could deliver abatement of *c*. 15 $MtCO_2$ by the 2050s, providing the substitution benefits of wood and timber products are taken into account (see Figure 6). This level of abatement would equate to about 10% of total GHG emissions from the UK if recent emissions reduction commitments were achieved. Such a programme of woodland creation might incorporate energy forestry, conifer forests, farm and native broadleaved woodland and would establish nearly one million hectares of woodland, bringing total forest cover in the UK to approximately 3.8 million hectares. This rate of afforestation would represent both a major change in, and challenge to, the forestry sector. However it would represent only a 4% change in land use and result in UK woodland cover of 16% which would remain well below the European average. If any such changes of land-use practice were to be implemented it would be important to ensure that the regulatory framework and sustainability standards for woodland creation in the UK were maintained.

Much discussion has centred on the potential of changes in approaches to forest management to deliver emissions abatement. Delaying thinning and harvesting operations to increase in-forest carbon stocks do deliver abatement in the short term if sequestration in forest biomass alone is considered. However, when the abatement associated with wood and timber products substituting for fossil fuels is considered in the analysis, the additional carbon retention delivered through storage in forest biomass is rapidly negated by the lost ability to deliver abatement through substitution. Within a period of 40–50 years, total abatement potential is lower for management scenarios that aim to increase in-forest carbon stocks (see Figures 6 and 7). There is therefore a risk that measures that focus solely on increasing forest carbon stocks are likely to limit the abatement potential because of lost opportunities for fossil fuel and product substitution. It is also evident (see Figures 6 and 7) when a range of options are considered, that there is limited scope for changes in forest management, alone, to deliver significant levels of emission abatement, implying that woodland creation should be the initial focus of activity.

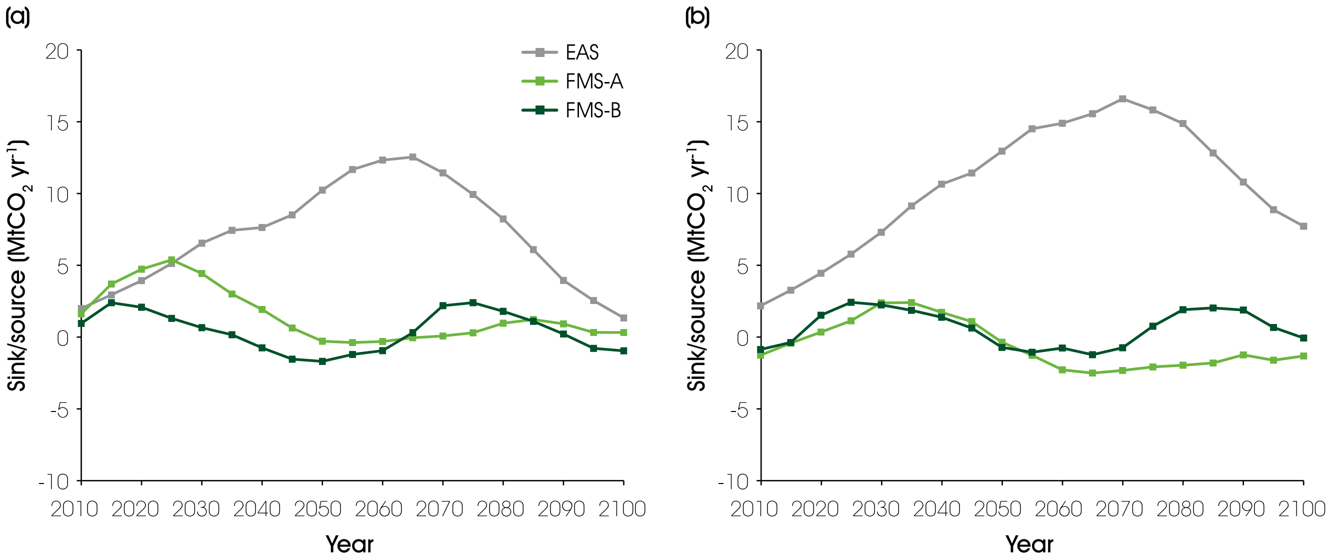
While it is evident from such analyses that the forestry sector has the potential to make a significant contribution to emissions reduction commitments, the economic viability of specific options for woodland creation has to be considered. In establishing the capacity for abatement to be delivered by all sectors, the first report of the Committee on Climate Change considered that abatement costing less than £100 per tonne CO_2 was potentially cost-effective. Here, a detailed analysis of new woodland planting scenarios shows that multi-purpose forestry provides highly cost-effective abatement (0 to £26 per tonne of CO_2), and that abatement using energy forestry (short rotation forestry and coppice) would be even more cost-effective. Indeed, in the case of highly-productive stands the value of timber produced can exceed the cost of establishment and management so that no net social costs arise. In the current assessment, the creation of new native broadleaved woodlands managed for biodiversity objectives is estimated to provide carbon abatement at £41 per tonne of CO_2. However this figure is pessimistic, as it does not include an evaluation of the co-benefits that such woodland creation would provide. Nor does this figure take account of GHG emissions or removal under the land use prior to the creation of the new woodland, which in some cases may be large and add further to the overall benefit of woodland creation. The scale of land-use change envisaged here would clearly require an integrated approach involving full consideration of GHG balances and of all the ancillary benefits of woodland creation.

