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Developing scenarios and visualisations to illustrate potential policy and climatic influences on future agricultural landscapes

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Abstract

The future evolution of our agricultural landscapes and countryside is the subject of considerable debate and policy discussion, alongside which is an increasing emphasis on the inclusion of public consultation and participation within planning and decision making systems. However, communicating different proposed policy options in a manner that facilitates informed decisions from stakeholders can be far from straightforward. This is particularly true with more abstract and uncertain issues such as potential impacts of climate change.

Scenarios depicting the possible outcomes of policy options provide a useful tool to evaluate the potential consequences of choices. This paper documents an approach to constructing scenarios that can incorporate potential climate change impacts, and reflect the uncertainty in climate change projections due to different environmental policies. It describes the construction of scenarios using the Humberhead Levels in the UK as a case study and portrays the scenarios using two forms of visualisation—digital photo-montage and a real-time landscape model. The method is equally applicable to other study areas across Europe where suitable data are available. Preliminary reactions from an audience to scenario images are discussed, as well as the technical and practical challenges of using visualisation techniques to support decision making.

Keywords: Scenarios; Landscape visualisation; Public consultation; Climate change; Agriculture

1. Introduction

The most severe projected impacts of greenhouse gas induced global warming are reserved for the centuries beyond our life-span, but within decades the changing climate is likely to have imposed modifications to socio-economic activities and our local environments and landscapes. Acceptance of climate change as a real issue is becoming more widespread, but public awareness of the need to make changes in the way we currently live to cope with the most extreme negative impacts that will affect our direct descendants, and to re-orientate policy to facilitate this, is lagging behind (Sheppard, 2004; Nicholson-Cole, 2005; Dockerty et al., 2005).

The major difficulty in initiating mitigating actions is a mis-match in time-scales. Policy life-span is short, generally 5–10 years; the realisation of current policy influences will materialise in changes in our local environments in one or two decades. With the exception of catastrophic impacts of possibly more frequent severe weather events (e.g. flash floods or forest fires), impacts of climate change will materialise more gradually so that it may be difficult to appreciate the influence that climate change is having amongst the myriad of factors acting upon our land, unless these influences are highlighted and appropriately communicated. Without proper communication it may be difficult to gain public support for implementing policy changes to mitigate against the worst effects of climate change, even though in later decades the consequences of present-day non-action will become more severe.

Sheppard (2004, p. 3) hypothesises that certain kinds of visual communication (i.e. landscape visualisations) which

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attempt to illustrate potential futures may substantially improve public awareness on the complexities and implications of climate change and may help motivate behavioural change at individual to societal levels. Nicholson-Cole (2005) also discusses the rationale for using visualisations in this way, highlighting the benefits and pitfalls. So serious is the climate change issue that Sheppard (2004) can see occasion for the use of dramatic visualisations to deliberately persuade people of the need to take mitigating action (whilst recognising that such presentations raise ethical concerns when undertaken by scientists whose fundamental role is a neutral evaluation of the available information).

However, there is a danger that the over-amplification of negative effects may have the opposite effect and that such visualisations could dis-engage the interest of the intended audience if they are seen to lack credibility. Such an example is given by Lowe et al. (2005) who surveyed audiences viewing the climate change disaster film ‘The Day After Tomorrow’ and found that the exaggerated representation reduced belief in the likelihood of extreme events as a result of climate change. Defensibility in visualising climate change impacts is therefore a key issue (Sheppard, 2004). In our view it is consequently important to develop a methodological approach where such visualisations are underpinned by the best scientific understanding available and are presented in a non-judgemental manner to facilitate informed decision making.

The aim of our research has been to tackle this issue by developing and demonstrating a methodology that can be applied across different time-scales and regions where the relevant data exist. Although a number of recent studies have visualised policy proposals over relatively short time-scales (e.g. Dolman et al., 2001; Tress and Tress, 2003; Hulse et al., 2004; Meitner et al., in press), producing visualisations of future landscapes incorporating climate change influences that involve longer time-scales is currently a new and evolving area (Sheppard, 2004). Dockerty et al. (2005) discuss a possible approach in the context of a rural landscape in eastern England, focussing on the incorporation of landscape-scale scenarios in a GIS and the technical aspects of creating computer-generated 3D visualisations from this information. This paper documents the rationale behind the development of such scenarios in more detail, illustrates the transferability of the method by presenting visualisations for a different region, and discusses some initial public responses to the images.

