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The nexus in a changing climate: a critique of competing demands for UK land

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About the Nexus Network think piece series

Funded by the ESRC, the Nexus Network is a collaboration between the University of Sussex, the STEPs Centre, the University of East Anglia, and the Cambridge Institute for Sustainability Leadership. The Nexus Network brings together researchers, policy makers, business leaders and civil society to develop collaborative projects and improve decision making on food, energy, water and the environment. In 2014, the Nexus Network commissioned a series of think pieces with the remit of scoping and defining nexus approaches, and stimulating debate across the linked domains of food, energy, water and the environment.

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Summary

Land is a valuable and finite resource that provides a wide range of goods and services to society. Both the ability of land managers and the capacity of the land to provide goods such as food, bioenergy and clean water become more difficult as the population continues to grow and climate variability increases. This raises questions over how the multiple demands placed on land can be managed both now and into the future. Whilst the importance of land to national economies appears obvious, in recent years numerous policies and planning trajectories, with competing and contradictory implications for land management, have emerged in the UK. Examples include the expansion of housing to sustain a growing population[1], increased production of bioenergy for a low-carbon energy system[2] and the stagnation in arable yields across Western Europe[3].

The aim of this think piece is to explore the interdependencies at the energy/food/water nexus, and to question how these are currently addressed within policy. The paper also considers a framework for more coherently prioritising 'land-use' among competing demands. Here, the lens of land used to consider this topic and its associated policy environment from a UK-centric perspective. The paper explores how current land uses and their related policies affect the UK's resilience in the medium to long term (e.g. from the present to 2050) and asks thought-provoking questions for land-use management, policy and modelling aimed at one or more components of the nexus.

Policy challenges

There are many specialised metrics, models and decision-making tools designed to quantify the capacity of land required for particular outcomes, such as food production. However, as this paper shows, a legacy of disjointed policies has resulted in energy, food and water being dealt with in isolation and often in competition, with policies and tools ill-equipped to provide sustainable outcomes that are considered appropriate by key stakeholders.

Despite recent progress in recognising the challenges of the nexus (see, for instance, the UK National Ecosystem Assessment Follow-on[4]), most land-use policies focus on either food or energy provision, remain compartmentalised by both scale and sector, and seldom acknowledge other elements of the nexus. One example is how the UK 2012 Bioenergy Strategy[5] poorly accounts for the implications of meeting bioenergy targets for food/water/land both within and outside of the UK. Similarly narrow policies include the UK's 2013 Forestry & Woodlands Policy[6] and the Common Agricultural Policy reform[7]. Moreover, some policies fail to acknowledge potential conflicts and trade-offs between objectives even within a single document (for instance, the four goals within the 2003 and 2007 Energy White Papers[8, 9]), particularly in relation to land.

On a temporal level, the absence of an overarching strategy or vision implies that longer-term interactions and interdependencies within this nexus are not considered. Accordingly, trade-offs between generations are typically neglected when designing and implementing policies affecting land use. Similarly, *intra*-generational trade-offs in terms of the distribution of land and resources between industrialised and industrialising countries, as well as between poorer and better-off groups within nations, are rarely acknowledged. These issues of equity and fairness are likely to be aggravated as climate change impacts intensify. In the medium to long term, the insularity and short-sightedness of land-use policy is likely to jeopardise the resilience of the UK to climate change impacts, particularly when set against a backdrop of increasing and competing demand for water, energy and food.

Future directions

This overview of the challenges highlighted by considering land-use in relation to a nexus of water, energy and food raises important questions that should guide further research and policy. Examples of the key questions are: Where are the main vulnerabilities of the UK's land system, given current trends and policies? How can policymakers be encouraged to factor in the various interdependencies of the nexus and who would have the authority to oversee this? What underpins the design and implementation of an overarching longer-term vision for UK land use, taking into account both spatial and temporal interdependencies? What further research is needed to assess the resilience of different blends of nexus components?

To support this agenda, a more integrated and interdisciplinary research programme is much needed to continue exploring the interdependencies of the nexus and the dynamic resilience of the land-use system, given the challenges and policies discussed. Such a programme would help coordinate planning and modelling across different sectors, which is long overdue, and facilitate more strategic and comprehensive policies. 'Policy toolkits' could be developed to include such criteria as affecting the ability of other countries to meet their own needs. Similarly, the UK policies would need to consider implications at regional and local levels. Ultimately, the integration of the nexus at different scales would help unlock the full value of land and ecosystem services.

Introduction

Background

Food, energy and water are inextricably linked, and failure to recognise the repercussions of actions and planning decisions in one sector can lead to substantial, potentially severe, consequences for another. For example the current drive towards bioenergy as part of climate change mitigation strategies has significant implications for the availability of land and water with ramifications for food prices and global trade[10, 11]. Nexus thinking represents a sustained effort to recognise the interconnections between these multiple socio-environmental resources; to understand their interdependencies, synergies and trade-offs; and to draw attention to competing demands and disparate visions.

