Multifunctional landscapes

Informing a long-term vision for managing the UK's land

THE ROYAL SOCIETY

Multifunctional landscapes: Informing a long-term vision for managing the UK's land
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Tribute to Dame Georgina Mace FRS

Georgina Mace was deputy chair of the Royal Society's Living Landscapes Programme Steering Group until her death in September 2020. Though she died before the report was written, her insights and wisdom have informed all the work of the Programme including this report. She is much missed.

Georgina read Zoology at Liverpool University and studied for a PhD on mammal evolutionary biology at Sussex University. In 1986, she joined the Institute of Zoology in London where she started a collaboration with the International Union for the Conservation of Nature to produce a 'Red List' of threatened species. Georgina led on developing defensible scientific criteria to determine extinction risk and her work has had a lasting impact on all areas of conservation biology. In the early 2000s, Georgina led the biodiversity component of the UN's Millennial Ecosystem Assessment, also playing a key role in the UK's National Ecosystem Assessment.

She was a leading figure in the reconceptualisation of biodiversity in terms of natural capital and related concepts, though also clearly articulated that biodiversity has intrinsic as well as instrumental value. Moving to Imperial College and then University College London, Georgina continued researching many aspects of biodiversity and played a very important role in stimulating research at those universities and elsewhere. Just how many young researchers Georgina encouraged and enthused was movingly demonstrated by a flood of affectionate and grateful reminiscences after her death. She will be remembered as an outstanding scientist by the research community and by many more people as a wise and influential contributor to many areas of national and international environmental policy.

Image: Dame Georgina Mace FRS. © Jussi Puikkonen/KNAW.

Executive summary

Globally, there are increasing demands on land to feed and house a growing and increasingly wealthy population, sequester carbon to mitigate climate change, restore biodiversity, and improve resilience in the face of extreme weather and global shocks such as pandemics and war. Successfully navigating these intersecting challenges will require science and innovation to increase the sustainable productivity of land for the multiple outputs society wants and needs, including those that have market value (such as agricultural produce) and those with no or partial market value (such as biodiversity).

Now is a critical moment for land use policy globally, but especially in the UK. A confluence of environmental and geopolitical drivers necessitates a strategic rethink of the way decisions are made about how landscapes and the services they provide are managed, not least the need to design replacements for EU agriculture, environment and trade policies by which the UK has been bound for decades.

Science and innovation have several important roles in helping manage landscapes better. Land is a finite resource and we need to research new ways to use it more efficiently, as well as to apply existing knowledge more effectively. The demands we place on the land are many, complex and interacting and policymakers need the best scientific evidence and analytical tools to help them navigate the difficult decisions they face.

The following recommendations are aimed at both increasing, and enhancing access to, science and innovation relevant to land use and supporting decision-making processes to help meet the challenges of the 21st Century.

Recommendations

RECOMMENDATION 1

Land use decision-making needs to embrace a multifunctional approach that considers multiple market and non-market land-based outputs.

A multifunctional approach considers simultaneously all the market (such as food, timber and energy crops) and largely non-market (such as biodiversity habitats, carbon sequestration, flood alleviation and recreation) products and services provided by the land. It considers trade-offs and synergies between different outputs and suggests how landscapes can be designed to increase benefits to multiple stakeholders, from individual landowners to society. It informs which outputs can best be produced in the same place, and which are best separated. It takes into account the spatial structure of the landscape so that benefits such as connected biodiversity habitats or upstream flood water retention can be realised. This, combined with evidence and analysis from the economic and social sciences, provides critical input into the political processes leading to landscape decisions.

RECOMMENDATION 2

Research and innovation is needed to improve the sustainable productivity of all land-based outputs.

In the past, land-based research has tended to concentrate on increasing the productivity and profitability of farming, forestry and other activities that produce goods with market value. This needs to continue but be expanded in three ways. The first is taking a multifunctional perspective, increasing the efficiency with which all landscape outputs are produced, not just those providing an immediate financial return. Second, much greater attention to sustainability is required – for example, reducing, eliminating or even reversing the negative environmental effects of farming, forestry and other activities. Third, more research on reducing negative trade-offs and maximising synergies between different landscape functions is needed. Land is finite and all land must be highly productive when production is interpreted to include all potential market and non-market outputs. Key areas of science that will contribute to meeting these aims are explored in this report, many of which span disciplinary boundaries.

RECOMMENDATION 3

New infrastructure will be needed to provide skills, training and advice for land managers to enable them to adapt their businesses and thrive on delivering multiple outputs from their land.

Managing multifunctional landscapes will require new skills and new sources of information and advice that are not currently available, or are in short supply. Skills shortages are already a limiting factor in the delivery of environmental projects and the transition to sustainable agricultural practices. Without training, land managers risk not being able to capitalise on the opportunities open to them, and the UK risks not having the right skills in its workforce to deliver important land-based policy commitments. Alongside skills development, innovation diffusion and technology transfer will be key to increasing productivity and will pave the way for enterprising land managers and new entrants to access new or enhanced income streams. Land managers will also require access to good quality, trusted advice as they make decisions about which management interventions to make where and when. Existing sources of advice are poorly designed to meet these needs. Innovative models of advice from private and public sources should be explored, especially with regard to increasing the provision of non-market outputs from land.

RECOMMENDATION 4

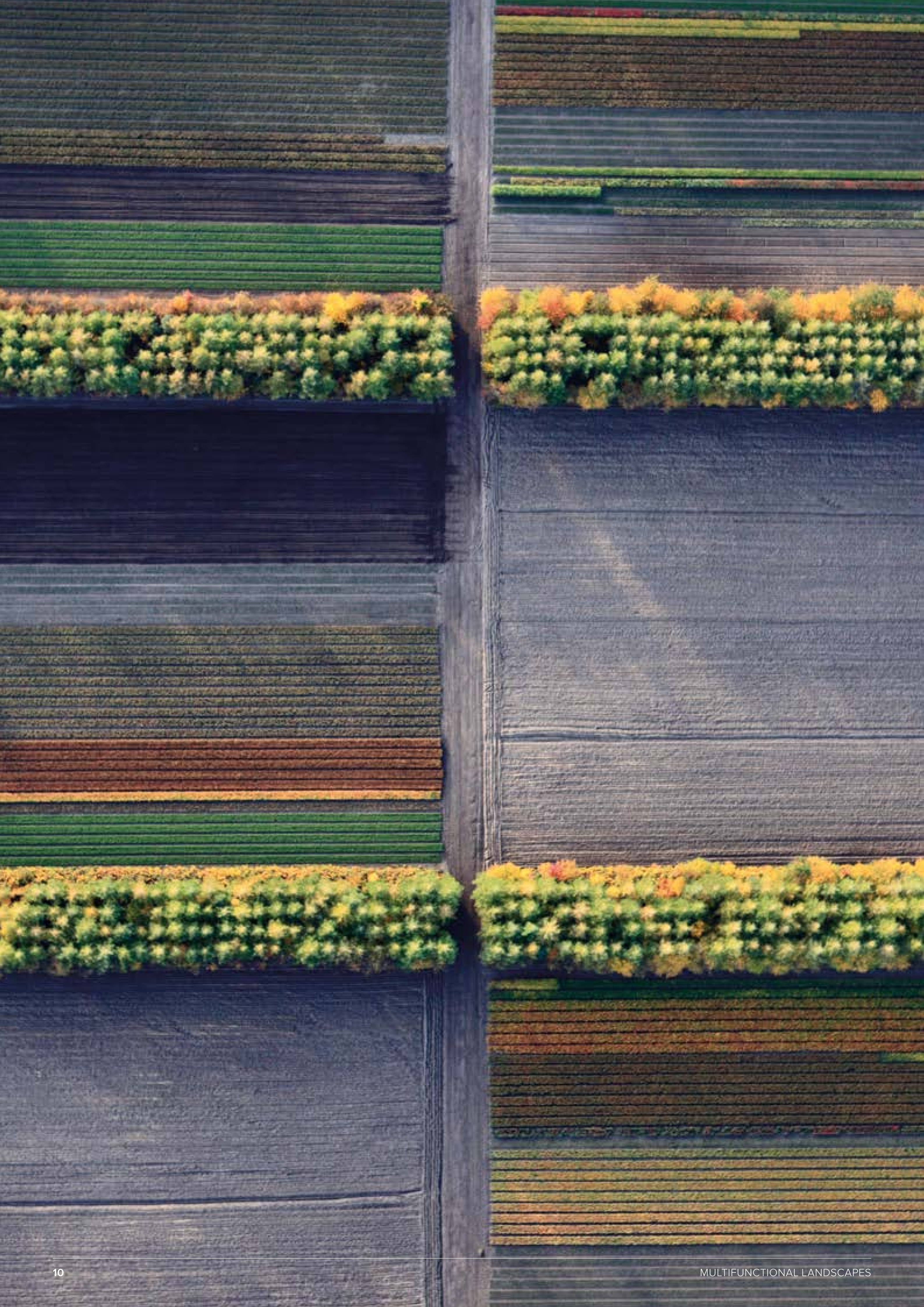
A novel data science-driven approach is needed to develop a high-quality common evidence base to underpin land use decisions.

Decision-making in multifunctional landscapes will benefit from integration of information about all aspects of landscapes including farm and forestry outputs, biophysical data (such as topography, climate, soils and biodiversity) and ecosystem services, as well as socioeconomic data such as land values, land ownership and livelihoods dependent on land-based-activities. Some of this information is available but is of variable quality, relevance, timeliness and accessibility. A more strategic national approach to land-based information, with clear data standards and protocols and creation of a common evidence platform, would empower decision-makers with a consistent set of science-based inputs from which to negotiate land use decisions. It would also facilitate the incorporation of new data streams made available by technological advances. Consistent and scientifically robust baselines, metrics and systematic monitoring programmes are needed to better understand the state of landscapes and what they are being used for, and to track progress towards meeting policy objectives.

RECOMMENDATION 5

The UK countries should develop and coordinate spatially explicit national land use frameworks to ensure coherence across different areas of land use policy and between national and local scales.

It is important that decision-makers can judge whether different policy commitments involving land use (for example, on food production, tree-planting, housing and biodiversity conservation) are compatible. This requires an overarching decision-making framework within which potentially competing commitments can be reconciled against one another. This report suggests a series of principles to help guide the construction of such frameworks in the UK countries: well-designed national land use frameworks should be based on robust data and analytics and developed in a transparent way to build trust across multiple stakeholders. They should ensure policy coherence at the national level and avoid policy incompatibilities, for example committing the same land to multiple incompatible functions. They can help to maximise returns on public investment in land-based activities as well as direct private green finance to where it is most needed. Frameworks should be spatially structured to facilitate decision-making at multiple geographic scales and to reconcile rural and urban planning decisions. They need to be flexible enough to evolve and improve as the evidence or policy needs change, and be in place long enough that individual land managers can use them to inform their own management and investment decisions. Different countries within the UK would benefit from coordinating their frameworks and using compatible methodologies.



Chapter one
Introduction

Left
Cultivation of tree seedlings in Bytow, Pomeranian Province, Poland. © iStock / DariuszPa.

Introduction

Land management is critical to many aspects of the economy and society. Land provides for basic human needs such as nutritious food, clean air, fresh water and places to live. The plants, animals and ecosystems that the land supports are of great value in themselves and provide indispensable services like pollination, nutrient cycling and climate regulation. Landscapes are interwoven with culture, language and history, providing a living for many and a source of enjoyment and wellbeing for all. Land is also the UK's most valuable asset (in 2020, it was worth £6.3 trillion[1]).

But land is a finite resource. Globally, projections estimate that by 2050 the world's population could reach 9.7 billion and demand for food will grow by 30 – 60%, set against intensifying problems such as climate change, loss of biodiversity and a decline in the amount of arable land per capita[2, 3, 4]. The UK's relatively dense population is also projected to grow to mid-century[5]. This puts increasing pressure on land for food, water, housing and other societal needs – though these demands need not be static and an important area of policy outside the scope of this report is to reduce pressure on land through, for example, food and water waste reduction and dietary change towards less resource-intensive foods. Land also plays an increasing role in mitigating and adapting to climate change. Land-based mitigation could provide up to 30% of the UK's planned net emissions reductions needed by 2050[6]. Land management is also central to preventing and reversing ecosystem loss – anthropogenic habitat degradation and loss is the single greatest cause of extinction risk[7].

To deal with this convergence of increasing pressures, the coming decades will see the biggest changes to landscapes in generations. To ensure these changes secure a sustainable future, and simultaneously tackle these interrelated challenges, landscapes will need to be managed more sustainably and strategically. Science and innovation will need to be harnessed to drive up productivity for all desirable land functions, both market and non-market.

1.1 Why is it helpful to take a multifunctional approach to land use decisions?

A core element of driving up land productivity is to explore the use of land for simultaneously delivering more than one 'function' – ie to take a 'multifunctional' approach. This considers simultaneously the multiple products and services provided by the land. Some of these outputs have prices determined by markets (market goods), for example, food, timber and energy crops. These can also be termed private goods as the returns chiefly accrue to the business owner. Other outputs often do not provide an income stream for the land manager, for example, carbon sequestered in soils and biomass, flood protection services provided by land that buffers heavy rainfall events, and the biodiversity supported by different habitats. Such products and services which benefit society are often referred to as non-market or public goods. Because the land manager is not typically rewarded for their provision, simple market forces alone will tend to lead to the under-provision of public goods to the detriment of society.

Landscapes have always been managed to produce multiple outputs, so the concept of multifunctionality within landscapes is not completely new. However, an explicit analysis of these multiple functions and their synergies and trade-offs is more novel and can provide both an evidence base and a set of tools and techniques to manage UK landscapes better. Some of the methodologies involved are the same as economic models that would be applied to questions of resource allocation in other sectors, but decisions involving land and landscapes have unique features. For example, location and relative location matters. Different places are endowed with different biophysical features; flood alleviation is most valuable upstream from a major conurbation. Land has cultural and political significance that is much greater than would be expected from its contribution to the GDP of a modern economy. The evidence base supporting decision-making about landscapes must be informed by the social as well as the natural sciences. It is also the case that different stakeholders may differ in how they value the various outputs of land so there is no simple optimum land use consensus. Political processes in the democratic countries of the UK can play a significant part in resolving such issues, but the sciences have a very important role in clarifying the consequences of different options.

1.2 The context of land use decision-making in the UK today

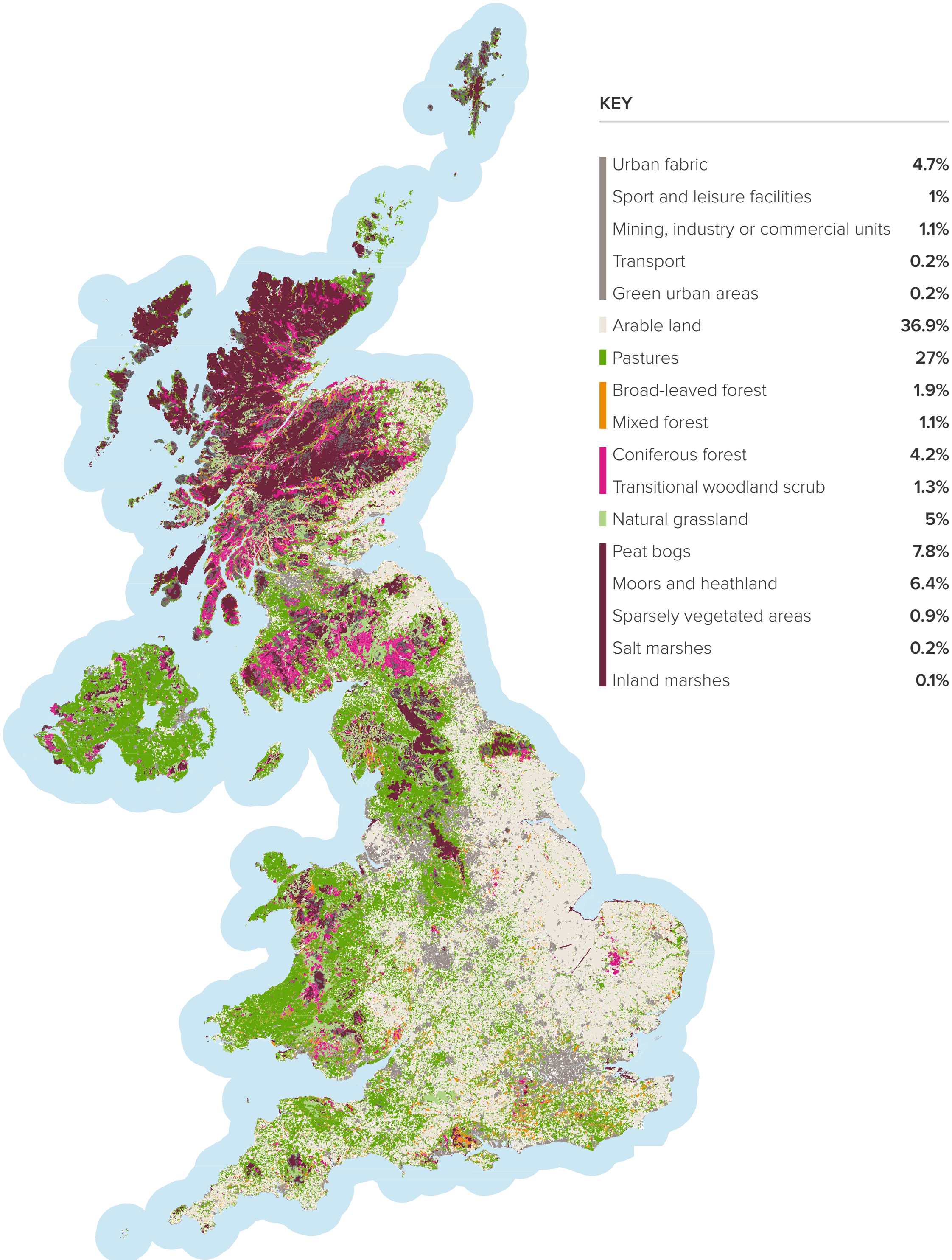
Decisions about landscapes can have ramifications that last for centuries. Figure 1 shows current patterns of UK land use. Peat bogs and (largely planted) coniferous forest dominate the Highlands and Islands of Scotland. Wales, Northern Ireland, southern and central Scotland and the uplands of England are primarily given over to pasture for livestock grazing, while arable farms cover most of England's lowland centre and east (farmland makes up 72% of the UK's total land area). Urban landscapes occupy 8% of the land area but are home to 84% of the population. The imprint of past landscape policy can be seen in many places, in patterns of urbanisation and beyond. For example, the draining of the Fens for agriculture in the 17th Century, the New Forest Act 1697 which ordered that the New Forest be planted with trees to supply timber to the Royal Navy, the Enclosure Acts between 1604 and 1914 which brought previously common land into private ownership, or the Highland Clearances which gave rise to the crofting communities of Scotland today. The effects of land use decisions made long in the past shape both landscapes themselves and our cultural appreciation and understanding of them.

