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**Original Article**

# A theory of change for transformation of the productive forest system in the United Kingdom

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## Abstract

Forests globally are facing increasing threats related to environmental crises, including climate change, deforestation, land-use change, increasing spread of pests and diseases, and agricultural intensification. At the same time, forests are expected to play a vital role in addressing these crises, requiring transformational change in forest systems and silvicultural practices. This paper develops a conceptual theory of change for this transformation in the context of the productive forest system in the UK. It draws on a participatory backcasting exercise with academics, policymakers, and forest industry practitioners to scope out what products and services future productive forests will need to deliver and to identify challenges to realizing those. The theory of change sets out four areas for action to meet this vision: transformative governance; knowledge exchange and skills development; innovative financing; and research and data access. Actions are identified, with the final goal of achieving productive forest systems in the UK that are climate resilient, biodiverse, and provide diverse products and services through a sustainable forest bioeconomy. The theory of change provides a framework for developing a feasible pathway to transformation and monitoring progress towards a set of desired intermediate and long-term outcomes.

*Keywords:* transformation; productive forests; backcasting; theory of change; United Kingdom

## Introduction

Forests globally are facing increasing threats related to environmental crises, including climate change (IPCC 2022), deforestation (IPCC 2022), land-use change (Hallaj et al. 2024, Rosero-Añazco et al. 2025), increasing spread of pests and diseases (Ambrose-Oji et al. 2024), and agricultural intensification (Garrett et al. 2018). At the same time, forests are also expected to play a vital role in addressing some of the world's greatest challenges, rooted within the same crises, such as increasing carbon capture (Piedra-Jimenez et al. 2025), alleviating extreme weather events (Broadmeadow et al. 2023) and pollution, addressing biodiversity loss (Mori et al. 2017), contributing to human wellbeing (Oh et al. 2017), and providing a supply of wood-based raw materials to replace petroleum-based products (Clancy et al. 2013, IPCC 2018, Daigneault et al. 2022). Healthy forests are the largest terrestrial carbon sink after soil (Pan et al. 2011, Pan et al. 2024) and contain most of Earth's terrestrial biodiversity (FAO and UNEP 2020). They support a diverse range of ecosystem services such as improving air quality (Baumgardner et al. 2012), flood risk management (Broadmeadow et al. 2023), reducing soil erosion (Wendel 2014), the provision of timber and other wood-based materials, supporting livelihoods, and providing psychologically and physiologically restorative settings for humans (Oh et al. 2017).

In recent years, there have been increasing calls for transformational change in forest systems (including productive forests) and silvicultural practices (Achim et al. 2022), to ensure the forests of the future are resilient and able to meet these growing demands. These calls are particularly relevant as the harnessing of forests to supply nature-based solutions in the context of our climate and biodiversity crises is pressing, and the Food and Agriculture Organization estimates that global demand for primary processed wood products is likely to increase by 37% by 2050 and demand for roundwood by 49% (FAO 2022). At the same time, these crises present real threats to this capacity, including the potential for 'catastrophic forest ecosystem collapse' (Tew et al. 2023). While the concept of transformation in response to global environmental change can be defined differently, it consists of realizing fundamental change in order to generate environmental and societal benefits (Feola 2014, Dinesh et al. 2021, Visseren-Hamakers et al. 2021). It involves system innovation across technological, institutional, and social domains that lead to a radical reconfiguration of the system, rather than incremental change (Meynard et al. 2017, Barrett et al. 2020, Dinesh et al. 2021). How potential system innovations are promoted, adopted, and enacted depends on who is framing the problem and solution. Different visions of what the future should look

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like are based on different worldviews or paradigms and result in different technological, institutional, and social innovation pathways.

Technological innovations, such as new forms of engineered wood, wood fibre insulation, or processing lignin and cellulose into plastic replacements or sustainable textile fibres will create new requirements for the properties of wood harvested from forests, which may create the need for transformation of forest systems, e.g. in species choice or silviculture (Hetemäki et al. 2020). Forest systems may also be transformed by innovation in the technology applied to forest management, such as precision forestry and harvest automation, or changes to forest management driven more by concerns about biodiversity and resilience at the stand scale such as tree species diversification, continuous cover forestry (Mason et al. 2022), and back-to-nature forestry. At the landscape scale, choices involve decisions about land sparing and land sharing (Betts et al. 2021, Bateman and Balmford 2023) or to meet the objective of applying the circular bioeconomy approach across the whole forest–forest products system (Forster et al. 2023). System innovation in this context is, therefore, about transformation of both the knowledge system (Dinesh et al. 2021) and the forest system, involving a range of actors and technologies (e.g. remote sensing, artificial intelligence) that generate, transform, transmit, and store knowledge (Foray 1997).

In the United Kingdom (UK), trees, woods, and forests have been recognized as key to government commitments to both reaching net zero carbon emissions by 2050 and meeting the UK's nature recovery targets. This requires an ambitious plan for afforestation to increase woodland cover in the UK to 17% through 1.5 million hectares of new tree planting by 2050 (Committee on Climate Change 2020) and better management of existing forests. Presently, 13.5% of the UK is woodland, with conifers accounting for almost half of the woodland area, although the proportion varies from 71% in Scotland to 22% in England (Forest Research 2024). The UK is the second biggest net importer of wood products in the world, with 80% coming from North America, China, and other European countries (Cameron 2022, Environmental Audit Committee 2023). Such extensive reliance on imports is an economically risky strategy, exposing the UK to the huge uncertainty of future global timber markets. It can perpetuate international environmental injustices such as the 'offshoring' of the negative environmental impacts of intensive forest management (Kleinschmit et al. 2024) to meet UK wood demand and may even prevent the projected increase in use of wood in long lifespan products from making the intended positive contribution to mitigating climate change (Forster et al. 2025). There is also growing recognition that innovation in our use of wood technologies and circular bioeconomies can support generation of novel sustainable products and product life cycles that also meet net zero requirements (Barnes and Leitch 2023, Spear et al. 2025). Meanwhile, the sector has complex decisions, yet to be made, about how we expand both conifer and hardwood species choice to supply the materials of the future whilst providing resilience to climate change and pest and disease threats (Potter and Urquhart 2017, Forster et al.) and improving its efficiency in combining wood production and biodiversity conservation objectives across the forest estate.