This think piece focuses on land-use management, as the arena in which some of the quintessential nexus contests are enacted. Land is a precious and finite resource, and of the 13 billion ha available globally, most of that suitable for crop production worldwide is currently in use[12]. Future decisions regarding land use will require policy-makers to balance a range of objectives and priorities. In the UK, recent years have seen the development of numerous policies and planning trajectories with competing implications for land management[13]. For example the expansion of housing and industry to sustain a growing population[1]; increased production of biomass for a low-carbon energy system[5, 14, 15] and for bio-derived plastics[16]; and the intensification of farming systems to support food security and increase self-sufficiency[17, 18]; along with other uses including housing, industrial uses, recreation, renewables, forestry, biodiversity, mining and landfill[19].

Key challenges for the nexus include understanding the spatial and temporal scales and the duration of impacts of different activities; inter-generational trade-offs in line with sustainable development goals; and intra-generational trade-offs (e.g. between industrialised and industrialising countries, as well as between poorer and better-off groups within countries). Recognising these, not only internally for each sector but at the nexus, is a significant and complex challenge which will necessitate joined-up thinking and collaboration. Failure to do so risks undermining the well-being of the UK population and its resilience to climatic change and global population growth, as well as negatively affecting other countries involved in the UK's supply chains.

Globally, climate change is expected to exacerbate food insecurity[20, 21]. While the UK is less vulnerable than nations in lower latitudes[22], the country's food security would eventually suffer as it relies significantly on globalised food supply chains. Furthermore climatic changes are likely to increase the frequency of droughts in the south and southeast of the UK [22]. The country's population is projected to increase from the current 63 million up to 77 million by 2050 [1], with corresponding increases in the demand for food and water. Primary energy demand is predicted to decrease slightly to 2025 before rising again when the effect of current policies on energy efficiency would cease and be unable to offset the economic and population growth [23]. Although there is much uncertainty about longer-term projections of population, climate change and other indicators [24, 25], they are symptomatic of broad trends that should not be disregarded.

Aim, scope and objectives

With these challenges in mind, this think piece sets out an agenda on resilient land use to support the development of more integrated policy- and decision-making. The focus is on the resilience of the system relying on various land uses under competing demands for space and for other 'services' that ecosystems provide (such as clean water, crops and biodiversity). The concepts of 'resilience' and 'ecosystem services' are defined in the sections below.

In terms of scope, this piece provides a synthesis and begins to critique existing policies and approaches affecting land availability. The geographical focus is the UK including implications at regional and local levels, within the context of key European and global trends affected by and affecting UK land use. All significant types of land-use in the UK are considered here, not just agricultural uses. Since a full assessment of all components of the nexus is outside scope, this analysis is limited to their implications for land use and to raising questions around the resilience of the existing system. This think-piece is primarily aimed at policymakers and researchers, but has wide industry and stakeholder relevance, particularly to those engaged in environmental and land management, agricultural production and bioenergy generation.

The paper starts by highlighting the range of land uses and goes on to analyse some of the key policies currently playing a role in influencing UK land use. It then questions how current land uses and their related policies affect the UK's resilience in the medium to long term (e.g. out to 2050) against the backdrop of ongoing and future climatic changes, the drive to deliver deep cuts in greenhouse gas emissions and changing demand for resources. Different temporal and spatial scales are considered, including potential impacts of the UK's current decisions on other countries and future generations. The concluding section sets out a number of thought-provoking questions for future land-use management, policy and modelling aimed at one or more components of the nexus.

Competing land uses in the UK and their interdependencies with water, energy and food

Current state of land use in the UK

The UK has a land area of 24,443,000 ha [26]. Of this, 2.4% has been designated as built-up areas (i.e. buildings and greenhouses) and 4.3% as artificial non-built-up land (i.e. streets and other surfaces covered with concrete, tarmac or gravel, but not buildings) [26]. If distributed equally across the UK population, each person would have access to 0.38 ha, which is lower than the European average. With the land being a fixed resource and the UK population expected to rise by more than 10 million people by 2030 [1], pressures on land use will continue to increase.

Land can be described in terms of its cover and its use. Land cover refers to the bio-physical coverage of land (for example, cropland, grassland, broad-leaved forest or build-up area), while land use is an indicator of the socio-economic use of land (such as agriculture, forestry, recreation or residential use). Various datasets exist to classify land in this way. LUCAS (Land Use and Cover Area frame Survey) provides a harmonised database of the European Union, collating time series data based on in-situ observation and photographic record since 2006.

In terms of cover, grassland is the dominant category in the UK (10.4 Mha, or 42%), of which about a third is located in Scotland. Cropland (4.8 Mha) covers 20% per cent of the land, with the richest cropland area in the east of England. In total 3.6 Mha is designated as woodland (15%), with 40% located in Scotland. With regards to land use composition (

Table 1), the main use in the UK is agriculture, accounting for approximately 65% (15.9 Mha), and a further 8.5% is used for forestry (2.1 Mha). Residential, commercial and community service use accounts for 7% of land use (1.7 Mha), with 2.7% for recreation (0.6 Mha) and 3.8% as nature reserves (0.9 Mha, one of the lowest values in the EU). There are 1.9 Mha of land with no visible socio-economic use (7.9%); of which approximately 58% occurs in Scotland, associated with forest, shrubland and moorland areas.

One fundamental question is whether the current composition of land use can help the UK cope with the ongoing and impending challenges discussed previously, and whether existing policies affecting future land-use change hinder or facilitate the long-term sustainability of land-use. The rest of this paper explores these questions in more detail.