Some of the greatest changes to UK landscapes have occurred since the end of the Second World War. In 1945, the UK's population stood at 49 million, while today it is a third higher at 67 million[9, 10]. Most of this growth has been concentrated in urban areas which have expanded on to land previously used for agriculture and other functions.

> "Farms, farmers and farmland have been around for generations. Are we going to say that the government has a right to take the land off these people if they don't want to diversify?"
>
> **Public dialogue participant, East Anglia**

FIGURE 1

The UK's current land cover.



Adapted from UK CORINE (Coordination of Information on the Environment) Land Cover 2021. UK Centre for Ecology and Hydrology[8].

Technological advances and increased demand for food, coupled with facilitative policies such as the post-war Agriculture Act 1947, have led to radical increases in agricultural production[11]. Commentators in the late 1960s and early 1970s, alarmed by growing population numbers, predicted widespread famines and food shortages (including in Europe) in the 20th century[12, 13]. These did not come to pass as predicted due to increases in yield, including those resulting from the genetic advances and improved production techniques of the 'Green Revolution'[14]. Modern food systems in the UK and other high-income countries now offer unprecedented choice, continuity of supply, affordability and freedom from harmful contaminants (though the lowest income groups still suffer from food poverty).

However, these advances have come with considerable environmental costs[15]. For example, 41% of the UK's monitored species have declined since 1970 while 97% of wildflower meadows have been lost since the 1930s[16, 17]. Only 32% of the UK's freshwater bodies are classed as 'good' under the Water Framework Directive (this falls to 4% if Scotland is omitted) with fertiliser run-off from farmland the chief culprit[18]. Soil is being eroded and compacted risking future productivity[19, 20]. Agriculture and land use accounts for approximately 12% of the UK's greenhouse gas emissions with the ensuing climate change having potentially huge economic costs[21]. Intensive farming has led to the homogenisation of large areas of the countryside, reducing its biodiversity and recreational value[22, 23, 24]. Overall, changes in land use and management since WWII have increased agricultural production but diminished natural capital – the stocks of natural assets in the environment that provide multiple important products and services.

1.3 Why now? The drivers of change.

This is a significant moment for land use policy globally, but especially in the UK. A confluence of environmental and geopolitical drivers necessitates a strategic rethink of the way decisions are made about how landscapes and the services they provide are managed.

The impact of humanity on the environment, and our dependence on it, are increasingly recognised, as is the urgency to act. Many countries have committed to net zero emissions to curb climate change, though over different time periods. Agriculture and land use accounts for approximately 12% of the UK's greenhouse gas emissions, so taking net zero seriously will require major changes to land use policy[25]. Because some emissions will never be eliminated, net zero implies some carbon dioxide removal from the atmosphere. Though direct air CO_2 capture may become economically feasible in the future, currently carbon sequestration in ecosystems is the only negative emissions technology possible at scale, which makes land use change essential in climate policy[26].

> "We are only at the start of climate change and really don't know what is yet to come. Farmers will be able to change or modify the crops that they grow but the weather is a strong force to have to work against."
>
> **Public dialogue participant, Southwest England**

Current rates of extinction are so high that the present epoch – the Anthropocene – is likely to rank as one of the six great extinction events in the history of the earth[27]. There are both practical and intrinsic arguments to protect biodiversity. Biodiversity provides important services such as pollination, while 'nature-based solutions' can help address climate change and other environmental challenges, as well as providing a source of genetic adaptability and resilience to improve pathogen resistance and productivity in crops[28]. Irrespective of the usefulness of biodiversity, there is widespread agreement that transcends cultures and nationalities that the current generation has a duty to maintain substantial biodiversity for future generations. Though not as developed as emissions pledges, countries are making commitments to protect biodiversity with significant ramifications for land use policy. Sir Partha Dasgputa's review of the economics of biodiversity notes the failure of GDP to account for quantifiable ecosystem services and their depreciation in national balance sheets, and the need for economics to redress this.

The world will need to produce 30 – 60% more food by mid-century to meet the demand of a growing and wealthier global population[29]. Demand for food is likely to rise in the UK but by a smaller amount[30]. The exact figure depends on, amongst other things, future diets and progress on reducing food waste. A policy question is whether the UK should aim to increase its food production to capitalise on, and help address, rising global demand, maintain its current levels of food production (the option favoured in the Government's response to the English National Food Strategy) or reduce production to use land for other purposes. All these options have major implications for land use in the UK and abroad (for example, if other countries supply imports to substitute domestic production). Responses to price signals will tend to align supply with demand but, in as complex an area as agriculture, trade and land use, with its many positive and negative externalities, the market alone is unlikely to deliver the outcomes that best meet society's needs. In addition, the recent manifest fragilities of international supply chains in response to shocks has focused more attention on security of supply.

In addition to these global drivers, there are a series of more local factors increasing the importance of innovative land use policies in the UK. Leaving the European Union means crafting replacements for EU agriculture, environment and trade policies by which the UK has been bound for decades. Exactly what replaces the EU Common Agricultural Policy (CAP) will be particularly critical. Under the CAP, funds were disbursed according to the area of land farmed with little conditionality. There is an opportunity now for UK countries to design rural support policies which direct funds towards improving the overall productivity of land, including sustainable food production and the provision of goods which are undersupplied by the market, with spatial targeting of outcomes to the places where they are most appropriate. The greater freedom to negotiate bespoke trade deals with other countries also has potential ramifications for agriculture and land use in the UK.

The UK is rethinking its position in the world and what is meant by the notion of 'Global Britain'. The Integrated Review of the UK's national security and international policy published in 2021 highlighted the role of the UK in providing global leadership in addressing major environmental issues such as climate change and biodiversity loss, in part building on the strengths of its science base[31]. The UK's role in hosting the United Nations' COP26 and being a thought leader in confronting biodiversity loss (see, for example, Sir Partha Dasgupta's *Review of the Economics of Biodiversity* commissioned by HM Treasury) shows this in practice, though the UK's global authority can only be as robust as its own policy actions.

Finally, the world has seen two major shocks since the beginning of the decade. The Covid-19 pandemic was the greatest global health emergency for 100 years. It led to a major economic shock, though overall the global food system showed considerable resilience. During the preparation of this report, Russia invaded Ukraine, a major exporter of wheat, maize and plant oils. Global food prices spiked and several governments introduced tariffs and trade restrictions. Increases in food and energy prices are driving inflation across the globe and the United Nations and World Food Programme are highlighting the risks of famine and reduced food security in many areas, especially in the Middle East and North Africa[32]. These two major shocks, plus increasing concerns about geopolitical and climate volatility, are raising questions about food system resilience and the advantages and disadvantages of globalisation. It is too soon to understand the consequences of these events for land use policy but they almost certainly will generate new challenges and require an adaptive and flexible policy response.

1.4 Current policies

The UK Government and the administrations of Scotland, Wales and Northern Ireland (to which most policy relating to land use is devolved) have made a number of legislative and policy commitments that create a complex nexus of issues involving land use. These include commitments to maintaining current levels of food production, net zero greenhouse gas emissions, protecting land for nature, tree planting, peatland restoration as well as plans for housing and infrastructure.

While it is important to have policies and targets that address these critical issues, it is also important that the policies are coherent and consistent. A basic test of this is whether the sum of the land explicitly or implicitly committed to different uses sums to the total amount of land in the countries of the UK.

It is not obvious that this is so, at least without a very careful assessment of synergies and trade-offs amongst different land use functions. Indeed, if existing land-based policy commitments are added together, one finds that the UK's land already risks being 'overpromised' (Figure 2).

By 2030, up to 1.4 Mha of additional land (equivalent to the area of Northern Ireland) could be needed by 2030 to meet current policy targets for net zero and biodiversity, if current agricultural production, diets and food waste remain static. This rises to 4.4 Mha by 2050 – over twice the land area of Wales and 18% of total UK land area.

To arrive at these figures, a series of assumptions were made about the overlap of different functions and demand-side drivers such as diets, food waste and water use.

These illustrative figures demonstrate the increasing pressure on the UK's land over time and emphasise the importance of:

- Ensuring all land is used productively and that productivity increases, where the concept of productivity is applied not only in its traditional sense to food, timber and other marketable goods but also to the full spectrum of public goods.
- Analysing land use within a multifunctional framework to maximise synergies and minimise negative trade-offs between different land use types.
- Investing in research to increase productivity (as defined above) and maximise synergies.
- Joining up policy development across all departments of government within a land use framework informed by a comprehensive and continually improving evidence base.

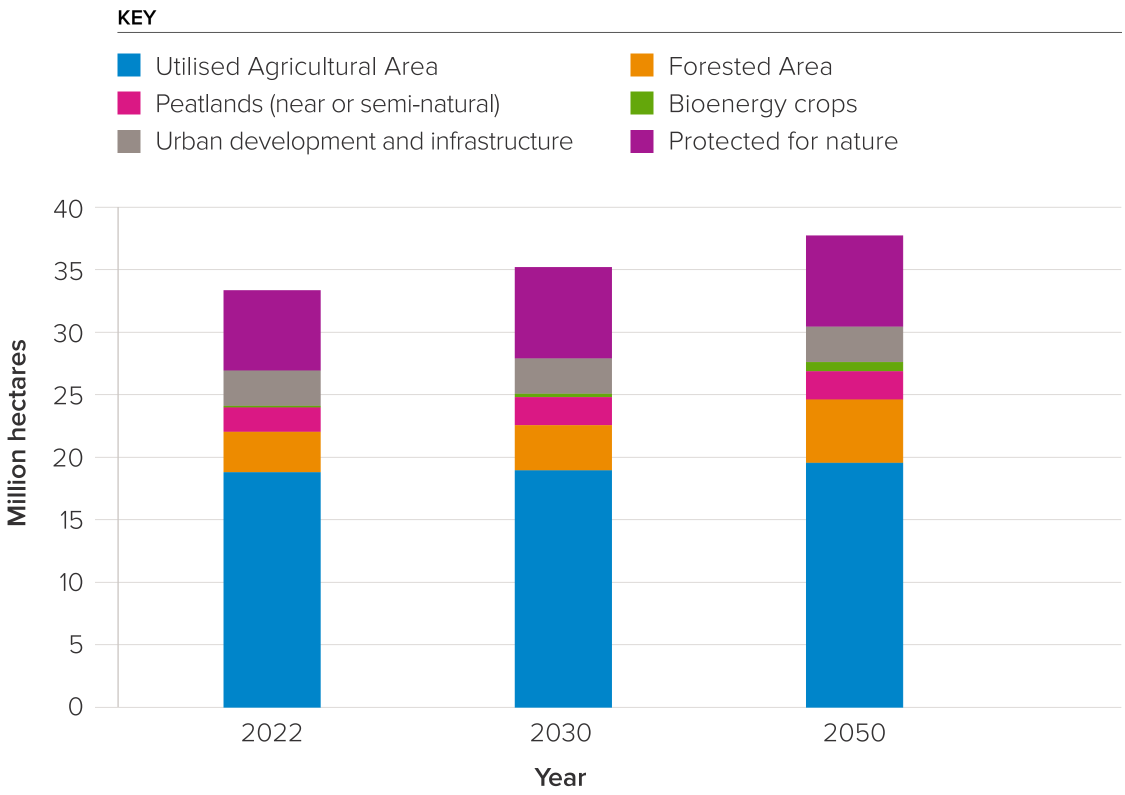
"Land really matters to us because it's all around us, it's everywhere, we touch it, in COVID we've had even more connection to it. So, it is different, that is why we need to think about land and food in a different way."

Public dialogue participant, North Wales

FIGURE 2

Potential increase in UK land area needed by 2030 and 2050 to meet net zero and biodiversity commitments if current agricultural productivity, diets and food waste remain static.

Policy commitments are: increase woodland cover to 14.8% of UK land area by 2030 and 17% by 2050[33, 34, 35, 36]; restore 300,000 ha peatland by 2050[37, 38, 39]; scale up bioenergy crop production to 23,000 ha per year by mid-2020s; protect 30% of land for nature by 2030[40, 41, 42, 43]. Agricultural output is calculated as a function of population projections[44].



Several recent analyses have explored the potential consequences for land use of meeting some of these targets, especially for greenhouse emissions. For example, UK-wide modelling conducted by the UK Centre for Ecology and Hydrology to inform the Climate Change Committee's Sixth Carbon Budget estimated that, to meet carbon targets while maintaining food production, between 7% and 16% of UK land would need to be released from agriculture by 2035 and used instead for emissions reductions and carbon storage (8 – 22% in England, 9% in Scotland, 5 – 7% in Wales and 8 – 17% in Northern Ireland)[45]. In Scotland, Wales and Northern Ireland, the shift would mainly be from pasture to forestry and, to a lesser extent, bioenergy with peatland restoration (including currently afforested areas). In England, the biggest shift would also be from pasture to other uses (forestry, bioenergy and housing and infrastructure), but a significant amount of arable land (13%) would also be released. The National Food Strategy estimated that 5 – 8% of English land would need to be released from agriculture entirely by 2035 to meet climate and biodiversity targets (pointing out that, as the least productive 20% of farmland produces 3% of calories, there was considerable scope to do so without severely impacting food production).

New modelling by Green Alliance sets out possible future scenarios that meet climate and biodiversity targets while producing enough food to at least maintain the current level of self-sufficiency in the UK[46]. In their preferred pathway, by 2050 there is a 45% reduction in the consumption of meat and dairy (with a significant proportion replaced by alternative proteins). This shift frees up land and allows approximately 30% of UK farmland to be farmed with an emphasis on high but sustainable yields, 40% to be farmed on agroecological principles (currently 3% of farmland is organic) and 30% to be managed as semi-natural habitats for carbon sequestration and nature. Green Alliance suggest this future scenario would deliver the bulk of negative emissions required for the UK to reach net zero and significantly lessen the need for engineered approaches to carbon removal that rely on imported biomass. As discussed later in this report, careful design of spatially sensitive financial incentives, which reward the provision of public goods where they are most beneficial, would ensure sustainable profitability for land managers across the UK.

1.5 What this report aims to do

This report addresses the increasingly pressing global and national need to ensure land is managed wisely to produce a broad spectrum of outputs. It has been informed by the academic literature, interviews with stakeholders, a commissioned review by researchers at the University of Reading on the history, politics and trends that have shaped rural land use in the UK (Annex B), and a public dialogue exercise on attitudes to land use run by Ipsos MORI (Annex C)[47, 48]. Quotes from participants in the public dialogue are included throughout the report where they relate to the topics discussed. The work was guided by a Steering Group of experts and reviewed at different stages by leading researchers in the field (Annex A).

The report offers a long-term vision for UK land use decision-making and provides guidance as to how this vision might be realised. It particularly concentrates on the role of the natural and social sciences, and novel data science approaches, in supporting better decision-making. Land use is an area of policy where reasonable people can come to different conclusions, so science alone cannot determine policy. Nevertheless, the application of the scientific method and scientific analysis can clarify policy alternatives as well as provide new options. To do this well will require the scientific community to work in new ways that transcend disciplinary boundaries.

The intended audiences of this report are all those involved in making decisions about land use. Its scope is landscape and related decision-making in England, Scotland, Wales and Northern Ireland. It naturally concentrates on rural landscapes that make up 92% of the UK but does not ignore the remaining urban 8% and in particular the needs of the people who live in towns and cities.

There are areas of research and policy relevant to land use that the report does not cover or only touches upon. A particularly important area is reducing the demands society places on the land. For example, dietary change to switch to food types that have fewer environmental inputs and require less resources in their production will be essential for feeding a mid-century global population of approximately 10 billion healthily, sustainably and equitably. If humans do not reduce the water they extract from the environment, many functioning ecosystems and large amounts of biodiversity will be lost. The focus of this report on land use and supply-side issues should not be interpreted as underestimating the importance of the demand side, and the need for governments and other agents to confront difficult decisions about how much, and what, society consumes.

Image: Glenariff Forest Park, County Antrim, Northern Ireland.
© iStock / Dawid Kalisinski Photography.

Chapter two
Multifunctional landscape analysis

Left
Mersea Island's marshland.
© iStock / Aerial Essex.

Multifunctional landscape analysis

Land produces a wide range of products and services that benefit the individual land manager as well as other stakeholders and all of society. This chapter discusses how scientific analyses based on the concept of multifunctionality can guide land managers and policymakers in deciding what to do where, and how to maximise synergies and reduce negative trade-offs. While, in theory, a scientifically optimum allocation of land use could be constructed for a region or nation given clear specifications of overall goals, constraints and metrics, this is both practically and politically unattainable. Science is only one input to policymaking, which also needs to take into account financial and economic considerations, as well as risk, feasibility and acceptability to stakeholders. Policymaking in a democracy rightly includes value judgments and weighting of local issues, such as heritage and cultural practice. Nevertheless, careful scientific analysis alongside recent advances in data science can greatly improve land use decisions at multiple scales.

Increasing pressures on land make it imperative to improve productivity where this includes the full gamut of land-based products and services. The science of multifunctional landscapes is thus inherently interdisciplinary, bringing together research from agriculture, forestry, ecology, geography, hydrology, rural economics, the broader social sciences, and other areas. This and the next chapter touch on all these disciplines but cannot exhaustively review all relevant research due to its sheer volume and diversity. Instead, the aim is to illustrate how systematic landscape analysis works and can be useful to policymakers, as well as providing examples of where it can already inform land use policy in the UK. The recently concluded UKRI-NERC Landscape Decisions Programme has sponsored novel interdisciplinary research in this area that will form the basis of new methods of analysis[49].