Figure 6

The projected impacts, from the present to 2100 of alternative forest management scenarios on uptake (i.e. abatement = net sink) or release (= net source) of CO_2 (Mt per year). The three scenarios are:

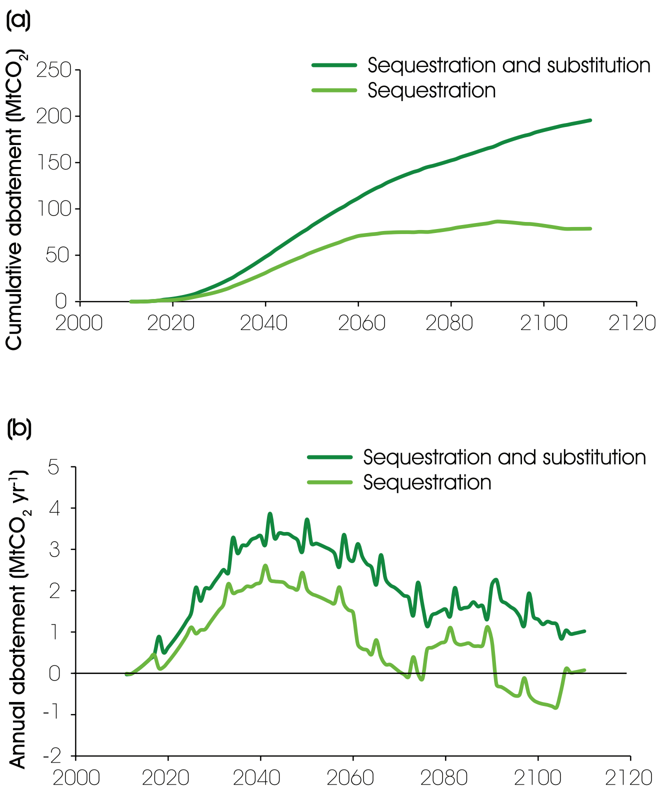
Enhanced afforestation (EAS): the planting of a total of 23 200 ha per year of new woodland between 2010 and 2050. This total is made up of 14 840 ha per year of new planting over and above the current (and assumed ongoing) planting of 8360 ha per year (grey line). FMS-A: management of existing forests to maximise retention of carbon stocks (light green line). FMS-B: management involving an increased intervention combined with optimisation of rotation length to maximise timber production (dark green line).

(a) The uptake/release of CO_2 by trees, litter and soils only. (b) The total abatement potential, i.e. as (a) but including carbon stored in harvested products, in product substitution, and saved as a result of fossil fuel substitution under the different scenarios.



All values are expressed as net uptake (positive values) or release (negative values) of CO_2 relative to those obtained under the current forest management scenario, i.e. Business as Usual.

Figure 7
The potential emissions abatements achievable by a woodland creation programme of 10 000 ha per year for 15 years using a mixture of energy forestry, conifer forests, farm and native broadleaved woodlands. The potential (a) cumulative and (b) annual abatement achievable through carbon sequestration on woodland biomass and soils (light green line) and total abatement if emissions reductions through fossil fuel substitution are also included (dark green line).



Impacts and adaptation of forests, woodlands and urban trees

Climate change is already having impacts in UK forestry. These include effects on productivity, tree condition, leaf emergence, woodland soil function, woodland fauna and flora, forest hydrology and, probably, also the incidence of insect pest and tree disease outbreaks. However, there is uncertainty over the likely severity and extent of these impacts in the future.