Table 1. Land use in the UK based on LUCAS 2009 Survey [27]

Land use category	Land use (ha)	Proportion (%)
Agriculture (excluding fallow and kitchen gardens)	15,521,800	63.5
Agriculture (fallow and abandoned)	371,000	1.5
Kitchen gardens	9,900	0.0
Forestry	2,083,800	8.5
Hunting and fishing	420,900	1.7
Mining and quarrying	96,400	0.3
Energy production	26,600	0.1
Industry and manufacturing	72,300	0.2
Water and waste water treatment	89,200	0.3
Construction	28,400	0.1
Transport, communication, storage, and protective works	482,400	1.9
Commerce, community services, residential	1,717,800	7.0
Recreation, leisure, sport	661,800	2.7
Nature reserves	929,700	3.8
No visible use	1,931,500	7.9
Total	24,443,500	

Existing policies and tools affecting land availability

The availability of land is influenced by a variety of factors including population size, expansion or contraction of particular economic sectors, agricultural practices and climatic changes. Most of these factors are driven by policy. Appendix A summarises global, European and the UK policies affecting components of the energy/food/water nexus in different sectors of the economy. In addition to the legislation, there are various initiatives established at different levels of governance. For example, the Scottish Government has funded the development of the Farming for a Better Climate website [28], which offers practical measures that farmers can use to reduce greenhouse gases, while the Welsh Government established the Land Use Climate Change Group [29] to consider how agriculture and rural land use can reduce climate change and help people adapt to it. Such policies and initiatives tend to focus on one or two elements of the energy/food/water nexus, at the exclusion of others.

Land supplies many services and products, from food and timber to clean water and biodiversity to space for power plants and pipelines. These are captured within the concept of 'ecosystem services' developed and advanced, among others, by Daily [30], Costanza [31] and a range of Millennium Ecosystem Assessment reports [32]. The UK National Ecosystem Assessment [4] defines this concept as "the benefits provided by ecosystems that contribute to making human life both possible and worth living". The processes of valuing and allocating land are directly related to the management of ecosystem services. The 'ecosystem service framework' in Figure 1 shows possible interactions between governance and institutions and the management of elements of the nexus. Land and water are key components of this conceptual framework that also includes the role of governance, as well as the functions of other forms of capital. Although there is a strong emphasis on the impacts of climate change, the framework does not explicitly mention energy.

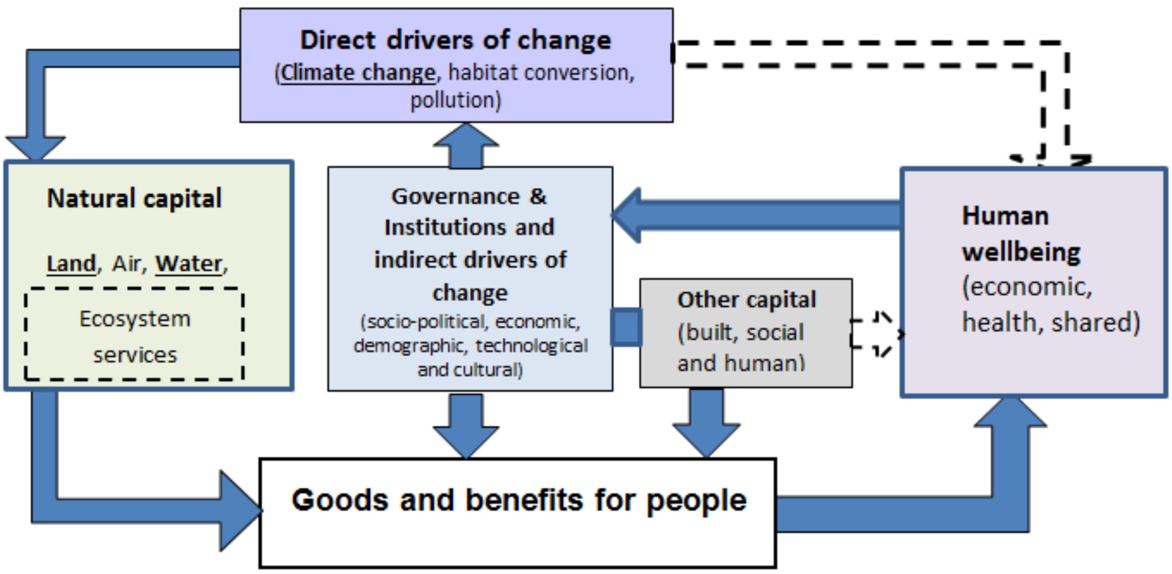

Figure 1. The 'ecosystem service framework' from the UK National Ecosystem Assessment showing possible interactions between governance and institutions and the management elements of the nexus [4] (emphasis on land, water and climate change, within the figure, added)

The energy sector

This paper argues that the 'ecosystem services framework' needs to incorporate energy alongside other ecosystem services. The UK Natural Capital Committee [33] define 'natural capital' as "the elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions". They indicate that it includes sub-soil assets such as fossil fuels, as well as the processes which give rise to wind and precipitation. Like other forms of natural capital, these energy sources are used to derive benefits, for example, heating and transportation. A range of energy sources also feed into the production of electricity that powers not only heating and transport but also lighting, entertainment and communications. Hence it is appropriate to include energy within the Natural Capital box in Figure 1, distinguishing between renewable and non-renewable energy.