2.1 Elements of the analysis

Objectives, metrics and measurements

A land allocation analysis begins with an objective and then one or more metrics to measure the value of alternative options given the trade-offs and synergies inherent in the system. The analysis then allows the best strategy to be chosen, perhaps subject to different constraints.

It is a challenge to find a metric that can be used to assess all the different products and services provided by the land. A frequent choice is monetary value, building on agricultural and rural economics, which concentrated on those products of the land that had market value. Modern environmental economics extends this approach to include externalities: the negative and positive consequences of land use decisions that are experienced by stakeholders and society beyond the land manager. It involves putting a cost on pollution and greenhouse gas emissions and assigning a positive value to services such as water purification, flood alleviation and the provision of habitats for biodiversity and recreation. A variety of techniques are now available to estimate values for different non-market outputs.

Especially where there are a limited set of options, it may be possible to determine which option is superior without a common metric. Thus, if option A outperforms option B on, say, food production, greenhouse gas emissions and biodiversity, one might conclude it is better without having to judge each output using a common currency. Systematically evaluating the performance of different strategies within a multifunctional framework can provide important information to inform policymaking and can be very valuable at improving decision-making where different stakeholders may not value different outputs equally.

It is important metrics do not ignore the context within which a service is being measured. For example, the UK wants to produce a certain amount of food, so it is necessary to measure landscape outcomes (eg biodiversity) under different management strategies per unit of food produced, rather than per area farmed[50]. This allows the relative benefits of different strategies to be compared with the same level of agricultural output. Studies which conclude biodiversity is better served by extensive, low-yield agriculture are often not comparable in terms of agricultural output.

Metrics also need to consider the condition of natural capital assets, as well as the flows of ecosystem services that come from them. Measuring only ecosystem services can prevent detection of unsustainable management[51]. For example, soil condition (structure, carbon content etc) may be deteriorating, but yields (a provisioning ecosystem service) may be increasing due to unsustainable management.

Much effort has gone into developing protocols for measuring greenhouse gas emissions and comparing them across different sectors. This task is made easier by the fact that emissions are mixed in the atmosphere, so location does not need to be taken into account, and because in many cases the majority of emissions are CO_2[52]. When considering emissions from agriculture and other land use activities the situation is more complicated because other greenhouse gases are important (for example, methane from ruminant production and nitrous oxide from fertilisers) and these have different warming potentials and residence times in the atmosphere[53]. Thus, CO_2 has a considerably lower warming potential than methane but persists much longer in the atmosphere.

Typically, non-CO_2 greenhouse gases are expressed as CO_2 equivalents based on their ‘global warming potential over 100 years’ (GWP 100). However, this fails to account fully for key policy-relevant differences between the two types of emissions (the current level of global warming is determined by cumulative CO_2 emissions since pre-industrial times, but by the annual rate of methane emissions in recent decades) and metrics such as the recently developed GWP* provide better guides to analysis of emissions associated with agriculture and land use[54].

Measuring and developing metrics for biodiversity is especially difficult. While only a small number of gases are responsible for greenhouse emissions, the number of species found in even a small plot of land is in the many thousands (more if micro-organisms are included). Identifying all the species present is typically unfeasible without unrealistic investment in time and resources. In the future, advances in environmental DNA monitoring and related technologies may allow direct assessment of total biodiversity but for the foreseeable future, proxies must be used. These tend either to use a subset of species that can be readily sampled and identified (for example birds, plants and butterflies) or use habitat type and diversity as proxy indicators. All methods have advantages and drawbacks, and this is an area that needs further research. Biodiversity also differs in that species extinction is irreversible and thus there are arguments that the value of species changes with rarity.

“We need to make the absolute most of what we’ve got and, where we can, we should be growing, planting and farming as well as protecting the landscape… we need to make the land work smart not hard!”

Public dialogue participant, North Wales

> "We need a combination of better flood defence, beavers and careful land management. We need to get farmers on board with the Environment Agency to make this happen."
>
> **Public dialogue participant, North Wales**

Trade-offs and synergies, and comparative advantage

Landscape functions interact with one another in highly complex, often non-linear ways. Some functions combine well, or synergistically, while for others there are negative trade-offs[55]. Trade-offs are inevitable because not everything can be done everywhere and some functions preclude others, but there are also many opportunities to capitalise on synergistic functions. There is much research on the nature of trade-offs and synergies in land use including on the sociocultural services provided by the land[56, 57, 58, 59, 60, 61].

Not all land is of equal value for producing different outputs. For example, soil, climate and topography affects the quality of land for agriculture, while a complex nexus of biophysical factors determines the richness of biodiversity at a particular site. The value of outputs may be influenced by where they are produced: land for human recreation is more valuable near population concentrations, and flood mitigation is most important upstream of urban areas. The comparative advantage of different areas for producing different outcomes, and how they are spatially related, can be an important part of land use planning analysis.

Spatial scale

Land use analysis can be done at local to national (even global) scales. The broader the scale the more comprehensive the conclusions can be (though the analysis may be more difficult), but land managers and policymakers may require analysis at scales that match land holdings or administrative/political areas. In making decisions about land use in a particular place, it is important to consider the impact of those decisions on other areas. These include direct impacts such as negative externalities (for example, pollution, greenhouse gas emissions or flooding) as well as positive consequences (such as migration routes for biodiversity, carbon sequestration or flood mitigation). There are also indirect impacts. For example, a reduction in food production will stimulate food production elsewhere with the precise response being determined by the economics and political economy of the food system. Given UK agriculture is comparatively carbon-efficient, any greenhouse gas advantages of less intensive farming may be offset by increased production in less carbon-efficient regions (or, worse, by deforestation). It is therefore misleading to value reduced greenhouse emissions per unit of land if this is achieved by reduced food production with the deficit made up elsewhere leading to net greater emissions (so-called carbon leakage).

Temporal scale

The consequences of land use decisions made now will often have ramifications far into the future. Carbon sequestered today will reduce global warming over decades, while damage done to soils will affect crop yields for many seasons[62, 63]. The temporal scale over which land use decisions are analysed will thus have a major effect on outcomes. A particular concern is that maximising short-term value can reduce the value-creating capacity of the land in subsequent years. Wales has introduced legislation explicitly to safeguard against this risk, including for land use, and protect the interests of future generations[64]. Future consequences of land-use decisions made today can be incorporated into trade-off analysis, though the costs and benefits are discounted compared to those currently experienced[65]. Discounting is justified by the time value of money (the same amount of money is worth more to an individual now than in the future because of its earning potential in the interim) and because of assumptions about the capacity of society in the future to absorb costs and enjoy benefits. The exact discount rate can have a major effect on ranking policy options and there is a large technical literature on how it may be determined[66, 67].

BOX 1

Multi-Criteria Decision Analysis

Multi-Criteria Decision Analysis (MCDA) describes a suite of interdisciplinary techniques that incorporate stakeholder values into decision-making processes[69, 70]. Unlike more commonly used cost-effectiveness and cost-benefit analysis approaches, it does not require monetary values to be ascribed to its inputs and instead uses a combination of stakeholder engagement and expert opinion to score and weight different options against a set of mutually agreed criteria. The result of an MCDA is a ranked list of options from most to least preferred. However, a single option is unlikely to be optimal for achieving all objectives, so MCDA is a tool to be interpreted by decision-makers. Its output should not constitute a final decision[71]. This is particularly important if applying it to land use decisions where multiple objectives are in play.

Undertaking an MCDA requires knowledge of and access to the relevant stakeholders and a range of skills including independent facilitation and mathematical skills to analyse weights and scores. Despite being advocated by the HM Treasury Green Book for decades, there is little evidence the technique is used often in policymaking. This may be because it is perceived to be time, resource and skills heavy compared to other decision-support techniques. However, the inclusive and transparent nature of MCDA, and its ability to incorporate values beyond the purely financial, make it a potentially powerful tool for land use decisions where there are many potential options and complexities to consider.

An important framework for thinking about the future is in terms of multiple capitals and inclusive wealth. Just as an investment fund may make decisions that preserve the financial capital upon which future income flows are based, land use decisions can be taken to preserve the natural capital upon which future ecosystem services are based. A country's (or other entity's) inclusive wealth can be thought of as the sum of multiple capitals – financial, produced, human, social and natural.

For social capital and other valuations that are difficult to monetise, there are analytical techniques for factoring these into decision-making, such as multi-criteria decision analysis (MCDA), a tool recommended by HM Treasury though not often used by policymakers (see Box 1). Over successive reports, the UK's Natural Capital Committee has explained exactly how a natural capital framework can be operationalised to improve land use decisions. In his report for HM Treasury on *The Economics of Biodiversity*, Sir Partha Dasgupta FRS addresses some of the most challenging aspects of natural capital accounting concerning resource allocation to protect biodiversity[68].

2.2 Examples of land use analysis

Careful scientific analysis can provide insights helpful for land use decisions, complementing evidence from other sources. However, as with any modelling, it inevitably involves simplifying and abstracting a much more complex reality, often using incomplete data. The value of such analyses depends upon the results being carefully interpreted and the limitations and assumptions communicated clearly to decision-makers.

A variety of approaches to resource allocation have been developed in economics, geography and other fields, and these methods have been adapted and applied to land use. Exactly which method is best to use depends on the precise land use question and framing that is being investigated. Below are two examples of trade-off analyses which have been applied to land use decisions. The purpose of these examples is to demonstrate the value of careful quantitative analysis, rather than to advocate any particular approach.

Example 1: Optimising land use for market and nonmarket value

The Natural Environment Valuation (NEV) tool developed by Bateman and colleagues at the University of Exeter is an example of a spatially explicit model which determines the economic consequences of land use decisions[72]. It divides the UK into 2km grid squares, for each of which there is information on climate, soils, slope and other factors that may affect agricultural and other outputs. Agricultural land is assigned to six major categories (cereals, oilseed rape, root crops, temporary grassland, permanent grassland and rough grazing) which together make up 88% of UK farmland, the remaining 12% forming an 'other' category. Land used for other commercial purposes such as timber or biomass for energy is included, as are protected areas such as nature reserves and urban areas where land use is assumed not to change (but which may be affected by changes in land use elsewhere in the landscape). Functions describe how the biophysical conditions combine to determine yields for different land uses, while the costs of inputs and prices of outputs determine the financial returns from different land use decisions. The model assumes all land managers are profit maximisers and finds the optimum pattern of land use subject to the constraints. Once this pattern of land use has been established, the extent and spatial distribution of its effects on both market and nonmarket value derived from landscapes can be determined. Effects on non-monetisable factors, such as some aspects of biodiversity, can also be included.

NEV and similar models allow classical economic modelling approaches to be extended to include concepts such as natural capital, and non-market products of landscapes such as cultural value, thus enabling a more complete, multifunctional assessment of different land use scenarios. It is of course a simplification to assume individual decisions are made about every 2km grid square in the country, and that all agents making decisions about land use are profit-maximisers. Models such as NEV are therefore unlikely to provide quantitative predictions about future land use decisions. Nonetheless, they are valuable for comparing the likely outcome of different land use decisions, or of future climate and/or socioeconomic scenarios.

An important early application of the tool was to demonstrate that decisions based on a consideration of all outputs of landscapes (compared with market outputs alone), resulted in greater net value being derived from those landscapes[73]. For example, through increased recreation, decisions to green urban and peri-urban areas increased overall economic value more than if those areas had been used to produce market goods. Similarly, connecting and increasing the extent of conservation areas into functional ecological networks increased economic value through recreation and GHG emissions reductions as well as the nonmonetary value of biodiversity. Now, the NEV suite of models is widely used to inform national and local land use decisions. For example, it has provided natural capital analysis for the Climate Change Committee, National Infrastructure Commission and Environment Agency.

Example 2: Modelling biophysical trade-offs within socioeconomic boundaries

The second example focuses on the trade-off between agricultural production and biodiversity. A methodology developed by Green, Balmford, Phalan and colleagues at the University of Cambridge asks how best to maintain biodiversity (and other non-market goods) in landscapes that are also used for agriculture. Is it better to try to preserve biodiversity on agricultural land, or to concentrate agricultural production in certain areas while managing other areas specifically for biodiversity?

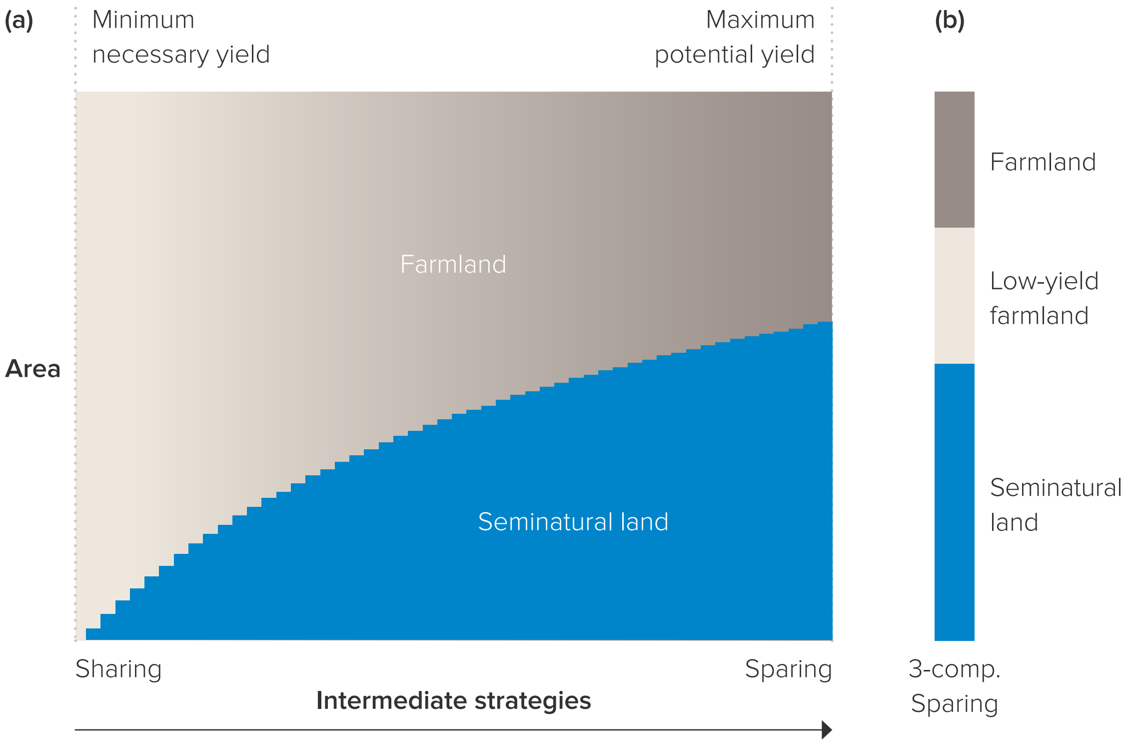
The analysis compares the biodiversity of different landscapes that produce the same amount of food. It does this by determining the trade-off or synergy between agricultural production and different components of biodiversity at a local level (Fig 3a). To give a concrete example, consider a naturally forested area, partially cleared for agriculture, upon which a spatial grid is laid. Investigators assess how agricultural yields and the abundance and diversity of species vary across grid cells with different levels of forest clearance. Using this information, the biodiversity supported by landscapes where agriculture and biodiversity are co-located or separated, and which produce the same amount of food, can be compared. If synergies are common, then co-location will tend to be favoured, while if negative trade-offs are more frequent, separating functions will be preferable.

This approach was first applied to birds and trees in tropical forests and gave a very clear result: the impact of even partial forest clearance on biodiversity was very negative and therefore separating agricultural and protected areas maximised biodiversity for a given food production output[74]. Indeed, to date, most applications of this approach have found that the separation of functions is favourable for biodiversity.

FIGURE 3

Illustration of the sharing-sparing continuum (a) and the three-compartment approach (b).

Each vertical column represents a distinct food production scenario of constant area (y-axis), all of which deliver the same amount of food overall.



Source: Reproduced from Finch T, Gillings S, Green R E, Massimino D, Peach W J, Balmford A. 2019. Bird conservation and the land sharing-sparing continuum in farmland-dominated landscapes of lowland England. Conservation Biology, 33(5), 1045-1055. (doi.10.1111/cobi.13316).

The methodology can consider other landscape functions – for example, carbon sequestration or urban development, or multiple different functions, with the analysis again supporting separation rather than co-location[75].

The approach can also be expanded to consider three different land management options: (i) land management with an emphasis on sustainable, high productivity agriculture (higher-yield farming); (ii) co-located agricultural production and the delivery of environmental benefits (lower-yield farming); (iii) land managed to maximise its value for biodiversity or other non-agricultural functions (semi-natural land) (Figure 3b). In systems so far investigated (primarily highly modified European landscapes including the UK), this 'three-compartment' approach delivers the best outcomes for biodiversity and carbon emissions given a particular food production requirement and has a positive effect on reducing pollution and improving the recreational use of the countryside[76, 77, 78, 79, 80].