2. Approach: development of scenarios

Scenarios are a plausible sequence of possible events used to inform future trends, potential decisions or consequences (Carter et al., 2001; UKCIP, 2001; Future Foundation, 2004; Shearer, 2005). As such they need to identify and incorporate the key drivers of future change. For example, studies to assess the impacts of climate change would be seriously limited if they simply assumed future climates would take place in a world with a society and economy similar to today (UKCIP, 2001). In addition, scenarios for a local area would also be restricted if they failed to take account of the influences acting across a range of spatial scales.

Our approach to producing local agricultural landscape change scenarios combines key international to regional policy drivers and local policy prescriptions with information gleaned from climate impacts studies at a range of scales, as well as the output of a Land Use Allocation Model that incorporates economic and environmental factors operating at global and national scales but provides land use information at a locally relevant level (Fig. 1).

Fig. 1 summarises the key policy drivers operating at a variety of scales that are likely to affect individual decisions on future land use over the next decade. Increasingly, national policy is implemented as a result of international policy. At the global scale policy drivers include world trade agreements and market prices for crops: market prices are themselves a response to policy/trade conditions, buyer behaviour and natural environmental conditions – including climate – that influence yield. The impacts of such factors are mediated at the European scale by the Common Agricultural Policy (CAP), and a series of Directives which are implemented at the national scale through further policies, strategies, schemes and incentives. Some of these policy influences have a greater direct effect on decisions being made by land managers than others. In England incentive led policies, e.g. payments under CAP, currently have more influence than opt-in agri-environmental schemes, though closer integration of these over the next few years through cross-compliance requirements is intended to enhance land management.

The importance of these policy influences as drivers of land use change was very apparent during consultations with a wide range of stakeholder groups (including farmers and landowners, farming and wildlife organisations, local councils and governmental organisations) in a study of water resources issues in Lincolnshire, England (Lovett et al., 2004). The main factors identified by these stakeholders are listed below in descending order of the emphasis given:

- The market price of different crops.
- Effects of Common Agricultural Policy reforms—farmers predict more variability on what is grown year to year, and foresee greater intensification in some farm enterprises. Other farmers may retire and lease out land (depending on size of farm and quality of land).
- Effects of world market/EU trade policies (e.g. in relation to sugar beet).
- Constraints imposed by supermarket buyers on crop management practices.
- Constraints imposed by other assured produce schemes (public food safety concerns).
- Water availability—frequency of occurrence of dry summers (concern about global warming and adequacy of water supply for irrigation).