Exclusion of nexus elements is pervasive in current analyses and policies. For example, the UK 2012 Bioenergy Strategy poorly accounts for the implications of meeting bioenergy targets for food/water/land both within and outside the UK. A recent life cycle assessment of the UK importing biomass from North America focuses on greenhouse gas emissions [34] but ignores other impacts. At the EU level, impact assessments of energy policies are common. For instance, for the EU's Renewable Energy Directive, Fonseca et al. [35] provide a comprehensive overview of the medium-term impact of biofuels on agricultural markets and on land use both in the EU and third countries. Following the EU's example, the UK Government may want to consider more such studies in future and to cover a wider range of impacts including water, food and land. However the question remains whether the policies and strategies under consideration will be modified if assessment studies raise concerns about the impacts.

Some overarching energy policies pay even less attention to nexus complexity than sector-specific legislation does, perhaps due to their general nature being at the expense of depth. For instance, the UK Energy Act does not refer to either food or land-use [36], while it only mentions water in a narrow legal context. By contrast, the latest Carbon Plan provides a lengthy analytical annex on "sustainability and wider environmental impacts" [37]. It highlights the UK Government's commitment "to champion a more integrated approach to global food security by governments and international institutions that makes the links with climate change, poverty, biodiversity, energy, water and other policies" [37]. The Carbon Plan refers to the importance of valuing ecosystem services and of the UK National Ecosystem Assessment (see Figure 1). This approach is an important step towards a more integrated framework for energy policy.

The agriculture and forestry sectors

Policies aimed at agriculture (taken here as a proxy for the food element of the nexus) and forestry often overlook many aspects of the nexus. Furthermore, it is rare for agriculture and forestry to be considered within the same policy framework. The EU Common Agricultural Policy (CAP) is concerned with maintaining land in good agricultural and environmental condition, whereas EU forestry policy has tended to develop independently of this. With the "increasing links between international food, feed, fibre and fuel markets", the EU has recognised that its new forestry policy framework needs to "allow synergies with other sectors" [38]. This is particularly relevant given that bioenergy and other bio-derived materials (e.g. for construction, chemical production and pharmaceuticals) can be sourced from both agriculture and forestry, while water quality and flood prevention often require a landscape approach that combines trees and agriculture. In this context the development of a land-use strategy by the Scottish Government [39] is commendable in bringing together agriculture, forestry, energy and water. Research in integrative disciplines such as agroforestry [40, 41], landscape planning [42] and life cycle assessment [43] can also provide tools and bio-economic models to inform some of the synergies and trade-offs.

In another example, while the UK's 2013 Forestry & Woodlands Policy Statement [6] acknowledges that woodlands provide clean water and energy (fuel wood), no note is taken of how the nexus components would be affected by implementing the policy's objectives. The EU CAP is similarly narrow; it marginalises ecosystem services, other than agricultural products. Some studies suggest the ongoing 'greening' the CAP might improve its impacts on ecosystem services and make it "an exemplar for redirecting agricultural policies elsewhere in the world toward sustainability" [44]. In particular, the CAP now requires 5% of arable land to be taken from agricultural production and set aside as ecological focus areas. However, many analyses suggest that the complexity of the CAP precludes straightforward answers and that its impacts differ widely at different scales [45-47]. This paper concurs that these interdependencies need to be assessed at a number of levels and scales, if long-term coherence of the policies is to be achieved.

The water sector

Water-related policies recognise that the water sector is inextricably linked with energy generation and food production, among other sectors of the economy [48]. Agriculture is evidently better integrated with the management of national water issues than the energy sector is. For instance, the Rural Development Programme for England (RDPE) [49] organises 'Efficient Water Management' events, and the Farming and Forestry Improvement Scheme [50] provides funding for and audits of resource efficiency, including water. Despite these efforts, the policies providing genuinely integrated management of water, energy, food and land are non-existent. The UK Water Act 2014 makes no mention of either energy/electricity or land use. While 'Water for Life', a White Paper on water resource management, acknowledges that the energy industry is a significant consumer of water [48], it gives no figures to illustrate the scale of the interaction. Since its publication, such estimates have been produced and/or updated, in relation to both established and new technologies. The Environment Agency [51] confirms that the electricity sector is currently the largest water abstractor holding more than 50% of abstraction licenses, with 95% of those used by hydroelectricity power plants and the rest by thermal power plants. However, most water use in this sector is non-consumptive, i.e., water is returned into the catchment after use, usually in the same quantity and quality as before use. By contrast, in agriculture, water abstractions for supplemental irrigation are almost entirely consumptive. Among forthcoming technologies, carbon capture and storage is likely to nearly double the use of water by power stations [37]. While many renewable energy options require water, mitigation action can save it by reducing demand for cooling in thermal power stations [52]. Such analyses of the nexus interactions may need to be incorporated into existing policies and assessments thereof.