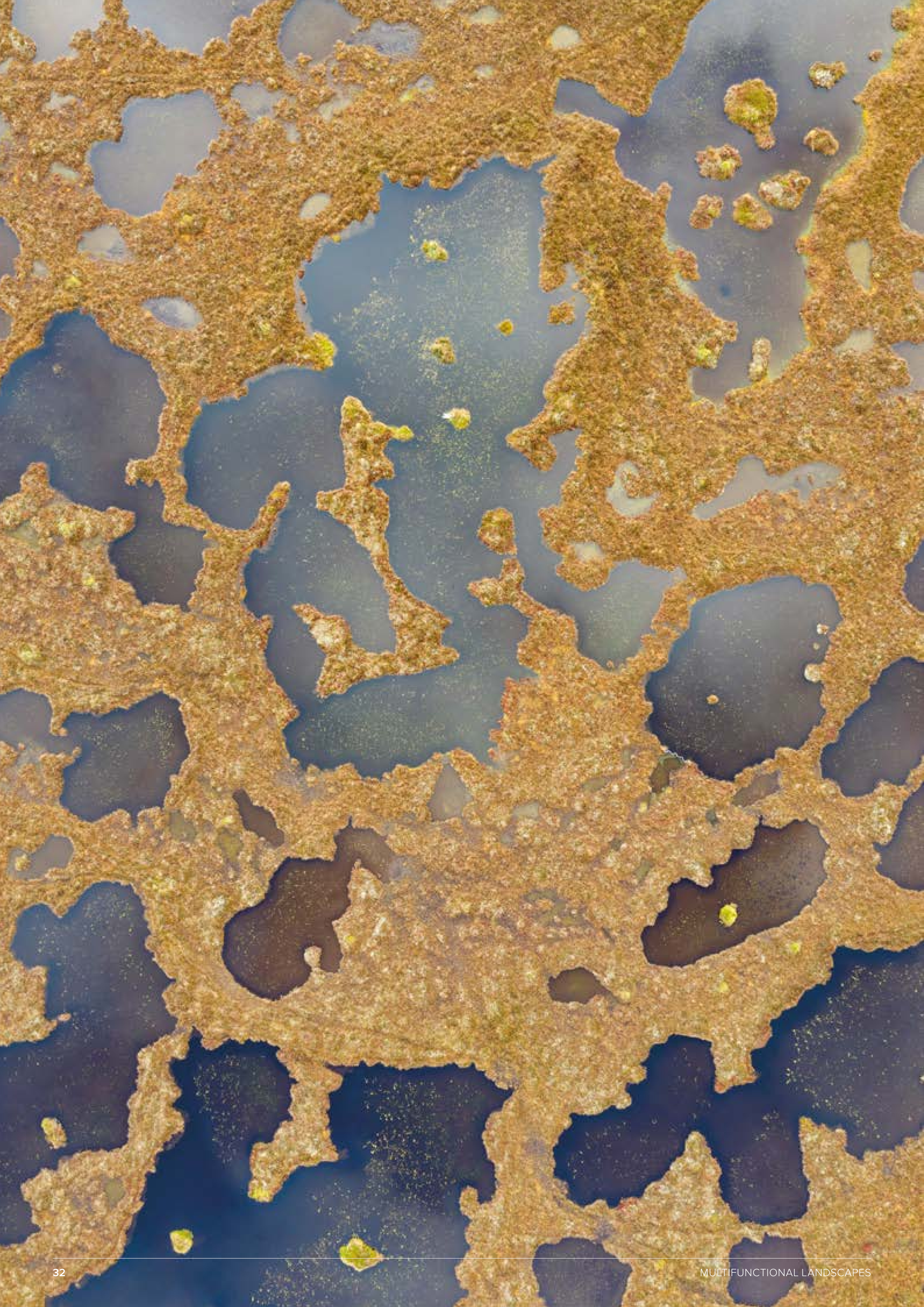
Of course, land management options are a continuum and do not neatly fit into three simple compartments. Nevertheless, this conceptualisation can be a helpful tool to consider how landscapes can best accommodate the different types and intensities of land use required to produce multiple goods and services for society. For example, it was used by the National Food Strategy and endorsed by the UK Government's response as a useful construct for thinking about future land use policy in England[81]. As stated before, however, scientific analysis is just one input to policymaking, and it would be critical for any suggested theoretical model to pass the normal policy tests of practicality and stakeholder acceptability. In practice, what is feasible to implement and what aligns with legitimate stakeholder interests are likely to result in heterogeneous landscapes that do not necessarily reflect experimental analyses.

2.3 Conclusions regarding analysis

Modelling and analysing the trade-offs and synergies between different land uses can make an important contribution to better policy. It forces us to accept that land is finite and that some activities preclude others. Spatially explicit models can reveal the advantages and disadvantages of the relative positioning of different land uses in a multifunctional landscape and provide a quantitative way of comparing different policy options. Depending on biophysical, socioeconomic and other factors, and the objectives and scale of the analysis, recommended management strategies may sit anywhere on a continuum of land uses delivering different functions.

But it is important also to consider the limitations of this type of analysis. Land use decisions are made by numerous different agents reacting to a broad range of influences and incentives, only some of which can be influenced by policy. Policymakers also have to be aware of the practicalities – political, logistical and economic – of implementing different options, some but not all of which can be included in quantitative analysis. Landscapes and place have immense cultural significance and stakeholders differ in the value they place on different landscape functions. While modelling can explore the consequences of these different valuations it cannot resolve differences, and final decisions are informed by a combination of science, economic and political economy factors.

It is also important not to think of the trade-offs and synergies between different land uses and outputs as fixed and immutable. New research, innovation, and the application of existing knowledge can help reduce trade-offs and identify and exploit synergies at any point along the land use continuum, from high yield sustainable production, through lower intensity systems and management primarily for public goods. The next chapter looks at the contribution of the sciences to increasing the value of outcomes that arise from the land.



Chapter three
Science and innovation for improving productivity and sustainability

Left
Peatland pools in blanket bog at Forsinard Flows RSPB Reserve, Flow Country, Northern Scotland.
© David Tipling / Birdphoto.

Science and innovation for improving productivity and sustainability

"Why are 80% of our farms so unproductive? Has our system of subsidies done this? If so, surely we need a system that, where possible, encourages innovative and sustainable food production."

Public dialogue participant, North Wales

This chapter sets out the breadth of science relevant to maximising benefits from multifunctional landscapes. It discusses the multiple types of innovation that are needed to achieve different policy goals. Innovation has led to extraordinary productivity growth in agriculture and forestry in the 20th Century. Borlaug's 1960s green revolution exploited new genetics combined with improved agronomy to achieve, over about 30 years, a near doubling of cereal production in high-income and many low-income countries[82, 83]. But the increased yields were accompanied by higher use of inputs such as pesticides, herbicides and fertilisers with consequent major negative environmental effects. An expansion of research on increasing productivity is necessary, where productivity is taken to include all desirable outputs of the land, not just those with market value, as is a refocusing of research on the sustainability of production systems. This new agenda will need to involve many scientific disciplines as is explored in this chapter.

New science itself is not sufficient to increase sustainable productivity; new ideas need to be adopted on the ground. Policy initiatives are needed that will facilitate take up and improve innovation outcomes. For innovations that directly increase revenues to land managers, these revolve around technology transfer and translation. For non-market goods of importance to society, new types of incentive will be necessary, including extension services to facilitate translation and innovation diffusion. Chapter 4 will examine how advances in data and related sciences can create the information infrastructure that will maximise the effective targeting and deployment of new innovations.

This chapter first explores how science can contribute to increasing sustainable productivity in land primarily managed for food production. Following this, land managed for food production and multiple other outputs is considered. Here the focus is often on increasing synergies and reducing negative trade-offs between different types of outputs. The chapter then turns to land not in agriculture and managed for functions such as habitat for biodiversity and carbon storage. The fourth section explores the research required to support the creation and management of different woodland types which provide a spectrum of market- and non-market outputs. Issues around using land for bioenergy crops are then considered. The final section concerns the skills and advice needed to realise the potential productivity gains made possible by such a wealth of science and innovation.

The aim of the chapter is to illustrate the numerous ways science and innovation can contribute to improving the outputs of landscapes. No attempt is made to be comprehensive, though the breadth of science described could form a useful basis of a common evidence platform underpinning future policymaking. It should also be noted that although we discuss innovation relevant to broad classes of land management – land used primarily for food production, for example – much of the science discussed is widely applicable across different types of land use.

3.1 Increasing productivity sustainably on land used primarily for agriculture

Meeting the global future demand for food will require radical changes in diets (especially eating less meat), food waste and food system governance. But the world will also need to produce more food and to do this sustainably from the same or even less agricultural land[84, 85, 86]. The challenge of 'sustainable intensification' was explored in the Royal Society's 2009 report *Reaping the Benefits*, some of the themes of which are reprised here[87]. Many participants in our public dialogue were especially concerned to learn how much of the UK's agricultural land could be defined as 'unproductive'. Four areas are outlined below where current science and technology are making important contributions to increasing yields sustainably. There is also much interest and excitement about non-traditional forms of food production such as lab-cultured meat or indoor vertical farms that may in time reduce the demands on land for food production. These are important areas of research outside the scope of this report but, at least for the foreseeable future, most demand for food production will need to be met by innovation in land-based agriculture.

Precision agriculture and robotics

Precision agriculture refers to a combination of rapidly developing technologies that enable fine-tuned responses to variability in crop or livestock needs. Together they can reduce costs, improve yields and minimise environmental damage from inefficient use of inputs[88, 89]. Precision agriculture technologies can be assigned to three broad categories: guidance, recording and reacting technologies[90].

Guidance technologies help to make machinery movement more precise which can reduce soil compaction and crop loss, and make the application of water, fertiliser and other inputs more efficient. Recording technologies collect information such as soil moisture and crop growth rates from the field before, during or after the growing period. They can use data from different remote sensing platforms including satellites, planes and drones, observe across different wavelengths and scan using LiDAR and related technologies[91, 92, 93]. Reacting technologies turn the gathered data into decisions guiding input applications through, for example variable rate irrigation or pesticide application[94]. Case Study 1 (Shimpling Park) is an example of these technologies being applied in situ.

Precision agriculture in livestock applies a similar suite of technologies to animal husbandry. Individual animals can be geospatially tracked or monitored for growth, health and welfare, for example by web-enabled continuous sensors[95]. Data analytics can prescribe individual treatments, the veterinary equivalent of personal medicine[96]. Pasture management can be improved by training animals to respond to audio or electric stimuli from neck collars that in effect create a virtual fence[97].

> "I think high-tech farming may have a place. I would be happier if my tax was used to work with farmers to move towards a way of farming that would reduce subsidies and increase production, and that may have some high-tech in it."
>
> **Public dialogue participant, North Wales**

CASE STUDY 1

Shimpling Park, Suffolk

Shimpling Park is a 650 hectare estate with a mix of sheep and crops. It has embraced a wide range of precision agriculture technologies that have allowed it to increase farm productivity while also reducing the need for inputs. By running samples of grains from crops through a spectrophotometer, they are able to measure moisture, oil and protein content during growth to pick the optimal time to harvest for greatest yield. Use of GPS technology, both as a means of gathering live data and as a way of ensuring accurate, reproducible soil sampling, helps to map out an accurate picture of each field's hydrology, pH and nutrient balance. This in turn enables the use of automated farm machinery which can apply inputs like seeds, water and fertiliser in a context-appropriate way. Reducing excessive use not only avoids wasting resources but also leads to improved soil health. A more comprehensive understanding of each field's layout not only improves outcomes for crop yields but can also help to identify areas of the farm which might be best suited to agri-environment schemes such as wildflower meadows, beetle banks or riparian buffers.

Image: © iStock / valio84sl

Modern robotics offer multiple opportunities for increasing productivity. Fully autonomous vehicles may find some of their first applications on farms which are more simple environments than roads and highways. Image recognition based on machine learning can be used to distinguish crops from weeds, with the latter then being burnt or mechanically uprooted by robot weeders[98]. Harvesting soft fruit and many types of vegetables is delicate and physically demanding work which few people in high-income countries are willing to undertake; robotic pickers and harvesters are already being deployed in some crops, and their use and sophistication will increase.

Robotic milking parlours are now widely deployed by dairy farmers and can improve yields, sustainability and animal welfare[99]. Systems can be trained to monitor bird behaviour in poultry rearing sheds, allowing early interventions to address welfare concerns and stop disease spread[100].

Modern plant and animal breeding

Modern plant and animal breeding uses a variety of genetic technologies which allow researchers to develop variants that could not be achieved, or not achieved easily, via artificial selection and natural mutation[101]. Marker-assisted selection and automated phenotyping may also be used to accelerate traditional breeding programmes. The goal of these approaches is to develop crop and animal varieties with beneficial characteristics such as higher overall yield, better nutritional content, carbon-sequestration capacity, nitrogen-fixing potential, improved root architecture, pathogenic resistance or extreme weather and climate resilience[102, 103, 104, 105, 106, 107, 108, 109, 110, 111]. The Royal Society has conducted work over many years on the potential role of genetic technologies in increasing productivity, mitigating the consequences of environmental change on productivity, and reducing biocide use[112]. It has also argued for effective and proportionate regulation focusing on health, safety and environmental outcomes, rather than on the specific techniques used, and for the importance of obtaining societal licence for the use of novel breeding techniques[113].

Pest and disease management

The use of relatively broad-spectrum insecticides, herbicides or antibiotics at scale to protect crops and livestock has many negative environmental consequences. New approaches for pest and disease management can help to reduce these negative outcomes and improve the sustainability of agricultural production. The value of gene editing and gene engineering to produce crops and animals with greater pest and pathogen resistance has already been demonstrated. There is much interest in exploring RNA-based insecticides which can be designed to target specific pest species as well as continuing research on manipulating pheromones and other ‘infochemicals’ used by pests[114]. Further in the future, ‘gene-drive’ methods, such as those under development for controlling mosquito-borne diseases, which allow a novel gene to spread through vector species in the field and suppress their abundance, could be repurposed for non-native agricultural pests (subject to stringent safety assessment and regulation)[115].

> “It would be better to have a natural pesticide. There’s too much money in these pesticides. It’s their product, of course they’re going to defend it as much as they can. They’re going to say, “No, it’s not killing the bees off,” they’re not looking 20 years down the road. They’re looking at profits year-on-year.”
>
> **Public dialogue participant, Southwest England**

Ecological intensification

Ecological intensification describes a suite of techniques that enhance ecosystems services to complement or substitute for anthropogenic inputs[116]. When successful they maintain or increase yields while reducing negative environmental externalities. The most widely investigated techniques include enhanced crop rotation and diversification, the use of nitrogen-fixing legumes to improve soil fertility, increasing soil organic matter by retaining crop residues or by adding manure or composted plant material, reduced tillage, and managing field headlands and boundaries to enhance natural pest control.

There is increasing evidence for the effectiveness of ecological intensification in different agricultural settings, though there are a number of barriers to its take up[117, 118]. First, farmers may not be aware of these techniques, or may not be trained in their deployment, in part because much farm advice is provided today by companies selling farm inputs who naturally prioritise their own products. Second, there is less research into ecological intensification compared to genetic intensification and traditional agricultural inputs, again in part because of fewer opportunities for commercialisation. Greater attention to these techniques is part of the refocusing of research on sustainable yield increases called for by this report.

3.2 Managing land for food and multiple other outputs

Analyses will identify some landscapes that are best managed to produce food, fuel or fibre at lower yields and where the production of other ecosystem services is also of high importance. The science challenges for this type of land typically involve looking for synergies between different outputs and reducing negative trade-offs.

Soil management for better yields and increased soil carbon sequestration

Well-structured and fertile soils directly improve agricultural productivity while providing public goods such as carbon-sequestration, flood management and a matrix for biodiversity. These significant synergies make improved soil management a no-regrets option for enhancing multifunctionality at the field and landholding scale, though with over 700 soil types in the UK, it is highly complex[119]. An evidence synthesis produced by the Royal Society in 2020 reviewed the importance of soil structure for the delivery of these benefits (summarised in Box 2) and how its management might be improved[120]. Research into new methods of improving soil quality would improve the provision of multiple public goods while maintaining or increasing yields. A key factor for uptake lies in engagement with land managers (especially those in livestock agriculture) about the potential benefits of soil testing to improving their outputs[121].

BOX 2

Summary of the benefits of good soil structure from Royal Society evidence synthesis

Biodiversity

Biodiversity and soil structure are closely linked; soil structure influences the composition and activity of soil organisms, while soil organisms affect the physical structure of the soil. Good soil structure benefits a number of species and habitats. In addition, soil biodiversity, and its associated influence on soil structure, contributes to a range of ecosystem functions such as decomposition of dead matter and nutrient cycling. Soil also contributes to ecosystem services such as support of above-ground biodiversity, control of plant, animal and human pests and diseases, and climate regulation.

Agricultural productivity

Soil is required for 95% of global food production[122]. There is a correlation between improvements in soil structure and increasing grain yield of cereals[123]. A well-structured soil can improve crop productivity through providing a habitat for earthworms and other soil organisms. Compacted soil is often associated with a decrease in yield through detrimental effects on the crop's root system. Improved soil structure can help to prevent soil erosion, where the upper layer of soil is displaced. Soil erosion significantly affects the productivity of soil, with Defra estimating the total cost of erosion in England and Wales is in the region of £150 million a year[124].

Clean water and flood protection

Soil can act as 'natural flood management infrastructure'[125] by increasing water infiltration into the ground and also by providing natural water storage, for example through uptake into root systems. However, both these benefits are negatively affected by compacted soil structure. Compaction of the pores within the soil reduces the ability of rainfall to infiltrate the soil and acts as an obstacle to root penetration[126, 127]. The degree to which soil can contribute to flood prevention is strongly reliant on it being well-structured. When water flows over the surface of the land it can also have negative impacts on water quality. For example, rather than steadily infiltrating the soil, surface runoff can increase the erosion of topsoil and wash chemicals out of the soil into aquatic ecosystems, potentially leading to the pollution of waterways and eutrophication[128].

Climate change mitigation

Soil is the largest terrestrial store of organic carbon and its potential as a carbon sink means it could have an important role in climate change mitigation. There is growing interest in soil management practices that help increase levels of soil carbon stocks. Many interventions that improve soil carbon levels also improve soil structure and contribute to the maintenance of healthy soil. There is debate over the extent to which practices that increase soil organic carbon can play a role in climate change mitigation. The capacity for soil carbon sequestration depends on soil type and land use. For example, the soil of wetlands and peatlands accumulates carbon at faster rates due to high soil moisture and decreased rates of microbial decomposition[129]. Changes in land use can have large impacts on soil carbon levels. Meta-analysis studies have shown that land use conversion from forest to agriculture results in loss of soil organic carbon[130, 131]. In contrast, the restoration of former crop fields to grassland or forests can restore soil carbon[132].