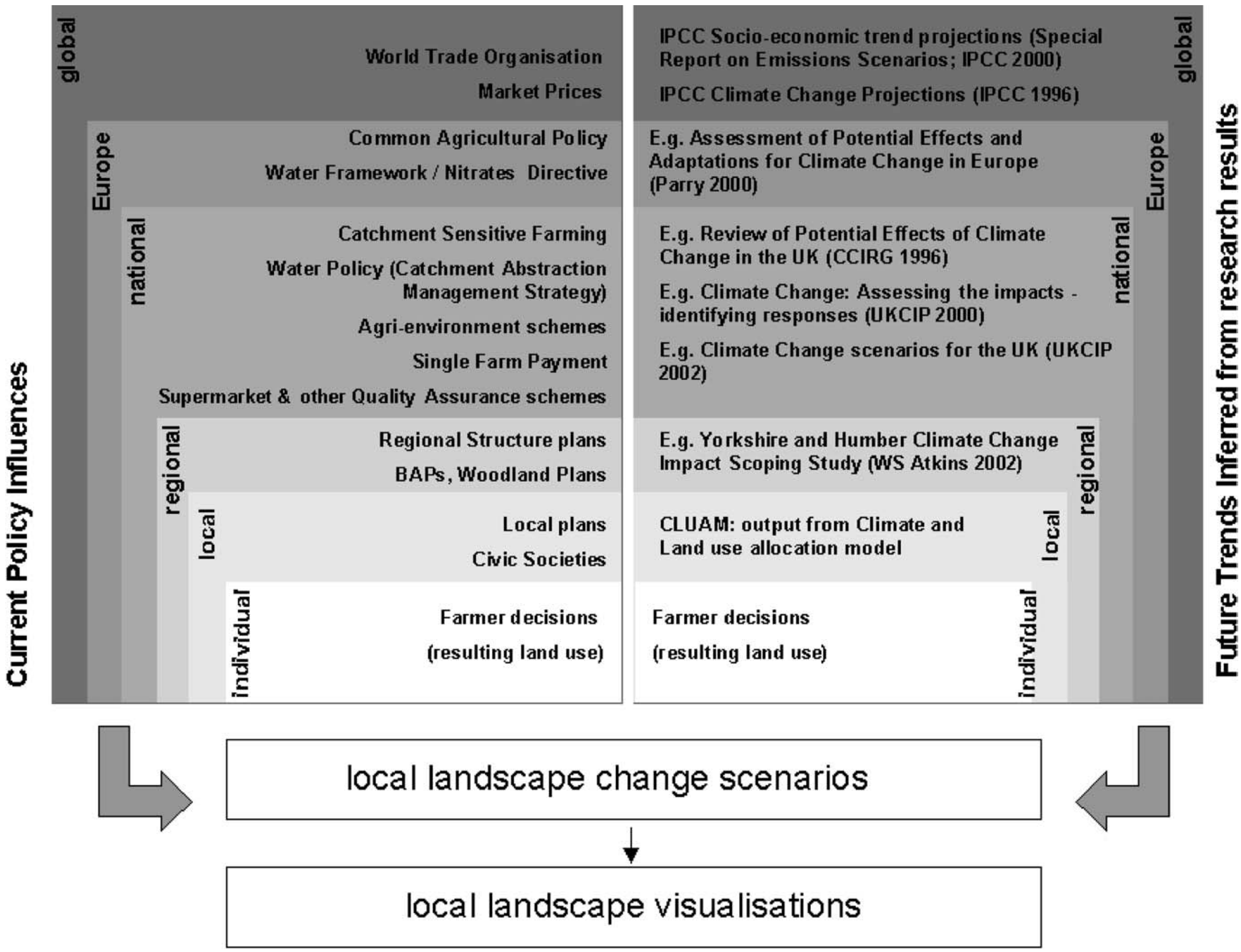

Fig. 1. The sources of information used in constructing local landscape change scenarios.

- New agri-environment schemes (likely to lead to wider prevalence of features such as field margins, though will otherwise have little influence on land use).

In the Lincolnshire study area the main manifestation of changes in these drivers is expected to be switches between crop types. Current proposals to reform the EU sugar regime, which in turn are likely to lead to a reduction in prices, could be a serious issue for some farmers and might also lead to land use change. In addition, stakeholders expressed quite a high degree of concern about climate change, particularly any increased incidence of dry summers which may impact on the viability of some crops due to increased irrigation needs/costs. Some interest was expressed in the scope for growing biofuel crops in the future if the economic conditions are favourable. These concerns will form the basis of calls for future policies to include financial support for items such as farm reservoirs or to support a switch to biofuel production, and indicate how current concern about climate change will manifest as future landscape change.

Identification of key policy drivers through literature review and consultation form one facet of the information needed to evaluate how future rural landscapes might evolve. However, the broad framework used in this study is provided by the socio-economic scenarios produced by the Intergovernmental Panel on Climate Change (IPCC) which represent possible directions for human development over the next 100 years, encompassing different systems of governance and societal structures (Intergovernmental Panel on Climate Change, 2001; Nakićenović et al., 2000). These have been interpreted for the UK by SPRU (1999) to produce four equip-plausible scenarios that are intended to provide the broadest coverage of the potential future directions society might take and hence encompass the impacts these changes could have. The benefit of using this recognisable framework is to allow comparability with other work.

As with the IPCC scenarios, the UK interpretations consist of four 'story-lines' developed by considering a range of socio-economic drivers hung on two principal axes. These are the degree of autonomy of the national system of governance from global influences and the degree to which