As acknowledged in the UK Forestry Standard (Forest Research 2023), addressing these interlinked and sometimes conflicting goals requires a holistic and multidisciplinary 'forestry system approach' that recognizes forests as complex socio-ecological systems that can deliver transformation. A forestry system includes the actors, stakeholders, behaviours, and outcomes involved in land use, tree growing (forestry), wood product processing and manufacturing, and supply chains from producer to consumer and takes into account the interdependencies, pressures, and drivers.

Currently, there is a gap in existing research to inform what a transformed productive forest system in the UK would look like to deliver the products and services that will be required in the future. This paper aims to address this by developing a theory of change in the context of the productive forest system in the UK. A theory of change constructs an impact pathway to reach a desired future set of outcomes (Thornton et al. 2017). It provides a framework for both developing a feasible pathway to transformation and monitoring progress towards a set of desired intermediate and long-term outcomes. To achieve this, the paper reports on the outcomes of a participatory backcasting exercise with academics, policymakers, and forestry industry practitioners to scope out what products and services future productive forests will need to deliver; how future forests should be managed to deliver these products and services sustainably; and what skills, supply chains, markets, evidence base, and governance mechanisms are needed to reposition forestry to meet the upcoming needs of society. Outputs from the backcasting exercise are used to develop the theory of change. The theory of change can then be applied to identify actions needed to realize desired future outcomes in the forest system.

## Materials and Methods

### Participatory backcasting

Participatory backcasting approaches are frequently used to identify pathways to transformation (Quist and Vergragt 2006, Quist 2007, Quist et al. 2011), recognizing that stakeholder engagement in such processes is crucial for creating viable pathways and legitimacy. Backcasting is commonly used to address problems where transformative change at a systemic level is necessary (Kishita et al. 2024). The approach involves creating a future desired vision or visions, followed by looking at what actions or strategies would be required to achieve the future desired state (Quist and Vergragt 2006). Backcasting was first applied to compare alternative energy futures (Lönnroth et al. 1980, Robinson 1982). Recognizing the importance of involving local stakeholders in the process, it has developed into participatory backcasting in recent decades to explore, for instance, sustainable households (Street 1997, Green and Vergragt 2002, Carlsson-Kanyama et al. 2008). There are various ways of understanding a participatory backcasting approach, but it essentially entails deliberative activities, such as workshops, to identify probable, possible, or preferable futures or scenarios (Carlsson-Kanyama et al. 2008). The future visions are then used to develop transition pathways of actions or strategies across the innovation and knowledge system (Eames and Egmose 2011).

In our study, participatory backcasting was used to explore feasible pathways to forest management scenarios that would support the UK's commitments to net zero, nature recovery, and human wellbeing in 2050 (Fig. 1). Participants included interdisciplinary researchers, policymakers, and representatives from across the forest sector, including one non-governmental organisation (NGO) (Table 1). A series of both in-person and online workshops were held to (i) identify what wood products and other benefits forests will need to provide in the next 25–50 years; (ii) how future forests will need to be managed to enable them to deliver the identified benefits; and (iii) identify the challenges of realizing these demands on future forests and potential pathways to transformation. Firstly, a preworkshop poll was conducted,

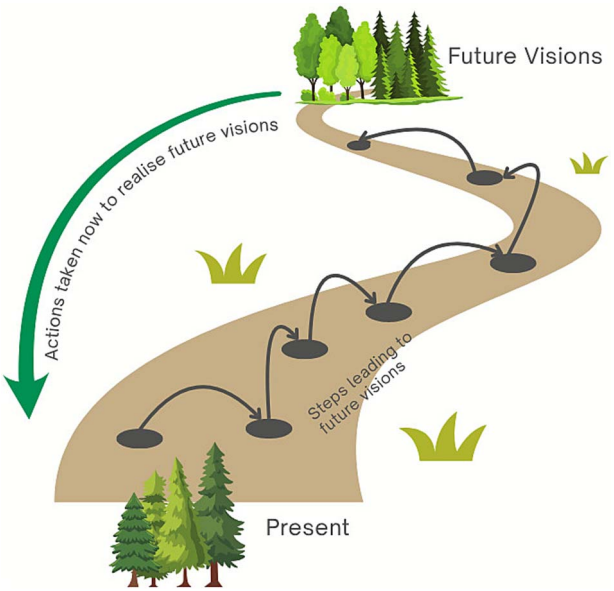


**Figure 1.** The backcasting process for creating pathways to desirable futures. Note: The diagram is a simplified representation of the backcasting process. In reality, more than one pathway to one or more visions may be identified.