The Royal Society's 2018 report *Greenhouse Gas Removal* recommended that soil carbon sequestration be a focus of future land management incentive schemes. The greatest potential for carbon sequestration is on severely degraded soils with low organic matter. As organic matter builds up, soil carbon content asymptotes or increases very slowly, and can drop if the soil is disturbed by, for example, ploughing. The extent to which different agricultural practices can sequester carbon is contested, with some very bold claims made for pasture and rangeland (reviewed in ref[133]). Policy in this area would be greatly assisted by further evidence syntheses and new data, and by the development of standards and metrics to enable better carbon accounting. Also, consideration of counterfactuals and indirect effects are critical in improving land use decision making. Thus, when considering pastureland as a store of carbon, one should consider the counterfactual of afforesting the land and, if this were done, the consequences for carbon storage and greenhouse gas emissions of any displaced production of meat and dairy.

Biodiversity in farmed landscapes

Some biodiversity provides valuable ecosystem services that support agricultural yields (for example, pollination, pest management) and, as discussed in the section on ecological intensification, there are a variety of ways that it can be enhanced which are of relevance to both high- and low-yield agriculture. Another set of possible interventions can enhance biodiversity with no or minor consequences for yields. For example, a long-running (10-year) study by the UK Centre for Ecology and Hydrology on a lowland arable farm found that provision of seed-bearing plants, wildflowers and tussocky grass margins found that most species of butterflies and birds studied fared better on this site than controls, while yields were maintained – and enhanced for some crops – despite the loss of agricultural land for habitat creation[134]. Research such as that carried out at the RSPB's Hope Farm, the Allerton Project (Case Study 2) and elsewhere is important to seek novel ways to improve on-farm biodiversity with the least consequences for yields and farm profitability[135, 136].

Though, as set out in Chapter 2, the weight of evidence shows maximum biodiversity for given agriculture yields is often obtained by separating food production and nature, there are specific cases of types of biodiversity that require farmland environments as well as political economy and other reasons for supporting areas of lower yield and higher biodiversity farming. Measures, such as adopting grazing schedules and stocking densities to enhance the quality of water meadows, saltmarshes, chalk grassland and upland pastures for biodiversity, as well as creating woodlots, ponds and wetlands, can come with loss of yield, but this can be reduced by clever agronomy and animal husbandry and situating interventions in lower yielding areas[137, 138, 139, 140, 141].

CASE STUDY 2

The Allerton Project, Leicestershire

The 320 ha farm in the English lowlands has been run as an agro-ecology field-test centre for the past three decades. The majority land use is for arable crops, with some woodland and permanent pasture. Between 10 – 15% of the agricultural land has been devoted to habitat creation and management with the primary focus being on songbird conservation. These habitats, along with winter feeding and legal predator control, have formed the basis of their land management biodiversity strategy – resulting in a 150% increase in songbird populations over the first 8 years of the programme. The study also observed changes in songbirds' use of different crops throughout breeding seasons. This demonstrated the importance of crop diversity in supporting the surrounding biodiversity. Further research has identified land management techniques to support insect populations using beetle banks or hedgerows. These populations go on to support crops by acting as beneficial predatory insects or pollinators.

Farming of this type that sacrifices some yield to provide biodiversity, a public good, typically needs to be supported by public money. Under the Common Agricultural Policy, farmers had to comply with certain biodiversity-friendly management practices to obtain their Single Farm Payment and could apply for further funding by joining agri-environment schemes of different ambition. Studies that have compared the effectiveness of agri-environment schemes have found that they generally do increase biodiversity but that to be effective they need to be carefully designed, and that they are expensive[142]. The UK's administrations have the opportunity now to redesign their methods of supporting biodiversity on farmland under new schemes to replace those of the EU. A major research challenge is to develop legally robust and administratively simple schemes that provide the greatest biodiversity (or other public good) returns from the investment of public funds.

Agroforestry

Agroforestry combines tree planting with arable (silvoarable systems) or livestock (silvopastoral systems) farming. Planting trees can provide direct benefits for agriculture such as shelter for livestock, protecting crops from wind, reducing run off, increasing water infiltration, improving soil structure and providing reservoirs for the natural enemies of pests[143, 144]. More extensive on-farm woodland reduces yield but may provide alternative market products such as timber as well as public goods such as habitats for wildlife and improved amenity value. The different benefits of agroforestry are quite context specific and long-term research is required to determine what works best in UK landscapes. Case Study 3 (Silvopasture Field Lab) is an example of one such long-term UK study. The AGFORWARD project, which brings together major projects across Europe including seven from the UK, is another important research initiative in this area[145, 146, 147]. Research is also needed into economic mechanisms to support agroforestry over the relatively long timescale it takes them to provide both market and non-market goods.

CASE STUDY 3

Silvopasture Field Lab, Devon

Rothamsted Research, in collaboration with The Farming and Wildlife Advisory Group, Woodland Trust and Organic Research Centre, have begun a 12-year trial of silvopastoral farming – a blend of forestry and livestock farming – with eight farms across Devon. This farming method can offer shade and shelter for livestock and pasture, providing a protective effect through changing seasons. The mix of broadleaf trees being planted for the trial include Oak, Willow and Hazel which will all be actively managed for timber, providing ongoing financial return for the farm businesses.

A key objective will be to evaluate the impact of silvopasture on the soil health of the farms. Further objectives include evaluating the effect on the livestock, such as how they use the silvopasture areas, as well as the impact on health and productivity. The effect on non-livestock animals will also be evaluated, with monitoring of population trends for birds, bats, moths and invertebrates. Through all of this there will be an assessment of the practical considerations in establishing and managing silvopastoral agriculture. The trial will also monitor the dynamics of pasture production as the trees develop and how it changes under different tree management and thinning regimes.

Image: © Jo Smith.

Reduced-input agriculture

Conventional modern agriculture relies on external inputs including artificial fertilisers and chemical biocides. The harm done to the environment from these inputs is well evidenced and, as discussed in the last section, a major research goal is to increase the sustainability of conventional agriculture by reducing the need for inputs through breeding and genetics, precision agriculture and ecological intensification. But there will be areas where a reduction in yield is acceptable if it leads to positive environmental outcomes, for example land where biodiversity protection is a high priority or landholdings in or adjacent to environmentally sensitive areas. In evaluating the costs and benefits of reduced-input agriculture it is important to include indirect effects, for example the environmental costs of food produced elsewhere to make up for lower yields, and the environmental benefits of reduced inputs to the surrounding environment.

A wide variety of reduced-input farming methods have been explored under different banners including organic agriculture, agroecology, regenerative farming and permaculture. Organisations such as the Organic Research Centre seek to improve yields from organic farming and further to decrease its environmental footprint, while the Soil Association (the UK's organic agriculture certification body) has set up its Innovative Farmers Network to run field trials on reduced-input agriculture.

Nevertheless, this area receives less research funding and attention than conventional agriculture research, in part due to fewer opportunities for commercialisation. There is an opportunity within the UK to bring together the research agendas of BBSRC and NERC (the Research Councils whose remits includes farming and the terrestrial environment respectively) to develop and rigorously assess new techniques for improving the agricultural and environmental performance of reduced-input agriculture. Some of the techniques described elsewhere in the report (eg gene-editing) are currently excluded from UK organic or agroecological practice, but under a different regulatory framework, such techniques have great potential to minimise trade-offs in reduced input approaches. Case Study 4 (Brecon Beacons Mega-Catchment) provides an example of where reduced-input agricultural practices are being incentivised to provide a range of public and private benefits across Wales.

CASE STUDY 4

Brecon Beacons Mega-Catchment, Wales

Dŵr Cymru (Welsh Water) is the only not-for-profit water company in the UK. It serves 3 million customers with over 800 million litres of water a day. Around half of this comes from a cluster of around 20 drinking water catchments across a 90,000 ha area known as the Brecon Beacons Mega Catchment (BBMC). Dŵr Cymru own less than 5% of the land within these catchments, so its success has hinged on it acting as an effective coordinating body with a range of partners whose motivations and interests differ greatly. These partners have ranged from local and national government to academic researchers, and environmental NGOs, as well as organisations and individuals from forestry, farming and other land-based sectors.

Through the programme, Dŵr Cymru have shifted their emphasis from reactive treatment of water to proactive measures that address water quality issues at their source. Many of these measures – such as reduced-input agriculture, improved livestock health, habitat restoration – are inherently multifunctional, simultaneously providing water quality, climate and biodiversity benefits.

Image: © iStock / Jonathan Lewis.

"I didn't know much about peat bogs previously and I think if they've got such an important part to play, maybe they should be known about a little bit more by the general public."

Public dialogue participant, East Anglia

3.3 Improving the productivity of non-agricultural land

A multifunctional approach to land use recognises the many different outputs from the land, including public goods that do not provide a simple income stream for the land manager. Just as scientific research is essential for increasing sustainable yields of food, fuel and fibre, it is also critical for increasing the provision of all other land-based goods. This is illustrated below with four examples of land primarily managed for non-market outputs.

Managing and restoring peatlands

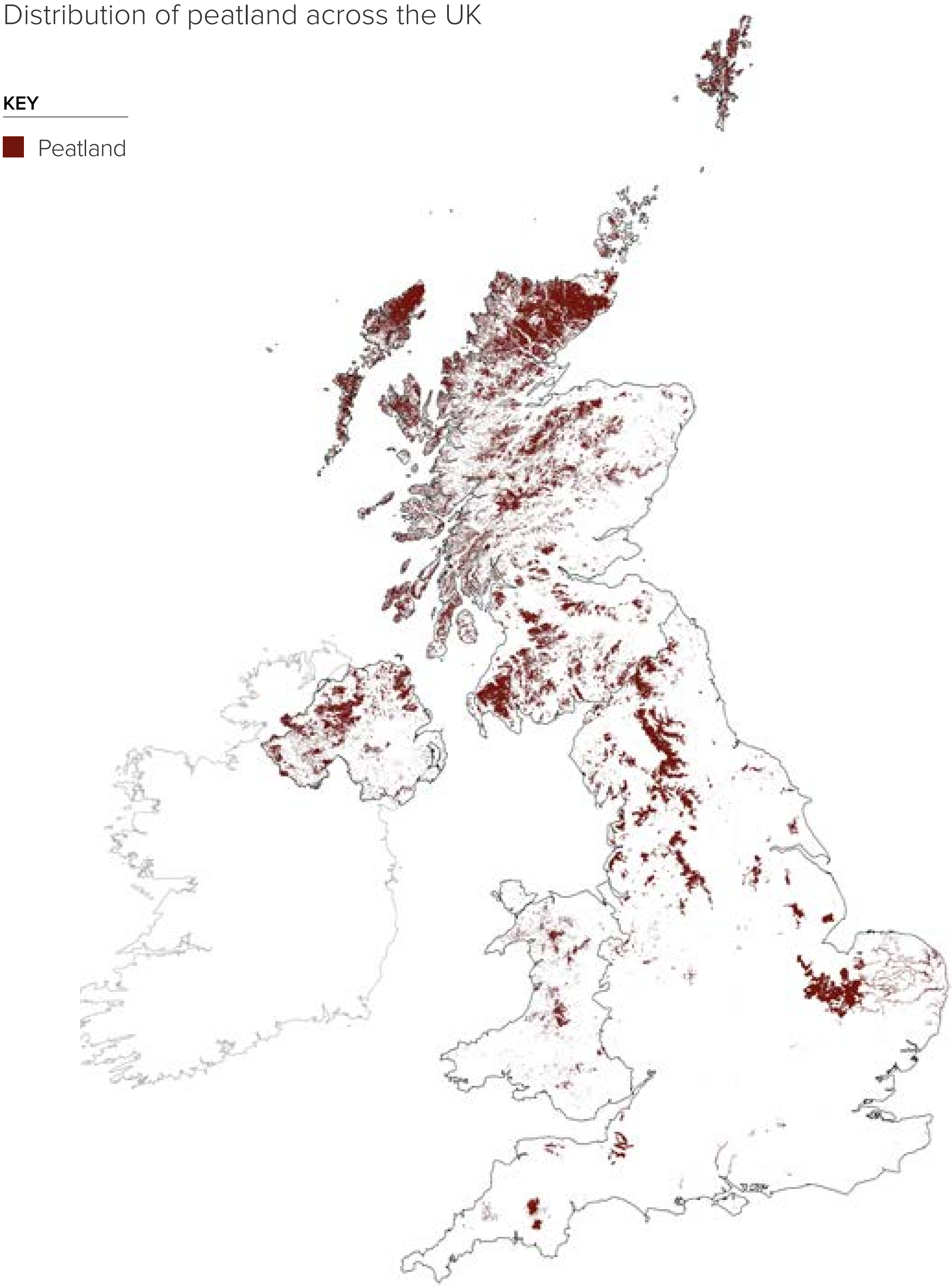
Peatlands cover 12% of the UK's land area and currently store 3.2 billion tonnes of carbon[148]. They are found both in the uplands, where they typically are used for grazing (often poor quality) or forestry, and in the lowlands where they are primarily used for agriculture (see figure 4 for UK-wide distribution).
If peatland dries out or is degraded, organic matter is broken down releasing substantial amounts of CO_2. It is estimated that 77% of UK peatlands are degraded, usually as a consequence of being used for agriculture or forestry, and what was once a sink has become a source of emissions (21 Mt CO_2 yr^{-1})[149, 150, 151]. The Office for National Statistics estimates the cost of restoring all UK peatlands to near natural condition would be between £8.4 and £21.3 billion, but it would deliver a return 5 – 10 times greater depending on assumptions about the cost of carbon[152].

In addition to carbon, restoring peatland provides other benefits including better habitats for nature, improved water quality and water storage to reduce the risk of flooding, but it can reduce land managers' incomes from forestry or food production. Peatlands do not enjoy the same visibility or appreciation with the general public as forests and woodlands, borne out by the lack of awareness of peatlands in our public dialogue. Public engagement that conveys their importance as habitats and carbon stores forms a major pillar of the IUCN peatland strategy[153].

The importance of peatland restoration was highlighted by the Royal Society in its 2018 report *Greenhouse Gas Removal* and the Climate Change Committee has since recommended restoring a minimum of 50% of upland peat and 25% of lowland peat by 2050[154, 155] which would reduce peatland emissions by a total of 5 $MtCO_2e$ by 2050. All UK administrations have targets for peatland protection and restoration and are considering phasing out the use of peat in horticulture by 2028[156]. Considering the challenges for the UK of reaching net zero by 2050, these targets may be insufficiently ambitious. They could be reassessed in the context of national land use frameworks (see Chapter 4), allowing carbon storage and emission reduction advantages to be assessed against other consequences of peatland restoration.

FIGURE 4

Distribution of peatland across the UK



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CASE STUDY 5

Garron Plateau Bog Restoration, Antrim

The Garron Plateau in Antrim is the largest blanket bog in Northern Ireland (4,627 ha). During the 1960s, gullies were dug into the peat to lower the water table allowing livestock to graze. The drying of the plateau led to changes in its vegetation from mainly sphagnum mosses to coarse grasses, which themselves were then reduced through grazing and trampling by livestock. The peatland was then vulnerable to even further erosion through weathering by wind and rain. This resulted in the peatland becoming inhospitable to many of its native species, an increased level of dissolved organic carbon output into the local water catchment and the release of carbon from the estimated 6Mt stored across the plateau.

In 2013, the RSPB NI Futurescapes programme formed a partnership with the Northern Ireland Environment Agency and Northern Ireland Water. Two thousand hectares were rewetted by refilling the trenches, restoring native vegetation and reducing livestock density. The result has been a return of rare species like the plant marsh saxifrage and birds such as hen harriers, curlews and cuckoos. There have also been public health and commercial benefits. Raw water quality coming off the bog has improved and now requires less processing before it is served to the 14,000 households in the surrounding Dungonnell catchment. With time, this restoration will also allow the plateau to return to being a valuable carbon sink that contributes to climate change mitigation.

Image: © iStock / Wirestock.

Many areas of research can contribute to improving the functioning of peatlands. Applied landscape ecology has been important in showing how areas currently planted with non-native conifers or drained to provide low-grade grazing can best be rewetted to maximise carbon storage and other ecosystem services. This has involved large scale projects such as the restoration of Garron Plateau in Country Antrim (Case Study 5) and work by the Yorkshire Peat Partnership which has been funded by Yorkshire Water (among others) who benefit from the improvements in water quality and flood protection. Where peatlands are not completely restored, research can mitigate some of the worse consequences of drying out. Agriculture on lowland peatlands can be made less damaging by, for example, developing techniques for growing crops on wet soils (paludiculture) or raising the water table in the non-growing season[157, 158].

Managing land for biodiversity

All UK administrations have committed to 'protect 30% of land for nature by 2030' to reverse significant losses in recent decades[159, 160, 161, 162]. Biodiversity is found throughout the landscape and land dedicated to nature is required to preserve much of the richness of biodiversity in the UK. This understanding underpinned the creation of the network of national and local nature reserves in the 20th century. Though, as an important recent metanalysis shows, protection alone does not guarantee good biodiversity outcomes if nature-positive management practices are not implemented[163].

Creating new habitats for biodiversity seldom, if ever, involves doing nothing and letting nature take its course. Management of different levels of intensity is required to direct and accelerate habitat creation. Important tools are provided by the science of restoration ecology, and these may be further improved if landscape restoration projects are explicitly designed to include an element of experimentation. For example, the Essex Wildlife Trust has partnered with the University of Essex to evaluate the effectiveness of a novel method of saltmarsh restoration[164]. Other issues that may arise when it comes to ecosystem restoration, and where research is needed, include sourcing plant seeds when natural regeneration is not possible (the Millennium Seedbank at Kew is an international leader in this area), the re-introduction of missing fauna, and the control of invasive species[165].

"If, say, the Berwyn hills near Wrexham were rewilded, I would not have a problem with it... if tourists would come to view the Berwyn wolves, think how that would benefit the local community and the town of Wrexham."

Public dialogue participant, North Wales

"I am blessed to live within the Loch Lomond and Trossachs National park, and have amazing natural forests on my doorstep… [but] when it is the weekend or holidays, I try to avoid them as visitor numbers are way up."

Public dialogue participant, Scotland

The spatial distribution of restored sites may be critical in maintaining viable populations of certain species, especially more mobile species, a point emphasised by Sir John Lawton FRS in his 2010 review *Making Space for Nature* which called on UK Government to establish 'bigger, better, more joined up' ecological networks[166].