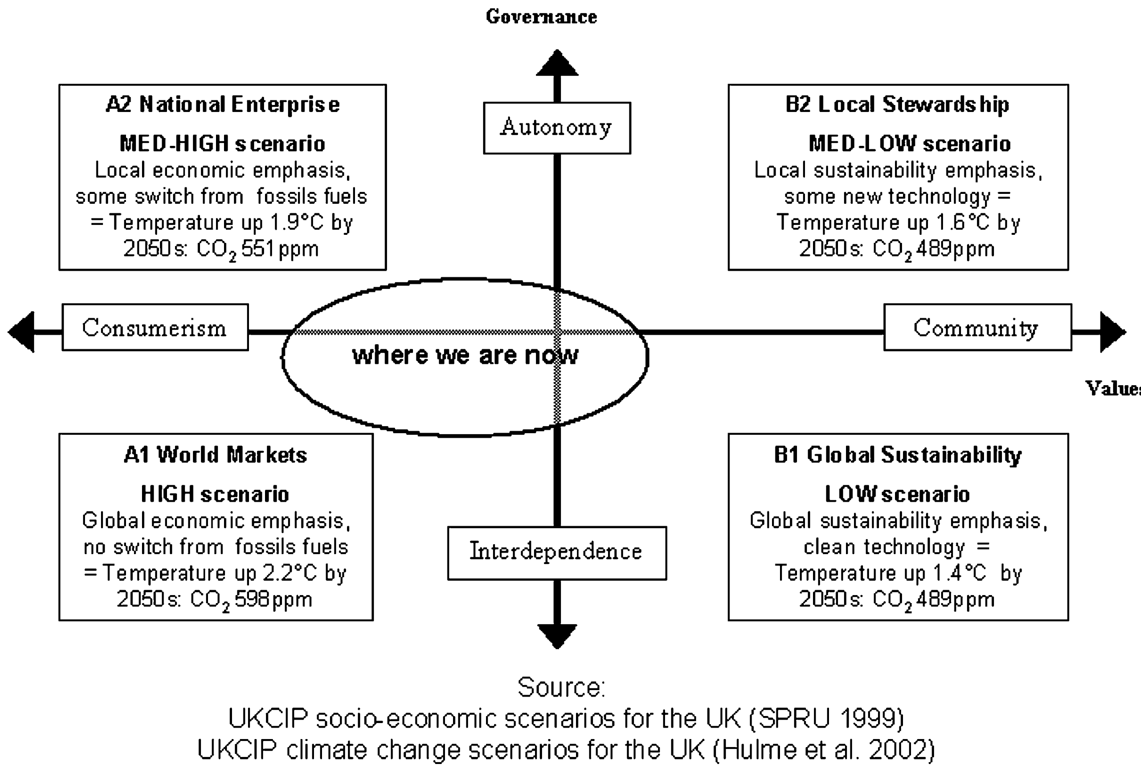

Fig. 2. Framework of projected directions for global development over the current century, with associated climatic consequences for the UK.

the satisfaction of individual wants/needs takes precedence over the wants/needs of the community as a whole (Fig. 2).

In each scenario the prevailing influence of these two principal factors establishes the ethos underlying socio-political values and role of the state, and this in turn determines how policy is likely to develop in specific areas. Those areas considered in the scenarios are: welfare and health; education, environmental policy, economic policy, regional trends; the manufacturing, services and construction industries; energy use, population, planning, transport, housing and the quality of the built environment; agricultural policy, trade, support measures and consumer demand, along with farming practices and production methods; demand, supply and quality of water; policy for biodiversity and potential impacts on it, and coastal zone development and protection. Table 1 provides an example of the differences in direction of policy development under each of the four scenarios. Overall, the world market and National Enterprise scenarios place an emphasis on economic development, whilst Global Sustainability and Local Stewardship feature stronger environmental policies.

To provide an indication of the potential impacts of climate change on land use, this study also includes the output of a Climate and Land Use Allocation Model. Examples of such studies are discussed by Parry et al. (1999) and Rounsevell et al. (2005). Recent work for England and Wales using the CLUAM model has been based on the IPCC Scenarios illustrated in Fig. 2 (Parry et al., unpublished results). Data are available for two of the four world views—National Enterprise (A2) and Local Stewardship (B2) and consequentially the scenarios and visualisation examples given later in this paper are based on these two views.

The CLUAM model employs linear programming techniques to allocate land uses within 1 km^2 in a manner that optimises the gross margin achievable from all the included agricultural activities on the different parcels of land (Parry et al., 1999). However, CLUAM does not operate at this scale in isolation from global influences as it incorporates climate and world food trade parameters through a model called the Basic Linked System or BLS (Parry et al., 1999). The BLS is run for a particular socio-economic and climate change scenario and the outputs (yields, prices and demands for the modelled commodities—crops and grass-based livestock production) are subsequently input to CLUAM. Total areas for each agricultural activity are calibrated to accord with Agricultural Census statistics, providing a baseline against which changes suggested by individual scenarios can be compared. The current baseline is centred on the mid-1990s. CLUAM output indicates the percentage land use per 1 km^2 for each of the following; wheat, barley, oats, oilseeds, peas/beans, sugar beet, potatoes, maize, sunflowers, ley grassland, permanent grassland and rough grassland.