Increased climatic warmth, the lengthening of growing seasons, and rising atmospheric CO_2 concentrations may improve tree growth rates so long as water is not limiting and pest and disease outbreaks do not have significant impacts. There is good experimental evidence that increases of CO_2 concentration can lead to increased growth of trees although considerable variability of response has been observed determined by genotype, tree age, air pollution and nutrient availability. In the UK, there is only limited evidence that any increases in tree growth or overall forest productivity can be attributed to longer, warmer growing seasons and rising atmospheric CO_2 concentrations. Recent studies attribute increased forest productivity across much of continental Europe mainly to changes in forest management and nitrogen availability.

An increased frequency and severity of summer drought is likely to represent the most immediate threat to UK woodlands from the changing climate. There is a very high likelihood that climate change will have serious impacts on drought-sensitive tree species on shallow freely-draining soils. Over the near future (<40 years) the range of species currently considered suitable for use in woodland creation in the UK is likely to remain the same. Exceptions to this general situation are likely to be found in south and east England and more widely in the latter half of the century. The planning of which species and species mixtures to plant on particular sites will be the challenge for forest managers. Over the longer term however (>40 years), especially if high GHG emissions scenarios are taken into account, an extended range of species will have to be considered, Further research is needed to establish which tree species will be most suitable for specific requirements.

Because tree crops take many years to mature, planning horizons in forestry are inherently long. In order to enhance adaptability and resilience of new planting programmes both the current climate and the relatively uncertain projections of the future climate must be taken into account. Models indicate that under a High GHG emissions scenario, significant impacts of climate change on the suitability of species currently used for forestry will become evident by the middle of the century. Under a Low emissions scenario similar impacts will be seen towards the end of the century. Predictions of 'suitability' for future UK climate projections have been obtained using a knowledge-based model (Ecological Site Classification) which assesses the influence of temperature, soil moisture, wind risk and soil nutrient availability upon tree performance. This shows that typical conifer stands currently in the ground are likely to reach maturity before serious impacts of climate change are apparent. Importantly, however, the need for adaptation has to be confronted at the time of planting both when restocking and when creating new woodlands. By the end of the century, the climate will have become unsuitable for some native and non-native tree species. The change of climate from suitable to unsuitable for many species will be particularly marked in southern England where even those species which will remain generally suitable for use in the wider UK will struggle on some sites. This is exemplified by the case of oak by the 2050s under a High emissions scenario (see Figure 8a).

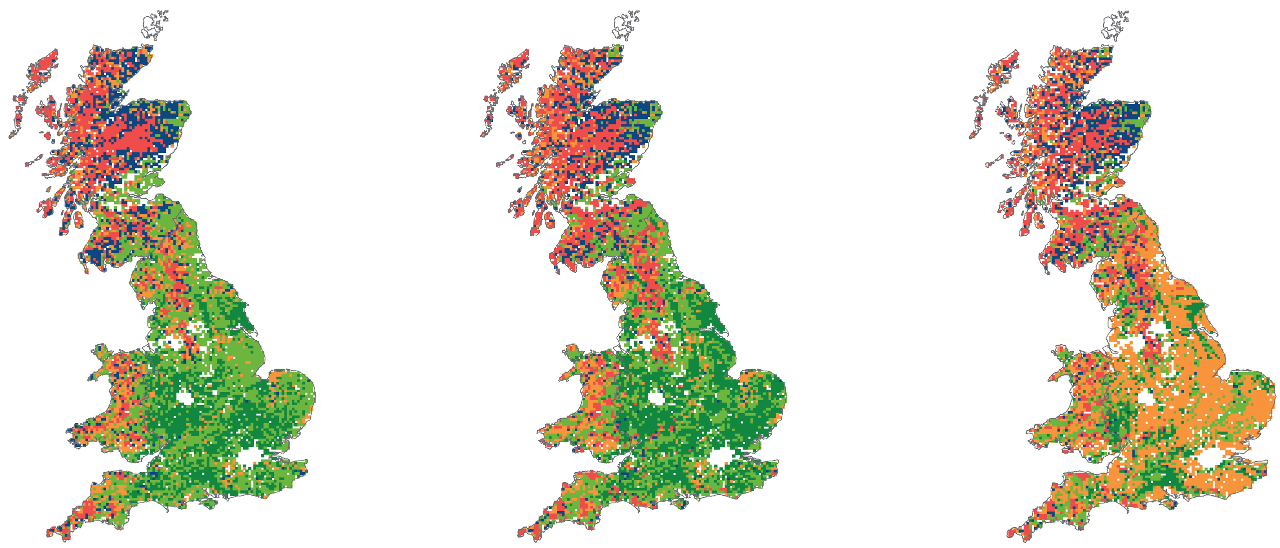
For such species the extent of regeneration from seed and successful establishment may also decline so that they become susceptible to competition from introduced species – by then better suited to the changed climate. The growth of other species may improve, as for example, in the case of Sitka spruce in the west and north west