Issues arising from policies and visions competing for the use of land and water policy scope

Despite the obvious interdependencies within and outside the nexus, there is a legacy of compartmentalising issues within isolated government departments and agencies. In terms of scope, both policies and modelling studies often fail to consider interconnections, synergies and trade-offs between the components of the nexus. Some policies do not acknowledge potential conflicts and trade-offs between objectives even within a single document, let alone considering implications of policies in other areas. A prime example is in the four goals within the 2003 and 2007 Energy White Papers [8, 9] (emission reductions, energy security, economic growth and reduction in fuel poverty) where the complexity of the issues is not addressed. Where such interdependencies are recognised (as evident in the recent CAP reform), the approach is piecemeal and contradictory. For instance, while CAP now requires 5% of agricultural land to be allocated to ecological stewardship, it also encourages a market-based approach by removing constraints on production [7]. In other words, if an agricultural product is in demand, farmers are allowed to produce as much as they can sell, possibly at the expense of other goods and services. This clause risks further side-lining the ecosystem services such as clean water with low or zero market value

Globally, policies on water and energy are disjointed in terms of their governance [53] and, as the analysis here shows, the same holds for the management of other aspects of the nexus. A similar disconnect exists not only *between* but also *within* sectors. For instance, within the urban water sector such services as clean water supply, wastewater treatment and floodwater drainage are typically delivered by separate entities and not coordinated, as well as being isolated from other urban planning processes [54]. There is also a complex issue of agricultural policies being separate from groundwater management where even existing 'best practices' have thus far failed to achieve groundwater sustainability [55].

Current UK policies give an impression that the elements of the nexus are isolated, for example, that the boundaries between land and water are distinct. However such boundaries do not exist in reality since land underlies water (lakes and rivers) water underlies land (aquifers and water tables) and there are intermediate habitats (wetlands, intertidal stretches and temporary water bodies) where both overlap. The manner in which land is managed determines not only water flows, energy use, productivity, environmental regulation and cultural benefits, but also affects other ecosystem services at a range of geographical scales.

Spatial scale

Both land models and tools often cover national or regional scales and are deficient in the granularity to provide appropriate guidance for management at a local (catchment) level, failing to both reflect local capacity (including finance, politics, experience / precedence, social capital, culture) and contribute to specific local goals and visions (e.g. poverty alleviation, employment, competitiveness, energy / food security, water scarcity/flood risk). Bateman et al. [47] argue that spatially disaggregated modelling demonstrates wide variations between results for different UK regions in terms of how the valuation of ecosystem services enhances the value of land. This suggests nationwide land-use policies may be less effective than those tailored to particular regions. Locally targeted planning might yield even more powerful insights for conventional land-use models, although it would undoubtedly increase the complexity of how national decision-making feeds into local planning.

The impacts of particular UK policies on UK land are regularly mentioned, although not necessarily incorporated, in impact assessments of policies in non-agricultural sectors. Some government documents are starting to acknowledge that the UK's policies are not only affecting land use within the country but also globally. For example, the Carbon Plan [37] warns that, in one of its scenarios, the UK's demand for bioenergy would affect about 4.5 million ha both in the UK and abroad leading to the loss of habitat and other ecosystem services. In addition to the potential land-use impacts, there is a concern that the UK 2012 Bioenergy Strategy might lock the country into imports dependence that is currently avoidable [56]. Yet, the UK 2012 Bioenergy Strategy itself takes little account of such impacts.

Negative impacts of the UK policies on other countries (including an issue of land grab overseas, usually leading to inadvertent 'water grab') raise concerns about international equity. *Intra*-generational trade-offs in terms of the distribution of land and resources between industrialised and industrialising countries, as well as between poorer and better-off groups within nations, are rarely acknowledged. These issues of fairness are likely to be aggravated as climate change intensifies, ultimately affecting *inter*-generational equity in irreversible ways.

Temporal scale

At a temporal level, the absence of an overarching land-use vision implies that longer-term interactions and interdependencies within the nexus are not considered. Accordingly, trade-offs between generations are typically neglected when designing and implementing policies affecting land use. In addition, current agricultural policies contain no strategy to be integrated with nutrition guidelines and, in turn, nutrition guidelines do not account for the impacts of recommended diets on the nexus [57]. Food is a necessity, but diets are typically shaped by choice, that in wealthier countries is extensive and apparently unlimited. A combined assessment of environmental and health impacts of food policies would contribute to the debate about 'needs vs. wants'. Such an approach to policy-making would highlight issues of equity and distribution both within and between generations.

It is also important to emphasise that the elements of the energy/food/water nexus can have very different time horizons. This is illustrated by the dissimilarity in both short-term projections and strategic (i.e. longer-term) planning horizons in the water and energy industries. The timescale of water-related short-term demand forecasts is weeks to months, with the energy industry relying on forecasting minutes to hours ahead [53]. For the longer term, the UK's water industry produces 25-year forecasts every 5 years [58], whereas the National Grid's future energy scenarios look further ahead out to 2030 and 2050 [59].

While both operational and strategic timelines are important for infrastructure investment, this paper emphasises longer-term considerations. At the same time, a short-term horizon is essential for avoiding policy lock-in. Large infrastructures tend to last for decades and to co-evolve, "intimately inter-linked" [60], with institutions. Therefore current investment decisions are path-dependent. If such decisions cater to either short-term interests or insular long-term objectives without considering implications for other elements of the nexus, there is a danger of locking out better (lower-carbon, more water-efficient, less polluting) technologies and institutions. For example, while the production of shale gas in the UK may be beneficial for the country's energy security, investment in this fossil fuel is incompatible with the Government's decarbonisation agenda [61].