asking participants (of the first workshop) to identify and vote on the products and services that they anticipate productive forests will need to deliver in 2050 and beyond. Secondly, an in-person workshop was held in June 2023 with 30 academics from a range of disciplines, policymakers, and practitioners. Participants were purposively recruited, via snowball sampling (Parker et al. 2019), towards achieving wide representation from sectors identified as appropriate or potentially aligned. These included individuals from different career stages, from senior staff to those early in their careers. This allowed for inclusion of ideas from those who had a lot of experience and history in forest management to those with new and fresh ideas. Academic disciplinary representation included social science, wood product technology, environmental science, ecology, hydrology, forest science, bioscience, forest genetics, soil science, creative arts, and design. Attendees from the tree health and tree planting teams at the Government's Department for Environment, Food and Rural Affairs (Defra) contributed in relation to the policy research agenda. Working in three groups with a facilitator to moderate the discussion, participants identified the products and services they anticipated productive forests would need to deliver in the future. Further, they identified potential forest management models (e.g. land sparing/sharing, continuous cover forestry) that might support the delivery of these products and services, together with the challenges to transformation pathways. The discussions were audio-recorded, and participants were further encouraged to note their main points on Post-it notes that were used in the plenary discussion.

A second online meeting was held in November 2023 with five representatives from the forestry sector who reviewed the outcomes from the first workshop in order to validate them and identify any gaps. A third online meeting was held in January 2024 with 37 participants across academia, policy, the forest industry, and the wood-based sector to refine the outputs. Recruitment to this workshop deliberately targeted gaps in representation identified in the first workshop, reaching for greater diversity of representation from the forest industry and forest science. The workshop was also used to further validate the results from the backcasting exercise, and the authors used the results from the participatory backcasting to develop a theory of change.

**Table 1.** Distribution of participants by sector.

| Sector | No. of participants |
|---|---|
| Research | 33 |
| Forest industry | 14 |
| Policy | 8 |
| Forest products | 8 |
| Practitioner | 4 |
| NGO | 1 |

## Theory of change

The outputs from the backcasting exercise were used to inform the development of a conceptual theory of change. The notes and transcripts from the workshops were systematically analysed by clustering similar themes together and looking for trends in the data. The first step in a theory of change is to define the goal, or long-term impact to be achieved. This was synthesized by the authors from the future visions identified in the backcasting exercise and sought to encompass the range of products and services identified as likely to be required. To reach this goal (or final outcome), a series of intermediate outcomes were identified, representing the long- and short-term changes that participants identified as necessary to achieve the final impact. Next, the actions or activities that need to be undertaken to realize the outcomes were defined by clustering similar actions together and the type of input that these represent (Government Analysis Function n.d.). These activities represent the pathways and actions identified in the backcasting exercise.

# Results

While there was some difference in future visions about specific forest management models, there was general consensus regarding some of the significant challenges that need to be addressed to support forest system innovation and transformation.

## What products and services will future UK forests need to deliver?

Fifteen participants responded to the preworkshop poll, identifying construction timber as the most important product, along with wood for laminate, paper and engineered products, or fibre (Fig. 2). During the workshop discussion, there was general consensus that more timber needs to be produced in the UK to reduce reliance on imports. However, a wide range of other products were also identified as likely to be important, such as biomass for energy, nonwood products (such as fungi, venison, and medical products), chemical products, plastic alternatives, and new biotechnological resources. Participants also identified the range of benefits that may be delivered by agroforestry, including the sustainability of food production from the farming system, as well as tree products.

Alongside forest products, participants mentioned biodiversity and flood alleviation most frequently as services UK productive forests will need to deliver in 2050 (Fig. 3), but also a diverse range of other services including climate regulation, cultural values, and recreation. While not included in the poll, pest and disease regulation was also identified in the workshop as a service provided

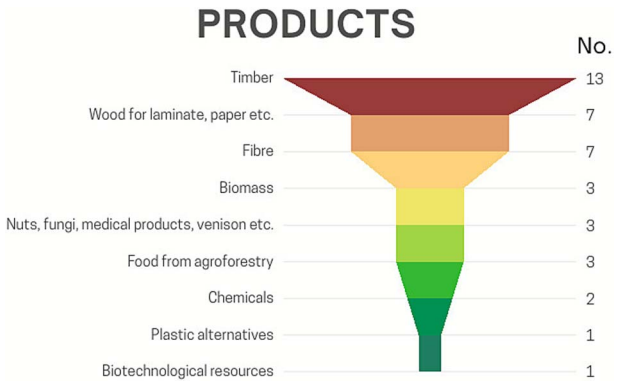


**Figure 2.** Results from preworkshop poll of participant opinion on what products productive forests will need to deliver in 2050. Data show the number of respondents who mentioned each product ($n = 15$).

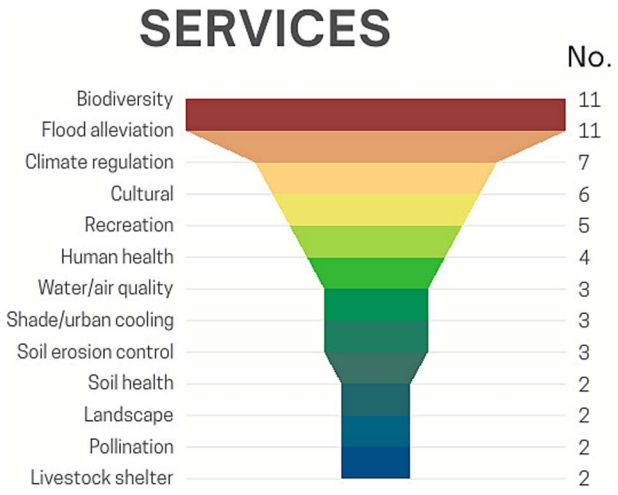


**Figure 3.** Results from preworkshop poll of participant opinion on what services productive forests will need to deliver in 2050. Data show the number of respondents who mentioned each service ($n = 15$).

by forests. It was also recognized that objectives for products and services from forests cannot be completely separated: there will always be overlap, and they are often jointly produced, even when there is a clear primary aim for management, such as timber production or nature conservation.