Figure 8

The 'suitability' (defined as productivity relative to maximum productivity achievable by that species under current climatic conditions) for (a) pedunculate oak, and (b) Sitka spruce under Baseline (1961–90, left) and UKCIP02 Low emissions (centre) and High emissions (right) climate change scenarios. The results are based upon Ecological Site Classification (see text for further explanation).

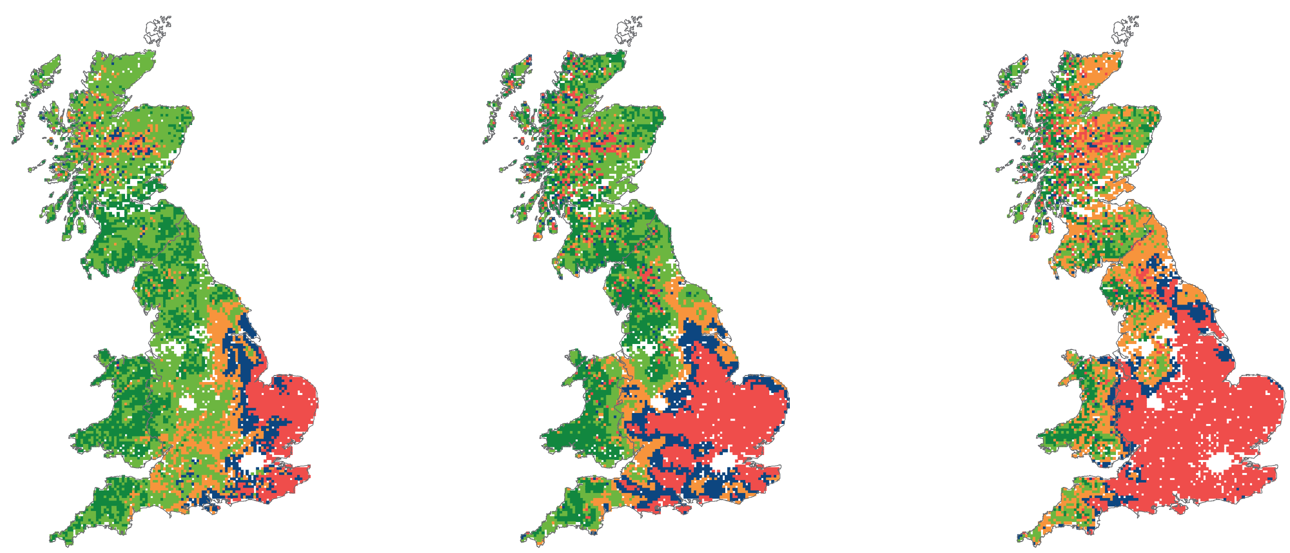
Dark green = very suitable (>70% of current maximum productivity); light green = suitable (50–70% of maximum productivity); orange = marginal (40–50% of maximum productivity); blue = poor (30–40% of max productivity); red = unsuitable (<30% of current maximim productivity).

(a) Pedunculate oak



Baseline | 2050 Low emissions scenario | 2050 High emissions scenario

(b) Sitka spruce



Baseline | 2050 Low emissions scenario | 2050 High emissions scenario under a Low emissions scenario by the 2050s (see Figure 8b). The regional variability of tree responses to climate change that is predicted by current models of perfomance or ecological suitability is crucial because it means that bespoke adaptation strategies are required rather than a generic 'one size fits all' approach. For example, of the 28 species assessed using the Ecological Site Classification model, 20 were predicted to increase in suitability in Central Scotland by the 2080s under a High emissions scenario. In contrast, all but two of those species are predicted to show a decline in productivity in southeast England and only one conifer species is predicted to be anything but 'unsuitable'. Further research is therefore needed to establish which tree species are most suitable for specific requirements and, in particular, to determine which infrequently planted (minor) or untried species are candidates for 'adaptive planting' (see Table 2). The extent of new planting and changes in species choice must, however, be appropriate and sensitive to the potential implications for biodiversity, agriculture, water harvesting, housing and infrastructure development, alongside the other associated costs and benefits.