The importance of both long-term priorities and short-term action is evident when it comes to climate change issues. Temperature increases are approximately linearly correlated with cumulative emissions [25]. Carbon dioxide stays in the atmosphere for hundreds of years; therefore, as this greenhouse gas accumulates, it will keep changing the climate for many decades to come. For this reason strong mitigation action in the short term is essential if the world is to avoid longer-term climatic changes. In particular the long-term pledges of major emitting countries and regions (such as the European Union, the USA and Japan) matter less for the future climate than their immediate actions [62, 63]. If emission reductions continue to be postponed, the infrastructural, institutional and policy lock-in will preclude decarbonising swiftly enough to avoid dangerous climate change. This would severely challenge the UK's and global resilience affecting all nexus components.

Resilience of land uses from socio-economic and environmental perspectives

Resilience is becoming a pervasive term in both policy and academia, yet its meaning is ambiguous and definition contested [64]. In 1973, Holling [65] defined resilience as a "measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables". Hence resilience refers to an ecosystems ability to tolerate disturbance without significant change to its ecological stocks, processes or functions [66, 67]. In contrast Pimm [68, 69] refers to resilience as an indicator of the time taken for a system to respond to shock and return to its pre-disturbance state [70].

These definitions refer to ecological or engineering resilience, while the social sciences have further contributed to the conceptualisation of resilience. Adger [71] introduces a concept of social resilience as "the ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change". This definition highlights the functional nature of environmental systems as a partial precursor for human society. More recently still, studies have recognised and incorporated the entanglement of social and environmental systems [66, 72-74]. These latter perspectives view resilience as part of ensuring the security of socio-environmental systems in the context of acute shock, as well as enabling adaptive capacity to respond to gradually emerging socio-environment changes. The later extensions not only move beyond a traditional dichotomy between society and nature [64], but also provide a more dynamic account of socio-environmental systems, recognising the risk that emerges when a system lacks the capacity to develop in response to emerging challenges. This offers an essential dimension to consider, particularly with regards to the energy/food/water nexus challenges where climate change, population growth, shifting geo-political situations and changing patterns of everyday consumption pose complex socio-environmental challenges in which nexus decisions are highly significant.

In addition to this ambiguity in the definition of resilience there is a risk that the term is translated as a means of protecting the status quo, or the capacity to support a rapid return of a system to its pre-disturbance state. In both instances resilience risks being deployed without critical reflection on the sustainability of existing or aspired conditions. To this end Standish et al.'s [70] distinguish between "unhelpful resilience" that maintains an ecosystem in a degraded state, and "helpful resilience" that maintains the functions of a system above a critical threshold, may be a useful advancement on the concept.

For the nexus, defining resilience is made even more challenging by the differentiated scale and scope of the resources it encapsulates. For example, arguably the main challenge in terms of resilience for water resources is to ensure sufficient resources remain available to retain operational and adaptive capacity of ecosystems, and supply for the demands of residential and various other competing uses (including food, industry and energy). Consequently resilience for water may be framed in terms of water security, made increasingly problematic by rising demands, the impacts of climate change on water resources, and the affordability agenda, which requires water companies to meet demands without prohibitive costs to consumers. In contrast, resilience for the energy sector may be seen to be both about security, to ensure supply, and as part of climate change mitigation and adaptation. The drive to decarbonise and adapt energy networks in the UK is a significant policy imperative that contributes to the long-term resilience (to climate change) of not only the energy industry, but also the economy and with it much of society. However achieving resilience for the energy system from this mitigation/adaptation perspective is problematic for the water industry as hydro-electric, thermal power and other options considerably increase demand for water resources. The pertinence of this is evident in the debate on shale gas in the UK where 'resilience' in the form of energy security is used as a justification for shale gas exploration and extraction, yet the long-term sustainability for water resources is uncertain, both in terms of water demand and potential consequences for local hydrological conditions and water quality [75]. Similar water-related concerns are applicable to tidal energy [76]. Alternative renewable options such as bioenergy not only have implications for water management, but are also significant for land use and the availability of land and water for food production [10, 11, 77].

Discussion

Present and short-term policy implications

Existing tools and metrics do not provide appropriate guidance for the availability of land in light of nexus challenges. This can in part be explained by the quality and availability of data, the accuracy of projections, and limitations of policy advice from models and other decision-making tools. Another major reason is insufficient coordination between and within modelling teams, government departments and the industry. While models, tools and policies in each of the nexus-related sectors have achieved high sophistication, they fall short of an integrated perspective on land use. Such integration would add further complexity and introduce new methodological and data challenges. Two approaches are being developed to tackle this challenge. Firstly, pairwise integration of the nexus components is gaining momentum, with some modelling teams starting to address, for example, energy-water interactions [78, 79]. This approach is not without difficulties. In particular, water models are much more spatially 'aware' of underlying geography but have a coarser timescale than energy models [53]. Secondly, a focal lens of land can help integrate all components of the nexus. Burgess et al. [80] develop a framework to map demand for energy, food and wood, following a balance sheet approach (note that they do not consider water). This framework can be applied at a variety of scales, from national to local, and explores trade-offs between different ecosystem services.