Few would argue against the role of some rewilding in the maintenance of UK biodiversity. However, some of its most enthusiastic proponents have advocated very large-scale rewilding leading to a backlash in parts of the farming community. Policymakers will need to decide appropriate levels of rewilding, which will be influenced by competing demands for land as well as the evidence for rewilding versus other means of protecting biodiversity – the common evidence platform and decision-support frameworks described in Chapter 4 will assist in this regard.

The best rewilding projects are explicitly designed to benefit the local community and economy and there is an important role for social science research to maximise the knowledge gained from existing schemes to improve future projects and ensure buy-in from people living and working in the local area.

3.4 Woodland for timber, carbon storage and biodiversity

Woodland and forest currently cover 13% of the UK's land area, a low percentage compared with most other European countries[167]. Forested areas are an important store of carbon, produce timber, deliver important biodiversity and flood protection benefits and provide cherished and amenity landscapes. The provision of these multiple outputs is subject to trade-offs and synergies and, indeed, analysis of the multifunctionality of woodlands parallels and is contained within the analysis of the multifunctionality of the complete landscape. Thus, the same techniques that were discussed in Chapter 2 that help maximise multiple outputs from land given existing trade-offs and synergies can be used to assist forest planning. Modern approaches to woodland planning have adopted the slogan "right tree in the right place" which emphasises the importance of thinking about synergies and local context, and avoids the mistakes of the past, such as the extensive afforestation of upland peatlands.

Forestry research traditionally concentrated on maximising financial returns from commercial products, in the UK chiefly timber. In parallel with agricultural research there is now greater emphasis on sustainability and resilience, important for forests that need decades to mature[168]. There is also a greater focus on research to increase the provision of public goods produced by woodland, such as carbon storage and biodiversity habitats, and on innovative ways that this might be funded.

Woodland creation is one of the most effective means of capturing carbon and will be essential for the UK to meet its net zero carbon emissions targets. Government has committed to increasing woodland cover from 13% to 17% with the Climate Change Committee (CCC) advising up to 20% is possible[169]. Different tree species vary in how they sequester carbon over time (see Figure 5) and in the other functions they provide: fast-growing conifers are productive for timber but poorer for biodiversity, while mixed broad-leaved woodland (with native conifers in Scotland) is typically best for biodiversity. A broad spectrum of different forest types will be required, varying according to the particular conditions and constraints in a landscape, to meet carbon sequestration and biodiversity targets as well as maintain a healthy forestry products industry. New active management practices, such as those being trialled at Ardochy Forest (Case Study 6), will need to be developed to maximise synergies between the different functions forests and woodlands provide[170].

The long-lived nature of forests makes research into their resilience to future shocks very important. Already, the higher likelihood of droughts in the future has led to a recommendation that drought-susceptible beech should not be planted in the most prone areas. The introduction of novel pathogens has accelerated in an era of globalisation. The UK landscape was permanently altered by Dutch Elm Disease in the last century and the spread of Ash Dieback may have as great an effect in the current. The establishment of Oak Dieback would be a major threat to UK biodiversity. The biology of many tree pathogens (such as the oomycetes that include several species of *Phytophthora* that attack trees) are poorly known and understudied. Research into preventing the depredations of native tree diseases is greatly needed[171].

"Seems to me that money would be far better spent rather than subsidise farming to plough the money into planting trees."

Public dialogue participant, East Anglia

CASE STUDY 6

Ardochy Forest, Dell Estate, Inverness-shire

Forest Carbon was set up in 2006 to facilitate woodland development for the carbon market. They have created 6,500 hectares of forestry with more than 10 million trees planted, equating to 2.1 $MtCO_2e$ transacted across 220 projects. One such project is the Ardochy Forest, a 300 ha mixed woodland on the Dell Estate spread across a range of altitudes on the southern bank of Loch Ness in Inverness-shire.

Beginning in 2011, the Green Insurance Company and Allstar Business Solutions partnered with Forest Carbon to create a multifunctional forest with three components. The lower ground has been designated for timber production with Lodgepole Pine and Sitka Spruce for its greater ease of access for maintenance and felling and better quality soil. On the mid-altitude slopes there is new native Caledonian Pinewood stock. The rockier uplands are forested with native broadleaf woodland through natural succession of birch, alder, juniper, aspen, ash, oak and rowan. The forest helps to support habitat connectivity by providing habitats for several protected species including red squirrels, pine martens, crested tits and crossbills. Across the entire site, the anticipated CO_2 capture will be more than 80,000 tonnes over 70 years.

FIGURE 5

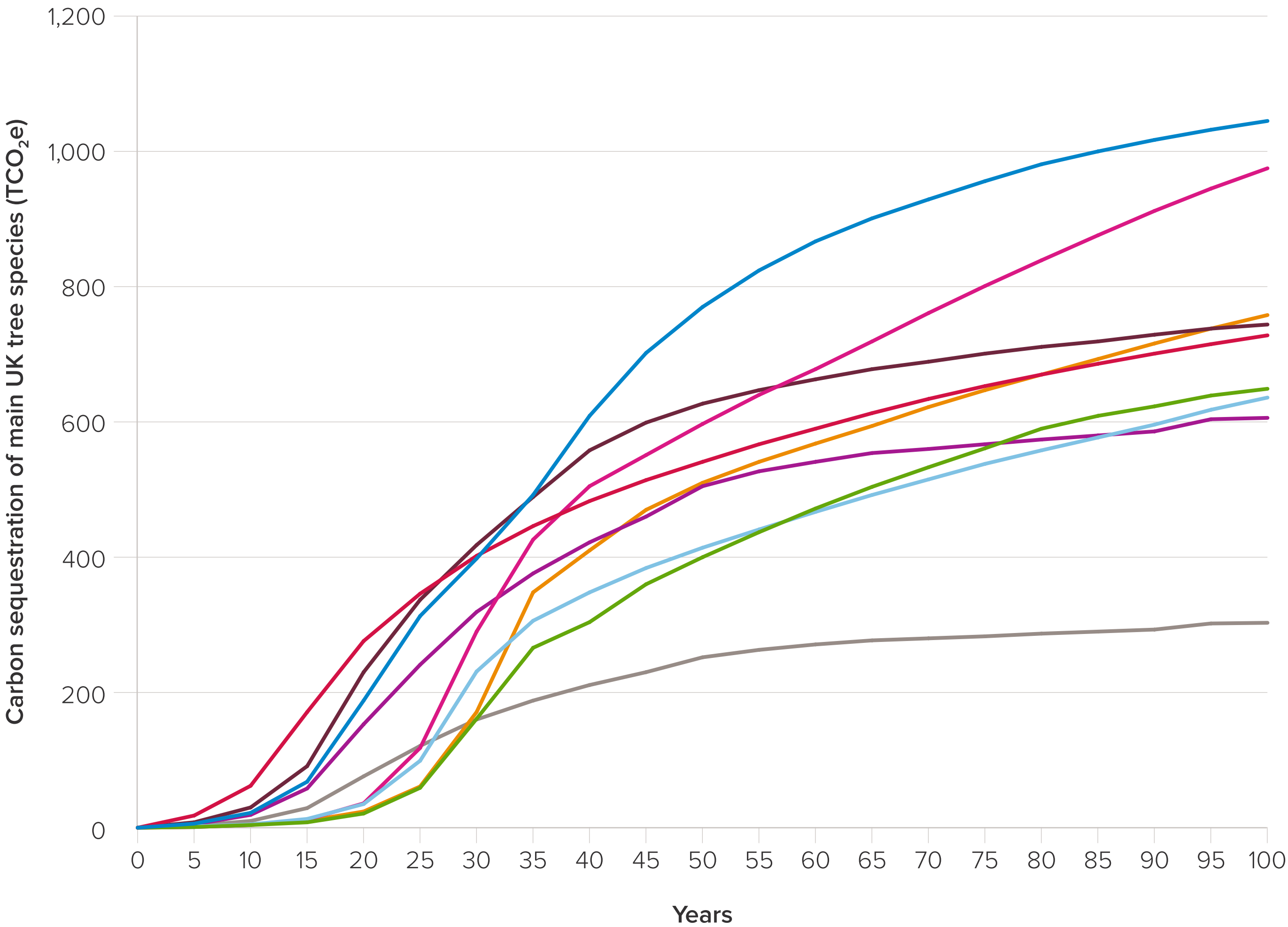
Comparative carbon uptake of the nine most common tree species in the UK.

Note that overall carbon sequestration of any given woodland will depend on the effective combination of species to deliver a rich woodland habitat.

KEY

(Median Yield Class, an index of the potential productivity of even-aged stands of trees, is given for each species)

- Sitka spruce (14)
- Birch (4)
- Lodgepole pine (6)
- Scots pine (6)
- Sycamore (2)
- Ash (6)
- Beech (6)
- Japanese / Hybrid larch (10)
- Oak (4)



Data adapted from National Forestry Inventory using the Woodland Carbon Code Calculator.

"In terms of paying farmers to store more carbon, we've got an ever-increasing food need that needs to be addressed but we also need to look at renewable energy and it's finding the balance between feeding everyone and looking after the planet."

Public dialogue participant, East Anglia

3.5 Bioenergy crops

There are three main types of crops grown in the UK to produce energy. First, approximately 11 Kha of wheat and 8 Kha of sugar beet are grown to produce bioethanol (a biofuel). Second, 67 Kha of maize is used for anaerobic digestion (AD). Lastly, 8 Kha of the grass miscanthus and 2 Kha of short rotation woody plants (chiefly willow) are grown to produce biomass for burning (all figures 2019)[172]. Overall, bioenergy crops accounted for 96 Kha (1.6% of total arable land area) across the UK in 2019. Different types of bioenergy crops compete with other land functions: biofuel crops and maize for AD compete most directly with agriculture, while biomass crops which can be grown on land less suitable for agriculture compete with forestry or land set aside for nature. British power stations import substantial amounts of biomass for burning from abroad, especially the east coast of United States, though discussion of this is beyond the remit of this report.

The carbon embodied in bioenergy crops is fixed from the atmosphere but it is wrong to think of this energy source as emissions neutral. The land on which bioenergy crops is grown is not available for other forms of carbon sequestration and storage or for food production – the emissions associated with displaced food production might outweigh any benefits of producing bioenergy. The advantages of bioenergy (BE) crops will be improved if linked with carbon capture and storage (CCS; BECCS) though this technology has yet to be demonstrated at scale[173]. Bioenergy crops may also have negative effects on the environment, for example, planting bioenergy crops on slopes or ploughing up grassland to plant crops can leave soil exposed and vulnerable to erosion, leading to water pollution and flood risk[174, 175]. However, growing perennial biomass on poor agricultural land with depleted soils may improve soil quality and sequester carbon[176].

To meet net zero targets, a significant scale up in total plantation footprint of bioenergy crops by 23 Kha each year has been recommended by the Climate Change Committee[177]. Analysis conducted by the agricultural consultancy ADAS to inform the UK's Sixth Carbon Budget suggested that between 1.0 – 1.8 Mha of land might potentially be available for conversion to bioenergy[178]. The Royal Society's 2018 report *Greenhouse Gas Removal* also recommended an increase in domestic bioenergy crop production, but with concomitant research into the potential social and environmental co-benefits and disbenefits of such an increase.

A critical component of assessing if and where to grow bioenergy crops will be to include the opportunity costs and indirect land-use effects of conversion of land and to understand better their potential contribution to multiple national objectives. In both Europe and North America, biofuel production has attracted subsidies which have proved politically hard to reduce even when they were no longer required, hence the political economy of bioenergy crops is also important to research and understand. Irrespective of the extent of their short-term deployment, research into how best to grow and utilise bioenergy crops is important to maximise our options for the future including those made available by new technologies, such as BECCS.

3.6 Skills and advice to unlock productivity gains

To realise the productivity gains made possible by the innovation described in this chapter, new skills and advice will need to be accessible across the land management community and supporting sectors. Indeed, land managers will be required to employ increasingly diverse management approaches to maximise the productivity of their land and secure an income for the delivery of multiple outcomes.

Future skill requirements for the land-based sector

Skills shortages are already a limiting factor in the delivery of environmental projects and in the adoption of sustainable agricultural practices[179, 180]. As the pace of landscape change accelerates, this gap will only widen. Land managers will need to enhance their competence in many areas including agriculture, forestry, conservation, advanced technical data collection and analysis, and business, to enable them to capitalise on new markets for natural capital or ecotourism[181, 182, 183]. Upskilling, retraining and recruiting existing workers and new entrants will be needed within the land management sector as well as sectors which provide support functions. For instance, data managers will be needed at the local, regional and national level to facilitate the use of large, aggregated datasets. The agriculture sector would benefit from better training provision and continued professional development (CPD) through institutions such as the Agriculture and Horticulture Institute. ‘Chartered farmers’ could be considered, as in many other sectors (including forestry).

Agricultural colleges and universities also have an important role to play in ensuring that their curricula are responsive to the skills and roles their students will need if they are to thrive in their future careers. Apprenticeships delivered in accordance with the Green Apprenticeships Standard represent another important pathway into the sector, where public and private sectors can collaborate.

The transition to a new model of land use could help to diversify employment opportunities and provide new fulfilling outdoor career paths – an idea which many of the participants in the public dialogue found appealing as the country recovers from lockdowns during the Covid-19 pandemic. Research commissioned by Green Alliance estimates that improving woodland, peatland and urban parks could create 16,050 jobs across the 20% of British constituencies experiencing the most severe employment challenges (the majority of jobs being in urban park creation and management)[184]. Scottish Government analyses provide a more conservative estimate that increasing peatland restoration four-fold per year would create 200 new full time equivalent jobs across Scotland[185]. Greater emphasis in school education and careers advice on land-based employment opportunities could make these opportunities more accessible to young people[186]. The Royal Society’s Education Committee is currently scoping how sustainability and regeneration can be better taught in schools and inform all aspects of the curriculum. All UK administrations have recognised the need to nurture new skills to support a green economy – it is paramount that land use is given due prominence in these considerations alongside other prime green job sectors like energy.

> “If their business can’t run successfully, they either have to move out of the business, or find something that they can do that’s different on the same land.”
>
> **Public dialogue participant, East Anglia**

Advice provision

Alongside skills development, land managers will require access to good quality, trusted, independent advice as they decide how best to structure their business to make the most of opportunities afforded by innovation and new income streams. The Welsh Government has recognised the vital role of advisers stating: '… advice should be seen as an investment in the capacity of farmers and farms rather than a cost …'[187]. Advisers will be needed who can take account of a range of complex issues and spot opportunities for synergies across a land-based business portfolio. Expertise in business performance and policy will need to complement knowledge of the environmental and social aspects of land management.

There are previous examples of independent farm advisory services in this country. Following WWII, county and district agricultural committees, a public farm advisory service, and a wide geographical spread of 'experimental husbandry' research and demonstration farms were established to allow farmers to learn good practice[188]. However, this infrastructure no longer exists, and advisory services have been privatised (though public advisory services do still exist in the forestry sector). The advisory capacity of public agencies like NatureScot and Natural England has also been greatly reduced in recent years. Some advice is currently provided by farming organisations and NGOs, and is offered for free by agrochemical, mechanisation and feed companies. However, this is patchy, and often part of otherwise commercial relationships with farmers[189]. There will be a role for both the private and public sectors in providing advice in future, the former where this results in increased profit margins, and the latter where the aim is the provision of public goods that do not have commercial benefit.

Image: Adult curlew during the breeding season.
© iStock / Anne Coatesy.

Chapter four
Decision-making for multifunctional landscapes

Left
The Leeds and Liverpool canal in Bradford, West Yorkshire. © iStock / Duncan Cuthbertson.

Decision-making for multifunctional landscapes

Previous chapters have explored the analytical techniques available to inform land use decisions and how research, innovation, skills and advice can contribute to making land more productive. However, these alone are not sufficient to improve land productivity. Two key prerequisites are needed to support decision-making which currently do not exist. First, there is a need for a much improved scientific evidence and analysis resource that provides spatially explicit data and analytical tools to a broad set of stakeholders. Second, there is a need for frameworks for making decisions about the land that can inform policy at multiple spatial scales: national land-use frameworks.

Frameworks will be informed by the science evidence base and its analysis, be built on agreed principles and designed to be helpful for decision-makers at all geographic scales from local to national. Several other bodies and reports have made the same or similar recommendations and, while this report was being compiled, the UK government, in its response to the National Food Strategy, said it would develop such a framework for England. The other countries of the UK have, to differing degrees, policies and mechanisms in place which could form the basis of a land use framework, such as Scotland's Land Use Strategy or Wales's National Spatial Plan.

4.1 Data and analytics to underpin robust land use decisions

Information that can contribute to land use decision making includes spatial data on geology, soil type, climate and land use. These data can be enriched by an explicit consideration of the natural capital embodied in different parts of the landscape as well the ecosystem services that flow from it. Information on agricultural, biomass and forestry yields and inputs is needed to understand the contribution different areas make to national objectives for production. It is also important to know the vulnerability of different areas to threats such as pollution, drought, fire and flooding, both now and in the future.

Landscapes are places where people live and visit and information on both can inform land use decisions. Data on the income people receive from land-based activities, how it flows through local economies, and what people spend on activities like recreation and tourism can be useful. Further geolocated information on, for example, demographics and population health can help understand the consequences of land use decisions, and ultimately facilitate more joined up policies.

Also of interest are data on the beliefs and values of different stakeholders concerning landscapes, such as those contained in community history and narratives. This is an often-neglected and difficult-to-obtain type of data. A new research project, led by the University of Aberdeen, will use the arts and humanities to explore notions of cultural value of landscapes that are useful for decision-making, and go beyond economic and environmental rationales[190].

Image: Cotswolds Area of Outstanding Natural Beauty. © iStock / fotoVoyager.

A further category of information concerns land ownership, tenancy and legal constraints and duties. Some information is available in land registries, but this is a very complicated area due to multiple models of land ownership (some where the beneficial owner may be hard to identify). There are also many different types of land manager from owner-occupiers through tenancies to several types of contract land management. An owner-occupier might also let land to other operators, often for only a short period of time. The review conducted for the Royal Society by the University of Reading explored land ownership in more detail[191]. Greater understanding, subject to appropriate privacy protections, about the ownership structures at play in a landscape could provide policymakers with useful insights as to the motivations and contexts of those managing the land. Furthermore, different areas are subject to a wide variety of legislation. Special rules apply to National Nature Reserves, National Parks, Areas of Outstanding Natural Beauty, Sites of Special Scientific Interest, Nitrate Vulnerable Zones and along water courses, amongst others.