It is important to note here that those products and services that were most frequently mentioned are likely the ones that are the most familiar to respondents (e.g. timber, biodiversity), while others (e.g. plastic and textile alternatives) may currently be less familiar but may significantly increase in importance by 2050.

## How do future forests need to be managed to deliver these products and services?

Workshop participants recognized the need to identify the types of forest management models that are required to balance public good priorities alongside growing more timber and an understanding of future risks to commercial forests and how these can be mitigated, in addition to the potential impacts of forest transformation on ecosystems. As outlined above, participants recognized that there are likely to be multiple objectives of forest management, even if there is a primary aim, down to the level of a single stand. That being said, there were various and sometimes conflicting views on how this should be managed, reflecting different perceptions about the role of land sparing and land sharing within forestry. Some participants supported a land sparing model, where intensive commercial forests would be managed to produce as much timber/wood as possible (and thus absorbing carbon during their lifecycle), while conforming with a minimum level of delivery of biodiversity and other services, which would mainly be delivered in other forests managed with the primary aim of conservation. Others endorsed a land-sharing approach, where forests that prioritized timber/wood production would also have higher standards expected for biodiversity benefits. While participants mostly argued for a move away from monocultures in order to support better resilience, some suggested that there would likely still be a place for single-species stands, in the context of short rotations, clear risk management, and where production was likely to be high. Participants emphasized that it is fundamental to maintain soil health through sustainable soil practices, and a shift towards a circular bioeconomy in future forest management, highlighting that currently, much timber is wasted.

There was consensus, however, that future forests will need to be more diverse in terms of species mix, age structure, and genetic diversity. Achieving this will take time and may involve a decrease in production in the short term, as forests transition to forms that are more resilient in the longer term. Different views were expressed about the spatial scales of mixtures and species composition, ranging from calls to adopt the use of more non- or near-natives that are likely to be more tolerant of the future climate in the UK, to a preference for a wider use of a greater diversity of native tree species mixes.

Participants highlighted that data are often focused on those aspects that are easiest to measure, such as economic return and carbon storage and that reaching a true balance across carbon, aesthetics, and commercial value, for instance, would be difficult as some things are harder to measure than others. They argued for better tools to characterize trees and forests economically, but also next-generation sequencing, genomics, tree breeding and improvement of commercial species, and technological improvements such as precision forestry. An important component that was agreed will be understanding the value and behavioural changes that might be needed by landowners and society. Some further suggested that current management models are too constrained by economic frameworks focused on material benefits and do not account for the inherently chaotic and dynamic natural world. The point was also made that a focus on transformation of forest systems through a continuing focus on production is embedded within an anthropocentric narrative of leveraging nature to overcome human-driven ecological crises. Such nature-based solutions, it was suggested, risk the exclusion of other ways of valuing nature.

## What are the challenges and solutions to achieving these future visions?

Participants identified a range of challenges to achieving transformation in the productive forest system, together with potential solutions to overcome these challenges and meet the desired outcomes (Table 2). Some challenges related to knowledge gaps including a lack of data and evidence, alongside high levels of uncertainty about change and the likely response of forest systems. Others described knowledge and skills barriers such as forest workforce skills' deficits and a lack of collaboration across government, the forest sector, and academic bodies that hinder data sharing and innovation. Some describe structural and resource challenges such as inflexibility in the existing supply chain infrastructure and the capacity of sawmills. A further set relates to cultural barriers to change such as existing landowner and societal perceptions.