Similar to modelling teams, the private sector has thus far been highly fragmented and shaped predominantly by disjointed policies (e.g. CAP in the agricultural sector and abstraction licensing strategies in the water sector). Industries retain much of the control over their own area, be it energy, food, water or land. Their focus is typically short-term, and coordinated management of the nexus elements is all but non-existent. For example, potential conflicts between the water and power sectors are prompted at least in part by policy. Water companies measure leakage at night when water use is low and, hence, there is virtually no water flowing through the pipes and it is quiet enough to hear leakage; however smart meters are supposed to switch on certain appliances, such as washing machines, in the night-time to reduce peak demand for electricity during the day. If smart meters are rolled out on a large scale, as envisaged by energy policies, current ways of identifying leakage will become inadequate.

On a positive note, many in the industry and in Government are starting to appreciate the importance of coordination. An industry group related to agriculture has recently produced an integrated vision for the UK's land use: "By 2030, UK agricultural land will be optimised to support the multiple needs of a 70 million population and deliver an improved and sustainable natural environment." [81]. Despite the absence of a national land-use strategy, some progress has been achieved by both the UK Government and devolved administrations. The Government Office for Science published Foresight Land Use Futures [13] in 2010 followed by a range of reports, including Making Space for Nature [82], The UK National Ecosystem Assessment Follow-on [4], and The State of Natural Capital [33]. The Welsh Government produced The White Paper on the sustainable management of Wales' natural resources [83] in 2013 leading to a consultation on an Environment Bill. Common to these documents is an attempt to attribute value to ecosystem services. Yet this progress in the Government's thinking regarding the multifunctional use of land is not sufficient to address the on-going environmental and demographic changes, as the rate of these changes is currently much faster than the pace of policy-making. Accordingly, the inadequacy of current policies and ensuing industry practices is likely to have negative repercussions in the longer term.

Medium to long-term policy implications

One of the key questions for land-use planning is how the physical and socio-economic implications of a significantly changed climate may play out for the energy/food/water nexus and their relationships with land. Alongside effects from the changing climate, inadequate policies are likely to become another major threat to the UK's ecosystem services in the longer term. One of the issues is that existing initiatives tend to make optimistic macroeconomic assumptions about future land availability, resulting from assumed annual increases in the mean yield of arable crop that are not occurring [84]. Based on scenarios of how current policies might play out, Montague-Fuller [81] estimates that, by 2030, additional demand for land would exceed supply by up to 7 million ha, which is more than a third of the UK's agricultural land.

In addition to the 'yield gap' and shortage of land, other potential vulnerabilities that might result from the current policy 'lock-in' are analysed by the Foresight Land Use Futures project [13]. It identifies nine areas that are expected to put extra pressure on the land-use system in the longer term, including agriculture, forestry, conservation, water resource management, energy, flooding, housing, transport and recreation. Developments in each of the areas are accompanied by countless trade-offs, with highly uncertain future consequences. For example, the report predicts increasing population density and smaller houses, which is contrary to people's aspirations and might cause social tensions. At the same time, this trend would arguably facilitate energy savings and lower emissions from buildings. However when transport and commuting are taken into account, the evidence on energy savings becomes contradictory. With resource constraints on water, food and land added and impacts partly determined by location, the emerging picture is highly complex and dynamic.

The dynamism and, hence, potential instability of the system is likely to increase, given on-going climatic changes and, possibly, rapid mitigation and/or rapid adaptation measures (particularly response-mode adaptation, which tends to be fast-paced). While coupled socio-economic and natural systems are by definition dynamic, current policies risk further destabilising them in the longer term and jeopardising the UK's resilience to the effects of climate change and resource constraints. It is worth noting that food, water, energy and other types of 'security' cannot be achieved fully. Consequently resilience requires a constant process of delicate balancing of different parts of the system. This on-going challenge calls for an integrated, long-term perspective on land-use and ecosystem services.

As discussed throughout this paper, a major systemic challenge of an integrated land-use approach is that government departments struggle to manage a nexus as they focus on the components and not the interactions. Considering the system lock-in and lengthy policy-making processes, it is essential to develop alternative ways of providing dynamic, flexible, practical decision support for policy-makers, both for the near-term and further into the future. First, a wide range of ecosystem services need to be valued and integrated into a land-use strategy, including the introduction of non-monetary, physical-unit constraints on the use of particular services. Ecosystem services and their societal benefits are often implicit within the existing tools and metrics. For instance, energy is largely absent from the ecosystem service discourse (see Figure 1), whereas it increasingly drives more land change. Water is also frequently excluded from assessments [47, 80]. Yet Bateman et al. [47] find that an inclusive assessment of several ecosystem services, in addition to agricultural products, increases the value of land. There is a need for a valuation system that looks at and beyond the three components of the nexus. Such valuation could be built around a combination of life-cycle assessment and multi-criteria analysis, although it must be recognised that individual people and groups will each have their own way of valuing that may or may not be stable. Stakeholder engagement would help capture these diverse valuations and negotiate more inclusive policies. Involving stakeholders, for example, through workshops, would not only give invaluable insights that current models may be missing, but also bring different interests together around the same table for the first time.

Conclusions: where to from here?