Technologies and innovation for data collection and analysis

Recent scientific and technical advances offer the prospect of obtaining more and better data at lower cost and at greater temporal and spatial resolution. Data acquisition platforms including satellites, planes and drones are becoming more available for remote sensing while better instrumentation allows data to be collected across broader wavelength spectra and through techniques such as LiDAR. Improved analytics allow more signal to be obtained from the data, including three-dimensional information such as vegetation structure and soil carbon profiles. As the 'internet of things' develops there will be greater opportunities to benefit from static sensors in the environment (some are already deployed to monitor river flow and related parameters).

Modern farm machinery collects large amounts of information that enables precision farming (see Chapter 3). This supplements and extends the information land managers have traditionally collected to help them run their enterprises. Much of these data are only partially used, and primarily focus on yield-relevant information rather than a broader set of outcomes. With due consideration of privacy and commerciality, information collected on farms could make a major contribution in helping understand landscape processes.

Obtaining spatial information about biodiversity is challenging because of the huge number of species involved and the specialist skills typically required for their identification. There are also questions about the types and granularity of biodiversity data needed to address specific questions. The availability of resources on the internet, plus the ability of social media to create communities of expertise, has greatly expanded the capacity of citizen scientists to contribute to monitoring biodiversity. Wales's State of Natural Resources Report (SoNaRR), Natural England's 'access to evidence' catalogue, data from the National Biodiversity Network and many other sources play a critical role in bringing all this information together. In the future, molecular techniques such as environmental DNA analysis may also have a role in assessing changes in the distribution and abundance of biodiversity.

Turning to economic and social data, the digitisation of all sectors of society has greatly increased the amount of data available for analysis. Indeed, the last decade has seen the creation of a new field of econometrics devoted to analysing high frequency, granular data. Data from mobile phone records can be used to track tourist numbers and behaviour, while information has even been obtained by analysing photographs posted on social media. The use of such data raises important issues concerning privacy and data ownership but the growth in sophistication and uptake of so-called privacy enhancing technologies (PETs) is supporting the safe exploitation of personal data[192].

Novel research utilising the full range of modern data analysis techniques is welcome but just as important is embedding them in the policymaking process. The Food, Agriculture, Biodiversity, Land Use and Energy (FABLE) Consortium seeks internationally to develop land use decision-making tools and to assess whether national and global policy commitments are consistent[193]. An important example of a current UK initiative is the Welsh Government's Environment and Rural Affairs Monitoring and Modelling Programme (ERAMMP) which collects data about many aspects of the Welsh landscape and links it to a range of socioeconomic and environmental outcomes, allowing analysis of different policy options and scenarios[194].

Improving data infrastructure for better land use decisions

All aspects of policymaking concerning land use can be improved by better access to data and better data analysis. However, there are challenges associated with achieving the necessary levels of integration, interoperability and accessibility of different types of data which require attention. Decision-makers and other data users report an issue of large quantities of nonspecific, under-curated data pertaining to land use, and not enough data that are relevant and of high enough quality to be easily useable. Huge amounts of data are collected and held by many different public, private and academic institutions. However, these data are of variable quality, relevance, timeliness and accessibility. This creates considerable inefficiencies in the system because, for each policy question or decision, it is necessary to locate and often request access to, or to 'clean up' or otherwise modify information to make it useful (eg aggregating geospatial data to a standardised grid in order to integrate it with other datasets). It may also become evident in this process that data are missing or out of date. Underlying data science research is needed to tackle these inefficiencies and establish more streamlined methods of data collection and curation. Indeed, technologies that enable more targeted and timely collection of data have great potential if the knowledge obtained can be readily incorporated into decision-making.

A further challenge concerns the trade-offs that exist at different levels of integration. Integrating data from a range of sources may help policymakers to determine options for land use allocations given a limited set of objectives, but doing so may mask some of the important complexity and uncertainty present in the rawer forms of data. There is also a risk that datasets which contain elements of personal data (eg demographic or land ownership) may be identifiable if presented at a high enough level of granularity (for example if there is only one household within a given search vector). Data integrated in this way may be useful for providing high level information to policymakers, for example in the development of land use frameworks (see section 4.2), but it may date quickly and be inflexible in terms of the analyses it can support. At the other end of the spectrum is a less targeted approach in which larger amounts of open source data (and code) are made available, for example via GitHub, which are not standardised or heavily integrated, but which enable a broader range of analyses when accessible to people with the requisite skills. This represents a trade-off between flexibility and the simplicity of a more highly integrated approach. However, flexibility and integration are not mutually exclusive and in developing data infrastructures to support land use decisions and policy, several approaches with different applications are likely to be useful.

In recent years, there have been several moves towards improving government use of data in the UK, culminating in the recent development of the Office for National Statistics (ONS) Integrated Data Service (IDS – launched in 2021), which is starting to create a series of Integrated Data Assets (IDAs)[195, 196]. IDAs are collections of linked datasets relevant to a particular policy area which give analysts access to a range of enriched data in one place in a way that is reusable, reproducible and enhanced over time through the addition of new data.

Development of an IDA starts with a 'semantic mapping' exercise – grouping relevant information into themes describing different aspects of a policy area and the connections between them, which are then validated with users. For land use policy, themes might include agricultural production, carbon sequestration, biodiversity, housing, leisure and so on. IDAs facilitate data linkage across themes which individually may use very different information sources, and special attention is paid to making sure that the resource is easy to use and consistent.

IDAs protect privacy and enhance trust by using privacy enhancing technologies (such as de-identifying IDs) and negotiating in-depth legal ownership disclosure and data sharing issues. The ONS has so far developed three proof of concept IDAs on net zero, levelling up and health. The integration of decision-relevant data on a common platform has the particular merit of helping to ensure that negotiations and decisions at the policy level are not confounded by varying underpinning evidential assumptions.

Image: Red Squirrel (*Sciurus vulgaris*), Scotland. © iStock / Gannet77.

Recognising the importance and opportunities offered by unlocking location data, the UK Government set up the Geospatial Commission who are responsible for setting the UK's geospatial strategy and coordinating public sector geospatial activity. The Geospatial Commission has launched a series of projects, under the National Land Data Programme (NLDP) to explore key land use pressures, such as energy, housing and decarbonisation, and how innovative data analysis can support better decisions about land use change. The National Land Data Programme will demonstrate how spatial data can inform land use scenario planning. Through regional pilots and in dialogue with land use stakeholders, the programme will explore selected use cases and develop a blueprint of capability improvements to support land use decision making[197].

These initiatives, and others like them, require ongoing support from the UK's administrations to continue addressing the challenge of making land use data useable for decision-makers. Doing so would put the evidence-analysis-policy process to improve land productivity on a footing of continual improvement and provide an unparalleled evidence base from which to negotiate complex decisions.

Given the complexity of land-use decision-making and the evolving state of data and science in the underpinning evidence base, investment in data infrastructure and an overt data strategy would be an essential component of a national land use framework (see section 4.2). There is also wider value in having commonly accessible evidence which helps to break down the inevitable silos of thinking across Governments, by having data from one policy area being accessible to others (for example, land use data could be valuable to health, transport and energy policy areas).

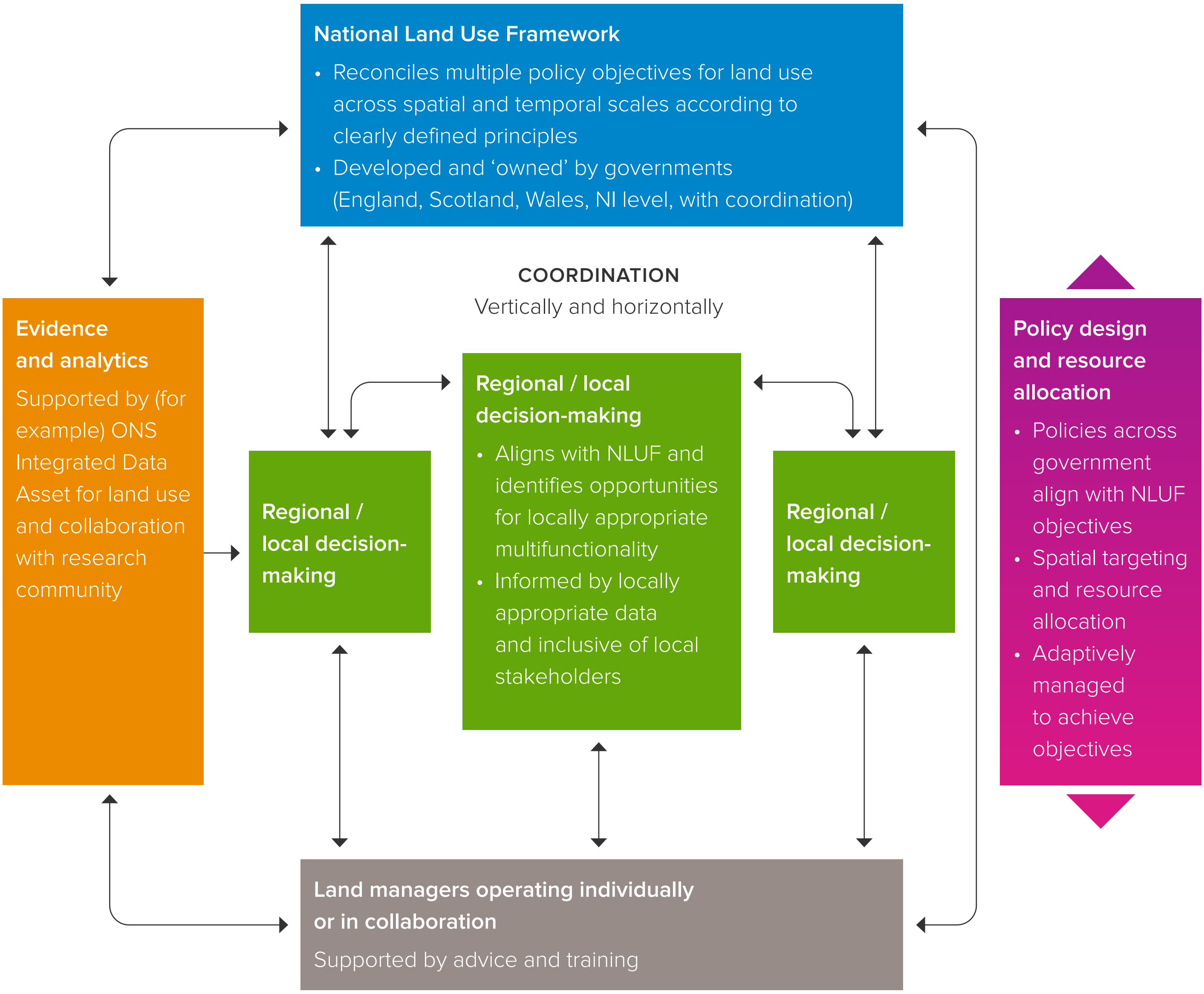
4.2 National land use frameworks

The Royal Society commissioned a review of land use policy and decision-making processes from the University of Reading. It illustrates how our current decision-making processes have evolved contingently and are a patchwork of mid-20th Century or earlier legislation upon which has been layered 50 years of European rulemaking. This structure is not built to cope with the increasing array of competing pressures on land and needs to adapt to these new demands as well as to capitalise on ongoing innovation to improve land productivity. The UK's exit from the EU necessitates change and provides a timely opportunity to create a decision-making framework fit to meet the challenges of the 21st century.

Land use policy is distributed across multiple Government departments and decision-making across multiple stakeholders operating from local to national scales, so coordination mechanisms must be purposefully designed. National land use frameworks at UK country level would allow for decisions concerning land use for agriculture, environment, development and infrastructure to be made in a coherent and consistent manner that recognises the finiteness of land as a resource and draws on the best science and innovation to identify synergies, avoid trade-offs, and improve productivity. They could also offer better opportunities to align land use decisions with other policy areas such as health, energy, regional development and trade. Land use frameworks are particularly important in operationalising the concept of multifunctionality since different incentives are needed in different places to reflect the varying suitability of landscapes for specific policy outcomes. Figure 6 provides a high-level overview of how national land use frameworks could operate to inform decisions at different spatial scales.

FIGURE 6

Theoretical schematic of how a national land use framework could operate to inform land use decisions at multiple scales.



The following principles could underpin a national land use framework.

Supported by robust data and analytics
To be most effective, national land use frameworks should be informed by the best data resources available which are analysed and presented in a way that is maximally useful to decision makers. A common evidence platform, for example the Integrated Data Asset (IDA) described in the previous section, would enable access to a consistent and high quality evidence base, continual improvement through additional data and data linking, and protocols to protect privacy and enhance trust.

Built on trust and transparency
Public confidence in a land use framework will be increased if the data and analytics underlying it are transparent and if the relationship between the evidence base and policy decisions is explained clearly and coherently. Clear articulation of a long-term vision was indicated by participants in the Ipsos MORI public dialogue as an important route to securing buy-in for potentially significant land use change[198].

Enable policy coherence
A land use framework should ensure policy coherence and avoid over-promising the land. The data-analytical core sets boundary conditions within which policymakers must work, for example land allocation needs to sum to one and the biophysical environment determines to different degrees what functions can occur in what places. Within these boundaries, decision-makers could explore different combinations of policies and their consequences, reconcile their different objectives for land use, identify opportunities for synergistically delivering multiple outputs from the same area, and mitigate negative trade-offs that may undermine delivery.

Maximise returns on public investment
An important function of a land use framework is to help determine how limited public funds should be allocated to different areas and activities to yield the greatest public benefit and to address the under-provision of public goods by the market. Analysis within a land use framework would help the development of policy to achieve environmental goals whilst avoiding unanticipated negative economic, social or biophysical consequences.
Land use frameworks are particularly important in operationalising the concept of multifunctionality since incentives will need to be spatially differentiated to reflect the varying suitability of landscapes for specific policy outcomes. A land use framework would help the design of rural support policies that will replace, and hopefully improve upon, the Common Agricultural Policy in the four countries of the UK.

"If they limited building on floodplains, you want to look at alternative uses for that land. You can't just say, "This is a floodplain. You can't do anything on it building-wise." What can you do in other ways to utilise the land?"

Public dialogue participant, Southwest England

Allow space for political deliberation
Scientific analysis is only one input to policy and decision-making, and feasibility, cost, risk, and acceptability (including value judgments and public acceptability) all need to be considered, alongside legal ownership and regulatory frameworks. Land use cannot be determined through a simple algorithmic process; nevertheless, a land use framework supported by a modern data and analytical infrastructure could create a common evidential starting basis for such deliberations.

Facilitate decision-making at appropriate spatial scales
Current data capture methodologies and geographic information systems allow the data informing a national land use framework to be represented at high levels of spatial detail. This allows a national land use framework to help create policy incentives that operate to drive outcomes that are spatially targeted, cohesive and mutually reinforcing at different spatial scales, from the local to the national (figure 6). The framework needs to accommodate current decision-making structures and hierarchies as well as the geography of natural features (such as catchments and areas of contiguous habitat) but be adaptable to future changes in these.

Integrate housing and infrastructure with wider land use decisions
The primary aim of the Town and Country Planning Act 1947 was to maintain the separation between 'town' and 'country' – an aim which it largely achieved. However, the Act effectively separated decisions about whether land is built on or not from other decisions about how land might be used, a separation that persists today to the detriment of both urban and rural policymaking. A land-use framework should not necessarily break down the separation of town and country but should break down the separation of decision making in the two spheres. There is also an opportunity for land use frameworks to inform more integrated decisions about nationally significant infrastructure and to allow fuller comparison of the benefits of, for example, built infrastructure for climate adaptation with large scale nature-based solutions.

Has ability to evolve and improve
Inevitably an initial framework and the tools developed to implement it will not be perfect. Different agents will react in unexpected ways to incentives and regulations, and assumptions about processes may prove incorrect. The climate is changing in ways that are only partially predictable, and the economic, trade and international political environment that has a variety of effects on land use decisions is highly uncertain. Land use frameworks must have the ability to evolve and improve, supported by the data and analytics that provide policymakers with the best current assessment of biophysical and socioeconomic conditions. The need for adjustments should not be seen as policy failure but as sensible adaptive management. The ability to update a land use framework and how it is implemented will be essential in meeting long-term targets.

In place for the long-term

Many policy commitments concerning land use have long time horizons, for example commitment to net zero by mid-century and plans for afforestation and peatland restoration. An (evolving) land use framework thus needs to be in place for the long-term, beyond political cycles. Agreement of all political parties to maintain an evidence-based land use framework would be helpful. The establishment of a transparent land use framework with forward guidance on the mechanisms used for its implementation would help land managers make better long-term investment decisions.

Help crowd-in private investment

Green finance and fintech is attracting huge attention in the private sector and there is great potential for private investors to help improve land use outcomes. A land use framework could help set the market conditions and rules within which the private sector could most effectively operate and provide the assurance of policy consistency to justify investment. It could also help to give advanced warning of potential issues. For example, concern has been expressed that a higher price for carbon might incentivise conifer plantations on low-grade agricultural land, missing the opportunity to provide other potential benefits such as better habitats for biodiversity[199]. Similarly, there is concern that demand for land for offsetting may increase land prices and affect food outputs and the viability of rural communities. Analysis within a land use framework may be able to anticipate and so mitigate or avoid these negative outcomes.

Should be sufficiently influential to make a difference

To be effective, national land use frameworks should be developed and maintained by a body that has the authority and powers to influence cross-government policymaking. It must be appropriately resourced and sensibly embedded within existing decision-making structures. Critically, it must have consistent political support at the highest level.

Mesh with other land use frameworks within the UK

As a large fraction of land use policy is devolved to the four countries of the UK it is natural that each develops its own land use framework. But some land use relevant policy, for example around net zero, is developed at the UK level and land in England, Wales and Scotland is contiguous. Each country will benefit from aligning aspects of their land use strategy with each other (and though not considered further here there may be scope for engagement between Northern Ireland and the Republic of Ireland).