There are likely to be significant changes to the composition, structure and character of the ground flora and other species of priority for biodiversity and conservation, particularly under High emissions scenarios and over longer timeframes. Current species descriptions of native woodland communities are unlikely to remain

Table 2
Species that are considered to have potential for use in UK forestry as new components of woodlands in climate change adaptation strategies.

Species for which there is existing UK-based knowledge of performance from operational trials/ forest gardens/arboreta	Species for which there is little or no UK trials data but expert knowledge suggests that they merit screening for UK potential
Conifers	
Abies alba (European silver fir)	*Abies bornmuelleriana* (Bornmueller's fir)
Abies amabilis (Pacific silver fir)	*Abies cephalonica* (Greek fir)
Abies nordmanniana (Nordmann fir)	*Pinus armandii* (Armands pine)
Cedrus atlantica (Atlas cedar)	*Pinus ayacahuite* (Mexican white pine)
Cedrus libani (Lebanon cedar)	*Pinus brutia* (Calabrian pine)
Cryptomeria japonica (Japanese incense cedar)	*Pinus elliottii* (*Slash pine*)
Picea omorika (Serbian spruce)	*Pinus koraiensis* (Korean pine)
Picea orientalis (Oriental spruce)	*Pinus monticola* (Western white pine)
Pinus peuce (Macedonian pine)	*Pinus strobus* (Weymouth pine)
Pinus pinaster (Maritime pine)	*Pinus taeda* (Loblolly pine)
Sequoia sempervirens (Coast redwood)	*Pinus wallichiana* (Bhutan pine)
Thuja plicata (Western red cedar)	*Pinus yunnanensis* (Yunnan pine)
Broadleaves	
Acer macrophyllum (Big leaf maple)	*Betula papyrifera* (Paper-bark birch)
Acer saccharinum (Silver maple)	*Carya ovata* (Shagbark hickory)
Alnus viridens (Italian alder)	Other *Eucalyptus* spp. (Eucalypts)
Alnus rubra (Red alder)	*Fagus orientalis* (Oriental beech)
Eucalyptus gunnii (Cider gum)	*Fraxinus americana* (White ash)
Eucalyptus nitens (Shining gum)	*Fraxinus angustifolia* (Narrow-leaved ash)
Juglans regia (Common walnut)	*Fraxinus pennsylvanica* (Red/green ash)
Nothofagus obliqua (Roble beech)	*Juglans nigra* (Black walnut)
Nothofagus alpina (syn. *N. Procera*) Raoul beech	*Liriodendron tulipfera* (Yellow poplar)
Nothofagus pumilio (Lengua beech)	*Quercus alba* (White oak)
Platanus spp. (Planes)	*Quercus frainetto* (Hungarian oak)
Populus spp. (Poplars)	*Quercus pubescens* (Downy oak)
	Quercus pyrenaica (Pyrenean oak)

The sensitivities of the listed pine species to red band needle blight would need to be considered.

valid so the changing climate raises difficult questions for conservation of woodland biodiversity. In replanting, the preference for use of native tree species and local provenances under all circumstances will need to be reconsidered. Diverse semi-natural woodlands are likely to be able to adapt through natural processes, particularly since the majority of native tree species will persist across the UK – albeit with changes in their distribution and growth rate. However for this adaptive potential to be realised, management intervention (i.e. conventional good practice for woodland management) will be necessary in most woodlands to create a diverse structure and promote natural regeneration.