**Table 2.** Identified challenges and potential solutions to support forest system transformation.

| Challenges | Solutions to support transformation |
|---|---|
| **Timber/wood products** | |
| Lack of evidence of quality and marketability of UK timber | Improved open access to data and clarity about responsibilities for evidence provision (government, research, industry) |
| Lack of evidence on use of waste from timber harvesting and processing for use in other products, such as lignin and cellulose | New investments (UKRI, government, private sector) in research to identify new technologies and processes to meet future demand |
| Current environmental footprint and social justice issues around high levels of timber imports | Government commitment to support and enable the UK to improve the quantity of domestically grown timber |
| **Education/skills** | |
| Skills deficit in the forest sector workforce and resistance to change | Monitoring the skills needs for future forest management, including ensuring forestry degrees are future-proofed, and expansion of other forms of education such as apprenticeships that develop a wider set of skills |
| **Supply chain** | |
| Inflexibility of supply chain infrastructure and capacity of sawmills | Research to identify how the supply chain might need to be transformed and supporting and incentivizing the processing of a wider range of tree species and wood/timber products, including stimulating new and emerging markets |
| **Data availability** | |
| Difficulty of reconciling economic drivers and other objectives | Decision-makers recognizing the validity of a wider set of sources of evidence (not just metrics) including qualitative data, historic evidence, and creative approaches |
| Lack of biodiversity data for intensive forests, so difficult to understand the wider benefits they provide | Invest in ongoing research and monitoring of ecological status of production forests |
| Lack of evidence on the benefits of land sparing and land sharing approaches | Further research on the benefits and challenges of different forest management models up to a landscape scale to make better decisions and transfer this knowledge into practice |
| Lack of certainty around future risks to production forests | Better empirical evidence and modelling of resilience and a quantification of risk, alongside understanding how the supply chain might need to transform to cope with a more diverse set of domestically produced wood and timber products. Better identification of mitigation options and supporting practitioners to take risks and undertake trials |
| **Public opinion** | |
| Public perception of productive forests | Improve government and industry communication about the role of productive forests and enhanced local community engagement to better understand what people want from their forests and to gain a social licence to operate; potential role for environmental non-government organisations (eNGOs) and others to improve the profile of the importance of productive forests |
| **Landowner/forester behaviour** | |
| Lack of landowner engagement with forest creation and management | Better utilization of existing research on landowner decision-making, and new research to fill gaps, and identifying what governance mechanisms would support innovation and forest transformation |
| **Partnerships/collaboration** | |
| Lack of coordination and collaboration across government, forest sector (and between forest businesses), and academic sector | Creation of feasible partnerships or networks to codesign and deliver research to inform and enable forest system innovation and knowledge exchange. This will require breaking down existing barriers. Long-term funding will also be necessary for the development and monitoring of experimental plots, etc., and improving research capacity such as a doctoral training programme to build future research expertise and capacity. |
| Government cannot fund everything | Identification and enabling the development of novel (private) finance options, including climate funds |
| Forestry in the UK is devolved | Enabling a coordinated UK-wide approach to forest management but recognizing different countries may require different emphases and objectives |
| **Deer and squirrel management** | |
| Establishment and natural colonization are impacted by grey squirrel and deer browsing | Identify and implement effective deer and squirrel control at scale, with defined responsibilities for government and the forest sector |
| **Unintended consequences** | |
| Uncertainty around ecological/ecosystem impacts of forest transformation | Improve empirical evidence and models of the impacts of change on ecosystems to support decisions around trade-offs and mitigation of impacts |

# Discussion

## A theory of change for transforming the UK's productive forest system

In this section, we present the theory of change (Fig. 4), discussing the activities needed across the four areas of input. This is followed by identification of intermediate outcomes that are expected to occur, leading to four specific final outcomes and, ultimately, achieving the intended impact.

As the results of the backcasting exercise suggest, forest systems will need to undergo transformative change if they are to deliver the goods and services that will be demanded of them. Thus, we identify the impact of transformation to be: *productive*