"I'm quite urban by nature. I appreciate the countryside, but I really don't think I understand very much about it."

Public dialogue participant, Southwest England

Engage with different publics
Land use frameworks will receive greater buy-in from different sectors of the public if their interests, opinions and values have been demonstrably considered. In part this occurs through the political process and through the action of civil society organisations who lobby decision-makers on the behalf of different constituencies. There are a variety of social research methodologies that can help understand public views on different topics, which range from large scale market research to more novel deliberative techniques such as public-dialogue and citizens juries, that have less statistical power but more in-depth insight, including on how views change with time, debate, and more engagement with information. The experience of the public dialogue exercise conducted by the Royal Society's Living Landscape Programme is that they can be a rich source of ideas and understanding[200]. For example, participants changed their opinions throughout the exercise as they had the opportunity to engage with new information and ways of thinking about landscapes. A successful land use framework should prioritise for public engagement those areas of policy most sensitive to the limits of public acceptability, such as dietary change as a means to reduce pressures on land.

There is potential for UK countries to lead the way internationally in developing a multifunctional approach to land use decision-making. The literature review commissioned by the Royal Society from the University of Reading found that, to date, no country has succeeded in implementing the kind of strategic, multi-level approach described here, though some have come close[201]. New Zealand's Resource Management Act 1991 – which sought to bring all aspects of environmental planning under a single framework – underdelivered on its ambitions, reportedly due to its lack of spatial focus and poor integration with subnational governance levels[202]. In Germany, the creation of a national habitat network was impeded by the fragmented and partial approach taken by different federal states due to lack of a strong national steer[203].

There is an opportunity for the UK to be a global leader in strategic land use and develop a model that can be replicated worldwide.

Conclusion

Conclusion

This report has set out the case for adopting a multifunctional approach to landscape analysis and decision-making. Modelling and analysing the trade-offs and synergies between different land uses can make an important contribution to better policy. Such analyses have the dual role of suggesting how multifunctional landscapes might be constructed, meaning which functions to combine and which to separate, as well as acting as a helpful guard against over-optimistic thinking about what one piece of land can deliver. They should not be, however, the only input to decisions about land use which must also consider factors such as public acceptability, cultural value and legal rights among other things. Interdisciplinary research will be needed to further develop modelling capabilities. Continued and strengthened collaboration between decision-makers and researchers will enable new tools to be designed with the greatest policy relevance.

The report envisages future landscapes as being explicitly designed to deliver multiple outputs of value to society from food and timber to habitats for biodiversity and places for human recreation. At any one site, some land will be managed to produce multiple outputs, some a more restricted set. New research, innovation, and the application of existing knowledge can help improve the provision of all outputs – an enlarged concept of productivity. The report has set out some of the areas of science that will be key to achieve this, including increasing the sustainability of high-yielding agricultural land, reducing negative trade-offs and exploiting synergies where land is managed for more than one outcome, or driving up the productivity of land managed for other outcomes such as biodiversity conservation or carbon sequestration.

The areas of research outlined here will provide the scientific foundation for the development of a common evidence base for land use. New skills and a better functioning advisory infrastructure will be required to ensure that land managers can access the benefits of innovation.

No country has yet achieved an integrated evidence base and decision-making framework for land use as described here, despite the increasing demands on the land in a changing world. The UK therefore has an opportunity to lead by taking forward the recommendations made in this report. The UK's administrations can capitalise on progress already made by the Office for National Statistics and Geospatial Commission that lays the groundwork for improved spatial data and analytical capabilities that could serve as a continually evolving and improving resource for the UK. Furthermore, this report has outlined some key principles that could underpin national land use frameworks, enabling the coordination and reconciliation of land use decisions across multiple policy areas and geographical scales and informing policy which is spatially targeted to encourage land managers to use land most efficiently for the purposes to which it is best suited.

The recommendations made in this report will take time, careful consideration and collaboration between multiple actors to implement, and the benefits of doing so are unlikely to be seen for some years. Embedding new systems now and iteratively improving them will be necessary, as will ensuring accountability for delivery which outlasts political cycles. But the rewards in terms of land productivity, societal health and wellbeing, economic returns and many more areas will be significant.

Annex

ANNEX A

Acknowledgements

Steering Group

The members of the Steering Group involved in this report are listed below. Members acted in an individual and not a representative capacity and declared any potential conflicts of interest. Members contributed to the project on the basis of their own expertise and good judgement.

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John Varley OBE, Chief Executive, Clinton Devon Estates
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Reviewers

This report has been reviewed by expert readers and by an independent Panel of experts, before being approved by Officers of the Royal Society. The Review Panel members were not asked to endorse the conclusions or recommendations of the report, but to act as independent referees of its technical content and presentation. Panel members acted in a personal and not a representative capacity. The Royal Society gratefully acknowledges the contribution of the reviewers.

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ANNEX B

Summary of *Review of key trends and issues in UK rural land use*

The Royal Society commissioned a review from the University of Reading to provide an in-depth evidence-base on the history of, and current arrangements for, rural land use decision-making in the UK. It is based on an extensive review of the academic and professional literature, a policy review and stakeholder audit. The research:

1. explored the historical development of the current system;
2. mapped-out the range of stakeholders that shape rural land use policy and practice;
3. evaluated current policy, practice and governance arrangements; and
4. drew lessons from selected international case studies and recent stakeholder proposals.

Authors: Dr Jeremy Burchardt, Mr Joe Doak and Professor Gavin Parker.

This annex summarises the review's key findings. As an independent piece of research, the opinions expressed are not necessarily those of the Royal Society.

History of land ownership and decision-making

During reconstruction after World War II, guaranteeing food security and improving nutrition were established as the primary objectives of the countryside. As a result, earlier plans to nationalise land (to deconcentrate ownership and share its value more widely) were abandoned in favour of a 'farming in the public interest' policy.

The highly influential Scott Report (1942) put forward solutions to key rural problems. It recommended subsidies for farmers, comprehensive town and country planning and creation of National Parks.

Following the Scott Report, the Agricultural Act (1947) promoted agricultural exceptionalism, where agriculture is treated differently to other economic sectors because it contributes to broader national interests and goals. The Act prioritised low cost, secure food supplies and introduced a combination of regulation and incentivisation for farmers. This led farm output to double between 1944 and 1974. However, there were significant environmental and social costs. Farmers drained marshlands, ploughed moorlands, grubbed woods, and removed hedgerows to maximise production which caused conflicts with conservationists and other stakeholders. In addition, the Town and Country Planning Act (1947) was successful in preventing urban sprawl and retaining separation of 'town' and 'country', but it generated problems through increased house prices and siloed decision-making. Today, this has implications as the planning system is still only concerned with whether land is built on or not, not what the best use of the land might be (eg housing, agriculture, forestry, biodiversity conservation and so on).

Contemporary patterns of land use

Over the past century, there have been some significant changes in the structure of UK land ownership. The most noteworthy changes include an increase in land owned by conservation organisations and pension funds, and a shift from tenancy to owner-occupancy in UK farmland. Today, most UK land is privately owned. The review noted that this often results in fragmented and insufficiently democratised decisions on rural land use.

The current (2018) landownership structures of England and Scotland are outlined in Tables 1 and 2 respectively. This data reveals several dimensions of ownership relevant to rural land use decision-making. Despite some decline and adaptation of the landed estate as a form of ownership, they retain control over a significant area of rural Britain. Much of this land is farmed for agricultural purposes or, in upland areas particularly, for forestry and game sports.

TABLE 1

Landownership in England (rural and urban).

Landowner	Area (ha)	% of England
Private Estates	3,998,140	30%
Companies (estimate for England)	2,392,884	18.0%
Other Private owners*	2,259,946	17.0%
Unregistered	2,259,946	17%
The Public Sector	1,098,071	8.5%
Homeowners	664,690	5.0%
Conservation charities	257,348	2.0%
The Crown	184,743	1.4%
Church of England	70,821	0.5%
Total	**12,176,579**	**100.0%**

* Defined as 'new investors', made up of a group of individuals who have acquired wealth since the industrial revolution.
Source: based on data in Shrubsole 2019).

TABLE 2

Rural landownership in Scotland.

Landowner	Area (ha)	% of Scotland
Private Estates**	4,140,460	57.1%
Public Bodies (including the National Forest estate and MoD land)	914,000	12.6%
Community	227,526	3.1%
Environmental Organisations	182,438	2.5%
Total	**5,464,424**	**75.4%*** **

** 'estates' are defined as landholdings with a range of interests that may include in-hand farming, let farms, sporting interests, forestry, residential property, workspaces, tourism and community facilities. The owners are mostly established aristocracy/gentry or 'new investors' as defined in Table 4.2. *** the remaining 24.6% of rural land not accounted for in the table includes farms, crofts and smaller estates that do not match the 'estates' description given above.
Source: Glass *et al* 2019, p. 12).

International comparisons

In the past, strategies and agreements from the EU and the UN have had the most impact on UK land use policy and practice. UK agriculture has been dominated by the EU Common Agricultural Policy (CAP) and environmental regulations for over 40 years. The UK must now devise its own agricultural and environmental policies to replace those of the EU.

This Report investigated international case studies relevant to the UK:

- Key lessons from Japan related to ownership structures, and the intentional and unintentional outcomes for sustainable development derived from more fragmented land ownership. Ownership fragmentation post-1949 created around 6 million land-owning farmers and led to widespread landscape change. The post-war legacy fostered strong local community ties and institutional arrangements to manage common-pool resources which then aided social sustainability. However, they have not delivered strong environmental sustainability.
- New Zealand has close ties to the UK. The country's Planning System was largely modelled on UK legislation but placed emphasis on Matters of National Importance (MNIs), including protection of high-value agricultural land, preserving heritage, and maintaining coasts, lakes and rivers. As a result, subsidies were withdrawn under neoliberal (market-led) reforms. This could give insight to a post-Brexit scenario for the UK. In addition, the Resource Management Act (RMA) (1991) sought to bring all aspects of environmental planning, including land, air, coastal and water-related resources, within a single framework. However, critics (from environmental organisations, business interests and Maori advocates) argued that it failed to compromise between environmentalism and neoliberalism. Some suggested that environmental goals could be more effectively achieved by a stronger spatial focus with better integration at the local level. Others emphasised greater investment in capacity and training within the planning system.
- Similar to the UK, around 85% of Sweden's population live in towns and cities. The Swedish approach could be of interest to policymakers in the UK given its attention to developing multifunctional countryside. The Swedes have recently put this principle into their national food strategy, with attention to all links in the food value chain.

Key conclusions

The principle of 'sustainable development' has gained some consensus as the aim for the future use of rural land in the UK. The integration required for sustainable development is important and useful for policy development, institutional arrangements, and delivery mechanisms.

Some level of multifunctionality already exists the UK. It is recognised as a solution to many rural land use challenges. However, implementation of effective multifunctional landscapes has remained elusive. Different stakeholders have different views so, while some formulations of multifunctionality can bring win-win outcomes, many involve trade-offs for some or all interests affected.

Neoliberalism currently has a strong influence on rural policy. However, the review notes that such an emphasis on market solutions, rather than regulation and state intervention, may be a contributing factor to disjointed land use decisions.

Overall, the review identified many unanswered questions and revealed a lack of recent research on land use decision-making and governance. It recommended that a case study from a particular area be undertaken ('locus study') to identify key issues and stakeholders and test different institutional arrangements. Also, more targeted discussions with international partners is recommended to focus on specific objectives and tools.

ANNEX C

Summary of Ipsos MORI public dialogue methods and key findings

Ipsos MORI were commissioned to conduct a public dialogue to understand public views on land use. The main aims were to 1) uncover people's attitudes towards rural land and their priorities for its use, and 2) reveal how much they know about land use decision-making and how it can be informed by science. This annex outlines the methodology and main findings. The full report contains Ipsos MORI's more detailed interpretation and recommendations.

Methodology

97 participants from four UK regions (East Anglia and the Fens, North Wales, Western Scotland, and Southwest England) were provided with pre-task booklets, discussion guides and possible future scenarios which were informed by a rapid evidence assessment and expert stakeholder interviews. Eight video diaries from UK farmers were conducted in August 2020 and their views were uploaded onto the Ipsos AppLife platform for participants to view and comment on.

Fieldwork was carried out between September to October 2020. Each regional group took part in two online workshops. In the three weeks between these workshops, all participants were invited to interact with one another in an online forum. Telephone interviews were held with eight participants who were otherwise digitally excluded from the fieldwork. Results from this dialogue are qualitative, with participants' perceptions, rather than statistical facts, reported.

The aim of the first workshop was to introduce participants to the idea of landscape multifunctionality and the six types of land use defined by the Royal Society based on the UK Government's 25 year Environment Plan and Agriculture Act (2020) (food production, biodiversity, combatting climate change, recreation, leisure and heritage, protection from environmental hazards, and clean air and water). Each workshop was facilitated by a member of Ipsos MORI's staff and supported by land use experts to help participants navigate the discussion accurately.

The second workshop presented participants with three future land use scenarios to show how the UK's rural landscape might look in 2035 depending on the pursuit of different policy options:

- **Home Front**
  measures implemented to increase the proportion of food consumed in the UK that is grown here. Land use changes drive up food production, for example with expanded agriculture or use of agricultural technology to achieve greater efficiencies.
- **Follow the Market**
  policy choices designed to promote economic growth are prioritised. Only land uses that are profitable will remain with recreation and leisure predominantly provided via private landowners.
- **Climate Co-ordination**
  decisions made to reduce UK carbon emissions. Land uses for carbon sequestration (and other public goods like biodiversity, and clean air and water) are prioritised.

Main findings

Generally, participants had little prior knowledge of UK land use and if they did, they had a very localised perspective. Participants were broadly grouped into six impressionistic typologies based on their views on the types of land use they valued and trade-offs they perceived (Figure 1). Most participants changed their views during the course of the dialogue, demonstrated by changes to which of the three scenarios they gave preference to at the start, middle and end of the dialogue. This could be due to participants transitioning from a consumer to a stakeholder perspective as the dialogue progressed.

Participants were generally happy to leave decision-making to those they perceived as 'experts' (for example land managers and policymakers) but voiced that although they weren't involved, they would still like to be provided with information about the decisions being made.

The six land use types were viewed differently by the different typologies but overall, combatting climate change was seen as the most important long-term and food production, and heritage, culture and leisure were deemed to be the most immediately necessary.

FIGURE 6

Six 'land value typologies' – groups of people with different attitudes to, and priorities for, the land.

DEEP ROOTS

- Older, ABC1, identifies as a rural person, tends to be female.
- Grown up in a rural area, or moved to rural areas some time ago.
- Wants strong action on climate change and biodiversity.

ESCAPE TO THE COUNTRY

- Middle-aged/family, ABC1 social grade.
- Moved recently to green/ blue area in striking distance of cities.
- Focused on lifestyle and choice but sees climate as concern.

URBAN TIME PRESSURED

- Less defined by age: C2DE, urban/suburban.
- Younger folk or young family with kids.
- Less engaged with local area and unsure how they can help.

Scenario preferences

Although scenario preferences varied, most participants were united in wanting to know how government policy might support people to transition to the different lifestyles proposed in each future scenario.

Home front

The view of the UK producing its own food was appealing to many participants, albeit participants' understanding of 'food sovereignty' or 'food security' were often distorted or unrealistic. There were concerns that an approach based predominantly on food production may be unsustainable. Overall, this scenario was viewed the least positively of the three. However, the 'grow for Britain' typology strongly supported this scenario because it prioritised domestic food production over all other land uses.

The scenario proposed that significantly expanded agriculture and use of agricultural technology would play a key role in meeting higher domestic food production targets. Participants considered this to be the most distant scenario from the present. Lab grown meat sparked the biggest debate; although initial reactions were negative, many participants changed their mind when they heard from experts about the benefits it could have for the environment and animal welfare.

This scenario would require dramatic land use changes from today and participants felt that large scale farms might be too industrial. Further concern was raised when participants heard that a focus on food production might have negative impacts on recreation and leisure and could be harmful to biodiversity.

GROW FOR BRITAIN

- Male, middle-aged, C1C2 home owner.
- Identifies strongly with local area and proud to be there.
- Food security a major concern and interested in agricultural technology.

CLIMATE RADICALS

- Younger, ABC1, university educated, urban.
- Urban but mobile.
- Most strongly in favour of action on climate; has made lifestyle changes and expects this of others.

LOCAL HORIZONS

- Pre-family/young family.
- Rural, rooted in town or village they grew up in.
- If close to recreation and leisure sector they want current land use practices to continue.

Follow the market

This scenario is driven predominantly by economic forces. It particularly appealed to the 'urban time pressured' typology who were most removed from their local landscapes and tended to have little interest in what happened to the land where there was no direct financial impact on them. The 'local horizons' typology also showed support for this scenario.

Some participants were concerned about the inequality this scenario could create, particularly with increased food prices and lack of access to good-quality, nutritious food. In addition, participants repeatedly returned to the principle that access to the countryside should be free and that charging for access to land could create inequality.

Most participants (57%) said that they would be fairly happy to live in this world, but very few (1%) said they would be very happy.

Climate co-ordination

This was the most appealing scenario, with 87% of participants saying they would be either fairly or very happy to live in this world. Some participants, especially those in the 'deep roots' typology said it felt like an ideal future as they value biodiversity and combatting climate change most highly.

Lots of participants supported climate mitigation policies with many commenting that climate change is one of the biggest challenges of our time. Participants belonging to the 'climate radicals' typology thought that this was so important that they wanted policies to be implemented now, rather than in 2035.

Participants raised some apprehensions about the significant lifestyle changes people would have to make in this scenario. This was centred mainly around the prospect of changing diets to include less meat and animal products. Farmers voiced their concerns about this most strongly. Others suggested that strict rules about land use would limit access to the land and could exclude some groups of people. It was suggested that rich people could continue to live as they do now, but poorer people would have to make significant lifestyle changes.

Many participants felt that the personal lifestyle changes required for climate co-operation may be too big to expect people to make in such a short space of time. The 'escape to the country' typology supported implementation of the policies set out in this scenario in the future, not now. Participants in general preferred climate co-ordination, but felt that they needed a narrative or vision that connected the current situation to where we might be in 2035.

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