Pests and diseases of forest trees, both those that are already present in the UK and those that may be introduced, currently represent a major threat to woodlands, by themselves, and in interaction with the direct effects of climate change. There have been a number of serious pest and pathogen outbreaks in the UK over the past 15 years and the types of attack which we have seen have the potential to compromise the ability of forests to contribute to addressing climate change. The extent to which increased world trade in plants and forest products and climate change contribute to current threats is uncertain, but there is a need to reduce the future risks and to manage the existing outbreaks. It is essential that appropriate and effective interception and monitoring systems are in place to prevent the introduction of pests and pathogens. We also need early warning of impending threats and an effective response when outbreaks do occur; this requires good interaction between scientists and those responsible for outbreak management.

Trees also have an important role in helping society to adapt to climate change, particularly in the urban environment. Tree and woodland cover in and around urban areas will be increasingly important for managing local temperatures and surface water. Large tree canopies are particularly beneficial. Guidelines should be followed by all concerned parties both to ensure that we continue to maintain and plant trees in urban areas, and to overcome perceived risks including subsidence and windthrow. Where soil water stress is likely to be a problem, planting should focus on more drought-tolerant species. It is crucial that we have a thorough understanding of the current pattern of tree cover in urban areas, to target where we need to maintain and increase cover. There is also an important role for planting woodland along urban river corridors to reduce thermal stress to fish and freshwater life. Tree and woodland planting should be targeted to: (a) places where people live (especially the most vulnerable members of society) which currently have low tree cover, and (b) places where people gather (such as town and local centres) which currently have low tree cover.

Wood fuel and wood products substituting for other materials

By substituting for other materials with greater climate impact, wood products and wood fuel have a significant role to play in reducing carbon emissions in the UK. Forest products should comprise a larger share in the supply of biomass energy and of wood products used in construction. The UK Renewable Energy Strategy considered that renewables could contribute 15% of total energy requirements by 2020, with wood fuel making a significant contribution to the electricity, transport and heat-generating sectors. The UK has a significant biomass resource although estimates of the potential contribution from forestry vary considerably. The Renewable Energy Strategy has identified biomass conversion to heat as a least-cost way to increase the share of renewable heat for which there is a target of 12% by 2020. The deployment of forest resources to achieve these renewable energy targets is now a priority. The annual production of 2 million tonnes of wood fuel from English woodlands is based on the Wood fuel Strategy for England, while the Scottish Forestry Strategy commits to delivering 1 $MtCO_2$ abatement per year through renewable energy production by 2020. Over the next five years wood fuel in the UK has the potential to save up to 7.3 Mt of CO_2 emissions per year by substituting for fossil fuel. If 1 million ha of dedicated energy forests were planted on current agricultural land it would be possible to increase this to the equivalent of 14.6 $MtCO_2$ abatement per year over the next decade. Biomass for heat provides one of the most cost-effective and environmentally acceptable ways of decreasing UK GHG emissions.

Of the UK's current 2.5% by volume of liquid transport fuel obtained from biological sources more than 70% is imported, the sustainability of this supply being largely unregulated. Both the UK and EU will address the issue of sustainability in the near future. The changes likely to be made will involve restriction of feedstocks to those showing at least a 35% improvement in GHG balance relative to fossil fuels. In the UK this could favour the development of the woody biomass energy industry and involve the conversion of woody materials to liquid fuels through biological processes and thermochemical routes such as pyrolysis. To date about half the biomass feedstocks for the UK have come from imports, including approximately 1 million tonnes of biomass for co-firing. The co-firing market in the UK grew by *c.* 150% between 2004 and 2006 and is likely to expand further. This will be driven in part by changes to the Renewable Obligation Certificates (ROCs) which will provide better incentives for home-grown biomass as compared with imported supplies. As a consequence of these measures, bioenergy, including that obtained from wood, is likely to make an increasingly important contribution to UK targets for renewable heat, power and liquid fuels.

Substitution of wood products for materials which release GHG in their manufacture contributes to mitigation of climate change both by storing carbon in our buildings and by reducing fossil fuel consumption. The estimated total quantity of carbon stored in the form of wooden construction products in the UK housing stock in 2009 is 19 Mt. If the wood construction products sector continues to grow as it has in the past ten years there is the potential to store an estimated additional 10 Mt carbon (equivalent to 36.7 $MtCO_2$) in the UK's new and refurbished homes by 2019. This would save a further 20 MtC (73.4 $MtCO_2e$) as a consequence of substitution for more carbon-intensive materials. To date, failure to accept wood products arises in part from conservatism in the construction industry. Outmoded attitudes need to be robustly challenged by drawing on the evidence and promoting the technical properties of wood.