The breadth of the issues discussed is such that only a brief, but nevertheless well-directed, analysis within this paper is possible. A focus on land allows for the interdependencies between the elements of the nexus to be identified and for some key relevant policies to be critiqued. A tradition of disjointed management often leaves energy, food and water in competition, with policies and tools ill-equipped to provide appropriate and sustainable solutions. There are many specialised metrics, models and decision-making tools designed to quantify the capacity of land required for particular outcomes. However such tools tend to have serious limitations, such as relying mostly on macro-economic factors, shrinking the nexus, and excluding qualitative information. A further challenge arises from stakeholders not engaging around nexus issues, but firmly remaining within their own sectors. The value of qualitative and stakeholder aspects for land-use policy-making tends to be underestimated.

Despite recent progress in recognising the challenges of the nexus, most land-use policies focus on either food or energy provision, remain compartmentalised by both scale and sector, and seldom acknowledge other elements of the nexus. The inadequacy of existing policy approaches is particularly stark when faced with both immediate and long-term challenges of climatic and demographic changes. In the medium to long term, the insularity and short-sightedness of land-use policy is likely to jeopardise the resilience of the UK to climate change impacts, particularly when set against a backdrop of increasing and competing demand for water, energy and food. Moreover, decisions taken within the UK could degrade the resilience of other parts of the world to their own challenges related to energy, food and water.

This overview of the challenges highlighted by considering land in relation to a nexus of water, energy and food raise important questions that should guide further research and policy:

- What are the additional policy challenges for land use posed by climate change, given the already complex policy environment?
- What are the socio-economic and environmental trade-offs between meeting bioenergy targets, increasing food production and complying with environmental regulations or aspirations?
- Where are the main vulnerabilities of the UK's land system, given current trends and policies?
- Does the current and anticipated future use of land match the intended outcomes of the policies?
- What further research is needed to assess the resilience of different blends of nexus components?
- How can academics assist policymakers through the provision of dynamic, flexible and practical decision support tools both in the near and longer term?
- How can policymakers be encouraged to factor in the various interdependencies of the nexus and who would have the authority/remit to oversee this?
- What underpins the design and implementation of an overarching longer-term vision for UK land use, taking into account both spatial and temporal interdependencies?

To support this agenda, a more integrated and interdisciplinary research programme is much needed to continue exploring the interdependencies of the nexus and the dynamic resilience of the land-use system, given the challenges and policies discussed. Such a programme would help coordinate planning and modelling across different sectors, which is long overdue, and facilitate more strategic and comprehensive policies. 'Policy toolkits' could be developed to include such criteria as affecting the ability of other countries to meet their own needs. Similarly, UK policies would need to consider implications at regional and local levels. Ultimately, the integration of the nexus at different scales would help unlock the full value of land and ecosystem services.

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Appendix A. Global, European and the UK policies affecting components of the energy/food/water nexus

Sector	Global	European	UK	National
Agriculture & Fisheries		CAP CFP Protected Food Names Protected Wine Names Animal By-Products Regulation	UK Bovine Tuberculosis Eradication Programme Farming Regulation Task Force Report	CAP Reform (E) CAP Reform (S) CAP Reform (W) CAP Reform (NI) Bovine TB Strategy (E)
Energy	Kyoto protocol UN Framework Convention on Climate Change Copenhagen Accord	Renewable Energy Directive IEA/EU Oil Stock Holding Regulation Energy Statistics Regulation Energy Efficiency Directive Fuel Quality Directive TEN-E: Regulation (EU) No 347/2013 on trans-European energy networks	1965 Nuclear Installations Act 1989 Electricity Act 1993 Radioactive Substances Act 1995 Gas Act 2003 Energy White Paper 2007 Energy White Paper 2008 Climate Change Act 2008 Planning Act 2011 National Policy Statements for Energy Infrastructure 2012 DECC Energy Security	2010 Environmental Permitting Regulations (EW)

			Strategy 2013 Bioenergy Strategy 2013 Carbon Plan 2013 Energy Act	
Water	1971 Ramsar Convention	Water Framework Directive	1975 Salmon and Freshwater Fisheries 1991 Water Industry Act 1991 Water Resources Act 2010 Flood and Water Management Act 2011 Water for Life - White Paper 2014 Water Act	
Industry		2009 Eco-Design Directive	Statistics of Trade Act	Waste Prevention programme (E)
Residential			2014 Green Deal 2014 Smart Meters	
Conservation	1992 UN Conference on Environment and Development (Rio) 2012 UN Conference on Sustainable Development (Rio+20)	1982 Convention on the Conservation of European Wildlife and Natural Habitats (Bern) 1992 Habitats Directive, 2009 Birds Directive	1981 Wildlife and Countryside Act 2006 Natural Environment and Rural Communities Act 2009 Control of Trade in Endangered Species	Marine Plans 2006 Commons Act (EW) 2011 Biodiversity 2020 (E)

			(Amendment) 2010 Conservation of Habitats and Species Regulations 2011 Natural Environment White Paper 2012 National Planning Policy Framework	
Forestry			2013 Forestry & Woodlands Policy 2013 Chalara Management Plan	
Health	UN Convention on Long-range Transboundary Air Pollution		1993 Clean Air Act	
Recreation			1857 Inclosure Act 1876 Commons Act 2000 Countryside and Rights of Way Act 2009 Marine and Coastal Access Act	
Other			2008 National Infrastructure Planning Act	

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