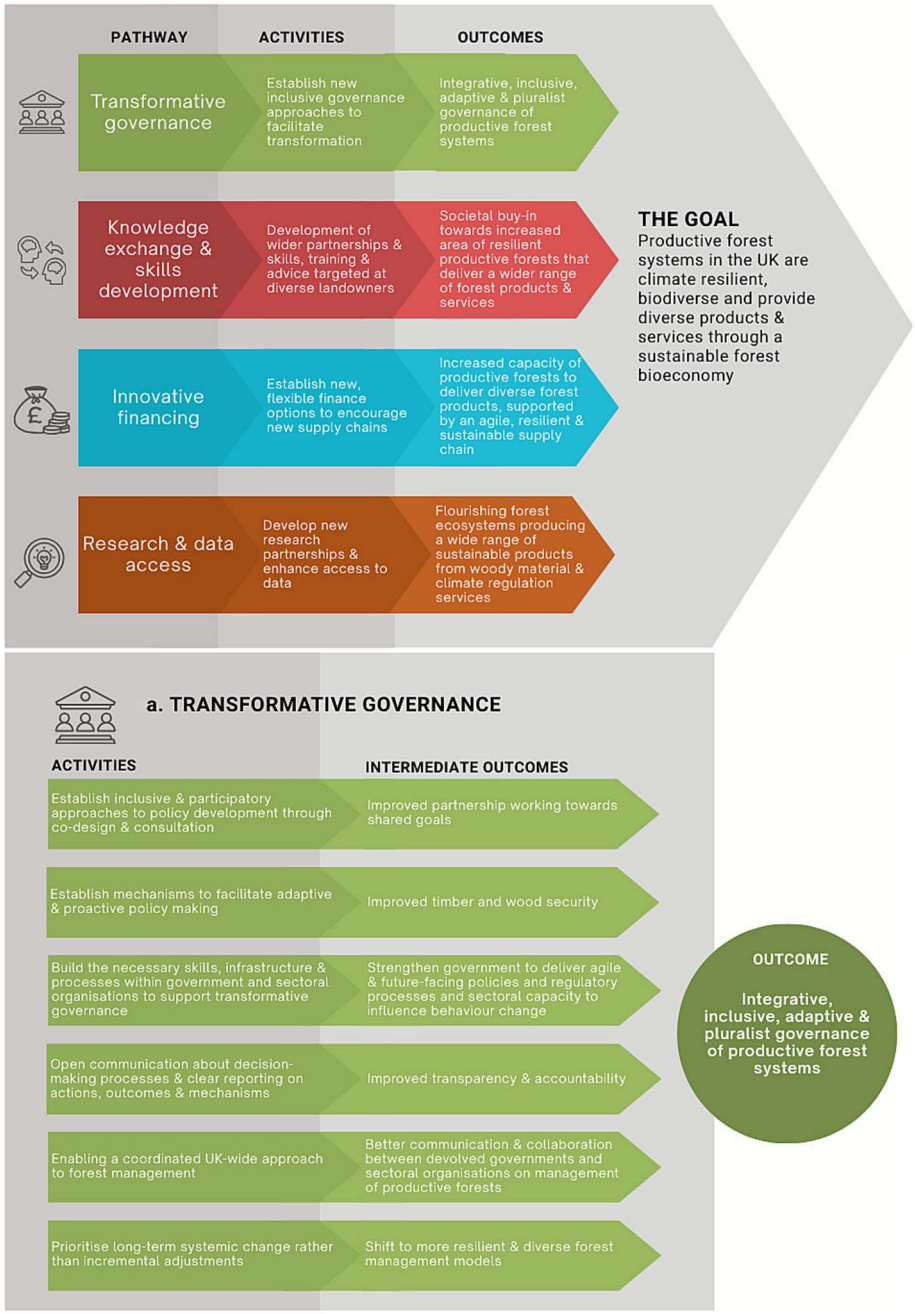


**Figure 4.** Theory of change for transformation of UK's productive forest system, with detail on activities and intermediate outcomes for (a) transformative governance, (b) knowledge exchange and skills development, (c) innovative financing, and (d) research and data access.

*forest systems in the UK are climate resilient, biodiverse, and provide diverse products and services through a sustainable forest bioeconomy* (Fig. 4).

To transform the forest system, we need to catalyse action in the key areas of activity set out in the theory of change. While these activities largely relate to action in the knowledge and innovation system, the outcomes occur across both the forest system and the knowledge system.

## Transformative governance

The outcome of successful transformative governance is integrative, inclusive, adaptive, and pluralist governance of productive forest systems (Visseren-Hamakers et al. 2021). Transformative governance moves away from 'top–down' forms of policy making and management towards more inclusive and participatory approaches to decision-making and policy design (Chaffin et al. 2016, Urquhart et al. 2023), which lead to improved partnership working towards shared goals between government and the forest sector. In the context of the forest system, this means policymakers working collaboratively with forest managers, landowners, and other stakeholders to identify feasible solutions and pathways to realizing the vision for sustainable and resilient future forests. This might involve a wide range of stakeholders being involved in the codesign of new policy, incentives, and other mechanisms to support and facilitate transformation in the forest system (Urquhart et al. 2023, Ambrose-Oji et al. 2024). However, although codesign approaches allow for more inclusive forms of governance, there are challenges for successful implementation,

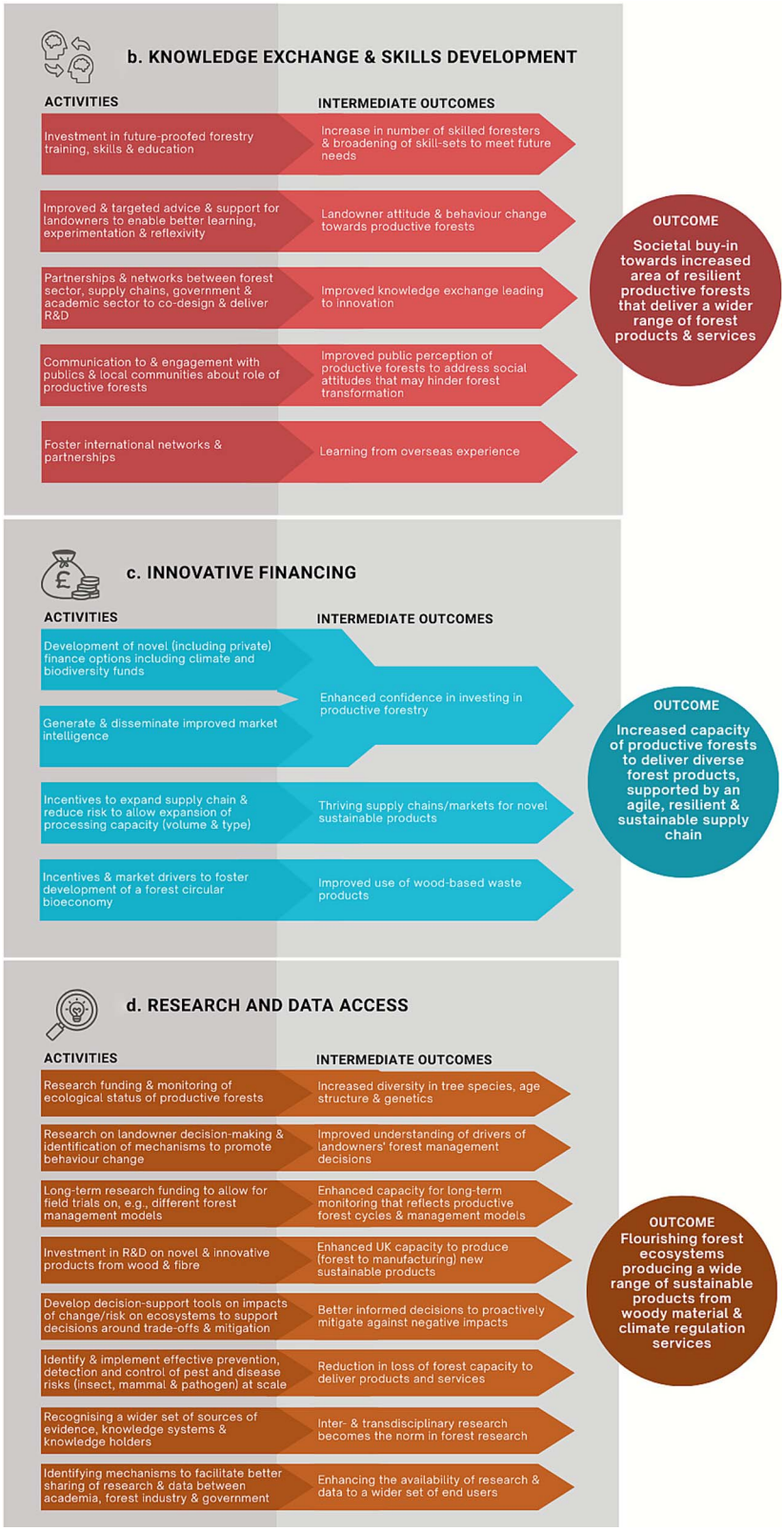


**Figure 4.** (Continued).

such as inequity relating to who is able to engage in the codesign process due to capacity or capability limitations, and resource constraints limiting the capacity of government departments to adopt more time- and resource-intensive forms of stakeholder engagement.