Sustainable development and socio-economic considerations

A complete assessment of the potential for our trees and woodlands to contribute to climate change goals can only be made by examining the social, economic and policy context within which UK forestry operates. The extent to which the potential for additional emissions abatement through tree planting is realised, for example, will be determined in large part by economic forces and society's attitudes rather than by scientific and technical issues alone. Private forest owners will require financial incentives to manage land for carbon sequestration, except where it is a joint venture associated with other types of forestry. Furthermore, trees and woodlands across the UK contribute to a wide range of policy objectives (including, for example, recreation provision and biodiversity protection), and woodlands need to be planned so that these objectives are achieved together with emissions abatement. Clearly, there are demands on land for other purposes – notably food production and urban development – which affect the economic potential for land to be allocated to forestry. Policies and practices in agriculture, planning and development and other urban and rural activities will affect the capacity of woodlands to deliver climate change mitigation and adaptation objectives, whilst the returns available through markets as well as Government support for competing land uses will influence how much new forest planting occurs. Policy incentives need to be re-designed so that adequate reward is given to the provision of non-market benefits, including those relating to the climate change mitigation and adaptation functions of forests. The knowledge built up in the UK and beyond should be used to facilitate more successful mitigation–adaptation interactions in the forestry/land use sectors in the wider context of sustainable development and promotion of rural livelihoods.

Trees and forests have a strong role in the way that people make sense of their environment and of how it is changing. This suggests a particularly significant role for those involved in forest management to engage with the public. By this means they will contribute to a broader understanding of the challenges posed by climate change. The scale and urgency of these challenges are such that they require to be driven at the institutional level, and cannot be left to the actions of individuals.

Grasping the opportunity – next steps to realising forestry's contribution

This Assessment provides the evidence base for a much greater involvement of UK forests and forest products in the fight against climate change. However, provision of the evidence to substantiate the potential contribution of forestry is only the first step towards its realisation. There remain large areas of uncertainty. We have identified research priorities at the end of the chapters in the full report of the Assessment that are targeted in particular at these uncertainties, but as important will be the processes of communication of the findings to those in decision-making positions in both the public and private sectors. Awareness at this level will enable the development of policies putting trees, woodlands and forestry at the heart of the UK's response to climate change. The key message of the Stern review was 'Act now or pay later'. In view of the fact that the strength of the carbon sink provided by UK forests is weakening so rapidly, the key message from this Assessment is **'Plant Now and Use Sustainably.'**

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Glossary

Abatement: to decrease GHG emissions including the reduction of net GHG emissions by increasing GHG removal (or uptake) from the atmosphere.

Adaptation: a process by which organisms become better suited to their habitat.

Carbon dioxide equivalent (CO_2e): Over a 100-year time interval the Global Warming Potential (GWP) of methane (CH_4) is 23 times that of CO_2 and nitrous oxide (N_2O) is 296 times that of CO_2. Therefore total GHG amounts are sometimes expressed as CO_2e where more than one GHG is being considered.

Carbon sink/source: the carbon balance of a forest is often described as a sink if there is a net transfer of carbon from the atmosphere to one or more of the carbon pools in the forest (resulting in carbon sequestration). When a forest is described as a carbon source there is a net transfer of carbon to the atmosphere.

Greenhouse gases (GHG): gases that have significant infrared radiation absorption bands in the troposphere. In order of importance, the relevant natural GHG in the troposphere are: water vapour, carbon dioxide (CO_2), methane (CH_4), ozone (O_3) and nitrous oxide (N_2O). UK forests exchange all of these GHG with the troposphere to a larger or smaller extent.

Mitigation: (of global warming) actions to decrease GHG emissions, to enhance sinks, or both, in order to reduce the extent of global warming.

Sequestration: (of C or CO_2) the removal from the atmosphere of carbon or carbon dioxide through biological or physical processes and their retention in living biomass or wood products.

Units

tC:	tonne of carbon
1 Mt:	megatonne equivalent to one million tonnes (1 Mt = 1 000 000 tonnes)
CO_2e:	CO_2-equivalent – see Glossary for definition

Abbreviations

FMA:	forest management alternative
GHG:	greenhouse gas(es) – see Glossary for definition
IPCC:	Intergovernmental Panel on Climate Change of the United Nations
UNFCCC:	United Nations Framework Convention on Climate Change

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