Transformative governance also requires governments to adopt mechanisms that facilitate adaptive and proactive policymaking, anticipating future needs and providing an enabling environment to allow the sector to make transformative change to support enhanced wood security in the UK. This shift requires

the government to build the necessary skills, infrastructure, and processes within government departments to strengthen government capacity to deliver agile and future-facing policies, in what Arnold et al. (2024) call 'policy entrepreneurship'. This involves more open communication about decision-making processes and clear reporting on actions, outcomes, and mechanisms to improve transparency and accountability. It also requires increased collaboration between the devolved administrations in the four countries of the UK, to balance coordination at the UK level, while also reflecting the different productive forest contexts and the capacity of each administration to respond to specific challenges.

A commitment to long-term systemic change rather than incremental adjustments is also needed, reflecting the long time horizon for enacting change in forest systems. Prediction of future objectives and constraints for the management of forest systems cannot be made with sufficient certainty to match the long time-course of the whole forest growth/management cycle (Wynne-Jones et al. 2022). Therefore, to meet these longer-term challenges, there is a need to move away from only prescriptive forest management (based on lessons from past practice) towards a greater component of adaptive forest management. To ensure that this is linked sufficiently with socially acceptable forest governance, forestry regulators and institutions should explicitly provide to forest managers a sufficient 'licence to innovate' (Moffat et al. 2016), provided it is accompanied by a sufficiently explicit requirement to implement the whole adaptive management cycle including monitoring, reflecting, adapting, and sharing their learning (Lawrence 2017). This could be tied in with a broader requirement (such as a condition of grant funding) for forest managers to monitor and report the outcomes of their management. Synthesizing and interpreting this information will impose a burden on the forestry institutions to whom managers report, though this will likely be reduced by artificial intelligence (AI) tools, and it will be very important for the capacity of the forestry sector at a national level to adapt rapidly to the accelerating challenges posed by climate change and associated threats of pests, pathogens, drought, etc. (Nagel et al. 2017).

Beyond adaptive forest management practice within each forest, the scale of anticipated future climate change impacts may challenge the viability of a heavily 'land-sharing' model for UK forests. Instead, in many cases, we may get a better outcome for the combination of wood production, climate change mitigation, and biodiversity conservation objectives at landscape and larger scales through adopting a more 'land-sparing' model, with a narrower focus in the objectives for the design and management of each forest, including the resilience of their delivery of specific ecosystem services (Harris and Betts 2023). With such a model, it is important to ensure that every forest conforms to a minimum baseline of environmental quality and that, as a collective whole, the portfolio of forests within a landscape do meet the full set of objectives required by society. Such collective planning of forest management between different forest owners and other stakeholders will pose a significant challenge for existing forestry culture and governance in the UK but has been advocated for other land use contexts in the UK such as food production and conservation as it potentially offers a more cost-efficient use of government funds and reduces the conservation and food security burden on countries exporting food to the UK Balmford 2021, Collas et al. 2022). However, at what spatial scale along the continuum from a fully land-sharing to a fully land-sparing model should the delivery of different ecosystem services be integrated? Betts et al. (2021) reviewed the case for a three-compartment sparing or 'Triad' zoning that includes: intensive wood production forests; forests managed for biodiversity and regulating ecosystem services; and intermediate multi-purpose forests managed for a combination of these services. The challenge for most of the UK is how to adapt such a model developed in the vast landscapes of north-eastern Canada (Messier et al. 2009) for the comparatively fine-grained patchy structure and much more complex pattern of land ownership/tenure of UK landscapes. To meet this need, there is good potential to use simulation modelling, as pioneered in Wales and Scotland, to explore adaptation of forest management and policy to climate change threats (Ray et al. 2015, Ray et al. 2019), and used recently to assess the impact of increasing wood harvesting levels through alternative forest management strategies on natural capital at the regional scale of Flanders, Belgium, by Verdonck et al. (2025).

## Knowledge exchange and skills development

Knowledge exchange across policy, research, the forest sector, and wider society, together with appropriate skills development, will support societal buy-in towards an increased area of resilient, productive forests that deliver a wide range of forest products and services. To achieve this, a range of activities will be required to support knowledge and skills expansion across forest practitioners, landowners, and wider publics. Firstly, access to forestry training needs to be expanded in the UK—currently, there are only three universities in the UK offering degrees in forestry (Bangor, Cumbria, and Highlands and Islands). Alongside this, forestry education, including universities and other training provision, needs to offer students a broad and future-facing set of skills that are appropriate to meet the forest management needs of future forest systems, including public engagement and communication skills.

Secondly, advice directed at landowners needs to be better targeted at a wider range of landowner/manager types to support engagement, learning, and trial of alternative approaches to forest management that is appropriate for them and facilitates a shift in attitudes and behaviours towards productive forests (O'Brien et al. 2017). This wider engagement will also require partnerships and networks between the forest sector, the government, and the academic sector to identify the need for and codelivery of future research and development, including learning from the experience in other countries. It also requires improved mechanisms for peer-to-peer learning and knowledge exchange between forest managers to allow for innovation sharing while also considering issues around commercial confidentiality and intellectual property in knowledge sharing (Evolving Forests 2025).

Thirdly, improved engagement between policymakers, the forest sector, and wider society is needed to support the engagement of publics and local communities in better understanding what role productive forests can and should play in delivering wood and forest product needs (Sing et al. 2019).

## Innovative financing

The aim of increasing the opportunity for innovative financing is to increase the capacity of forests to deliver diverse forest products and services, supported by an agile, resilient, and sustainable supply chain. For this to be achieved, there needs to be enhanced confidence among existing landowners to invest in productive forestry or for new investors to purchase or lease land to invest in commercial afforestation. In both cases, this could be stimulated by reducing the regulatory burden holding back such schemes and by ensuring that novel finance options, including private finance, provide a good return on investment while at the same time delivering the required environmental, climate,

and social benefits. Alongside this, improved market intelligence would help land managers to be more confident in their decisions about investing in forestry, notwithstanding the huge uncertainty in future markets for a product that will take at least 40 years to mature. However, both of these models for increasing forest cover in the UK are highly controversial, whether it be the threat perceived by many in the farming sector of government pressure (e.g. through new requirements for agri-environment payment schemes) to sacrifice farmland from food production to convert it to woodland (Staddon et al. 2021, Hardaker et al. 2022) or the threat to farming through the purchase of farmland by investors from outside the farming community.

Any novel finance options should be climate smart, with incentives and drivers to foster the development of a circular forest bioeconomy, such as improving the use of wood-based waste products and an expanded supply chain to allow sawmills to process a wider range of wood products (Low et al. 2023). In addition, nonproduct markets, such as those for carbon and biodiversity credits, are seen as an increasingly important source of finance for improved forest management; however, they are both beset by complexity and uncertainty, and current models present a major challenge of reconciliation with forest use for wood production.

### Research and data access

New research, data access, and research partnerships including forest managers are required to achieve flourishing forest systems producing a wide range of sustainable products from woody material and climate change mitigation.

New research is likely to include: (i) improved approaches for monitoring of the ecological status of productive forests to determine the outcomes of a transition to increased diversity in tree species, age structures, and genetics at contrasting spatial scales within productive forest systems; (ii) research on landowner decision-making and identification of mechanisms to promote behaviour change, in particular whether they have the motivation, information, and decision-support tools available to incorporate carbon, biodiversity, and forest resilience objectives into their decisions; (iii) development of novel and innovative products from wood and fibre; and (iv) identification and implementation of effective reduction in the risk of pest and disease impacts (insect, mammal, and pathogen) at scale to minimize reduction in the capacity of forests to deliver products and services (Roberts et al. 2020). Long-duration field trials extending over one or more forest growth cycles are crucial to test, for example, different forest management models. However, ensuring sufficient continuity of long-term funding to maintain and monitor these trials is an ongoing challenge, not just in the UK but globally. Diversifying funding sources beyond the state to include the private sector and NGOs may provide a way forward to improve the resilience of the funding base.

Underpinning these new forms of evidence is a need to recognize a wider set of evidence sources, knowledge systems, and knowledge holders, with inter- and trans-disciplinary approaches becoming normalized in forest research. Further, the identification of mechanisms to facilitate better sharing of research and its resulting evidence between academia, forest industry, individual forest managers, and the government is needed to enhance the availability of research-based evidence to a wider set of end users.

## Conclusion

In 2020, the FAO Director-General called for transformational change in the way we manage our global forests, unlocking their potential to address Sustainable Development Goals such as climate change adaptation and mitigation, biodiversity conservation, and food security (FAO 2020). However, a key knowledge gap is how transformation can be actioned and what transformation is needed across knowledge and innovation systems. This paper addresses this gap by developing a conceptual theory of change for transformation of the productive forest system in the UK across four key priority areas of activity. The theory of change can be used by policymakers, the forest sector, and researchers to identify pathways towards transformation and priority research agendas to support evidence-based decision-making.

The outcomes of this study should, however, be considered in the light of some potential limitations. As with any qualitative study, the results are contingent upon the participants who engaged in the research. While efforts were made to include a wide range of participants across the backcasting exercise, there is the potential that some views were not captured. In addition, in seeking to identify consensual perspectives, our study did not differentiate responses between participants, so we are unable to draw out differences in future visions for different respondent types. This would make a valuable focus for follow-up research. Further, the presented theory of change is a conceptual model based on a desk analysis by the authors. In order to fully operationalize this, the next step would be to validate and test the theory of change to ensure that outcomes are plausible and feasible and identify appropriate timescales for implementation and mechanisms for monitoring, evaluation, and integration of reflexive adaptation over time. This would include defining specific activities, success criteria, identified responsibilities, and likely cost implications. The resulting operational theory of change would provide a strategic pathway to transformation and a framework for evaluating progress towards the goal of productive forest systems in the UK that are climate resilient, biodiverse, and provide diverse products and services through a sustainable forest bioeconomy.

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## Author contributions

Julie Urquhart (Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing—original draft), Alice Goodenough (Conceptualization, Investigation, Methodology, Validation, Writing—review & editing), and John Healey (Validation, Writing—review & editing), Bianca Ambrose-Oji (Validation, Writing—review & editing)

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None declared.

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## Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

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