The process by which the modelling results and policy influences are combined in scenarios is described in Section 4. It should be noted that as the scenarios were intended to provide the information needed for the construction of visualisations, the information selected was that which

Table 1
Selected projections from socio-economic scenarios for 2020s/2050s

	World market scenario (A1)	National Enterprise scenario (A2)	Global Sustainability scenario (B1)	Local Stewardship scenario (B2)
Environmental policy	Environmental policy is aligned to meeting competitiveness goals and protecting local amenity and environmental quality. It relies heavily on economic instruments. Areas accessible to wealthier people for recreation enjoy higher levels of protection. Longer-term global issues such as climate change tend to be neglected	Environmental policy measures seen to impede economic development or restrict personal freedom do not succeed. There is little concern about global environmental issues. People support measures which enhance their immediate local environment, especially relating to clean air, the built environment and provision of recreational opportunities	Sustainable development is a political priority. Larger ideas such as the maintenance of biodiversity, protection of 'global commons' and resource efficiency drive policy. Policy is based on a mix of market-based and regulatory instruments	The conservation of resources and the natural environment are strong political objectives. Environmental policy succeeds as a result of structural and behavioural changes as much as on technological change and innovation
Agriculture	Subsides are reduced, CAP plays a minor role, lower food prices prompt farmers to increase productivity. Agriculture becomes increasing industrialised and global in scope. Farms increase in size. Use of GM crops becomes widespread, raising productivity. Substantial tracts of land are converted from agricultural to recreational uses or are sold for development	Policy aims to protect British agriculture/food industry. There is little concern about the rural environment. There is no link of environmental objectives to agricultural support measures. Current agricultural practices continue with high inputs of pesticides and fertilisers. Some uptake of GM crops. There is a moderate trend towards large farms. Productivity increases leading to surplus of agricultural land	Policy aims to balance high yields with low environmental impacts. Support payments to farmers are tied to the sustainable management of rural landscapes. Integrated Crop Management leads to lower pesticide inputs. Slow uptake of GM crops. Large-scale livestock farming declines. Substantial areas of land are taken out of production. These areas are used to support nature conservation rather than recreation	Policy aims to support a broader social desire for local self-sufficiency and 'traditional' farming. Large-scale farming i s not encouraged. Agriculture is heavily subsidised to protect food security, local landscapes and reduce environmental impacts. Rapid growth in organic and low input farming. Farm size declines and use of pesticides/fertilisers decreases. GM crops are banned. The shift to extensive farming leads to expansion in the area of land in agriculture. Arable production increases and livestock production decreases
Water resources	Water demand increases significantly. Water costs are high which encourages efficiency measures. New reservoirs are developed	Water demand increases. New and enlarged reservoirs are constructed. Supply difficulties arise in south and east of England	As a result of improved efficiency of water end-use, there is little need to develop new sources of water supply	Water demand falls as a result of low growth and controls on demand/water conservation measures

Source: Derived from SPRU (1999).

would reveal a visual impact. In addition, as the policy guidance documents we consulted were focussed on the near-term, we chose to illustrate landscape changes for the 2020s decade; the assumption being that by then current policy guideline measures will have been put in place but also that this is probably the earliest that the effects of climate change might begin to become evident. Importantly, it is also a time-frame that is considered tangible—near enough for people to relate to and care about. The further into the future, the more uncertain any given outcomes will be with less relevance and impetus for immediate action.

3. Selection of study sites

Several options were considered for the selection of possible study sites. Alternative strategies included identifying areas with greatest potential to highlight a range of climate change impacts, or to choose famous landscapes that would resonate with the general public. Given the resources available, it was also imperative to use locations where the variety of policy guidance documents had already been brought together to some extent.

A solution was found through a project being undertaken by The Countryside Agency. The 'Land Management Initiative' included nine study areas covering a wide variety of agricultural landscapes including urban fringe, arable, lowland pastoral and upland farming systems (Countryside Agency, 2004). The project commenced in 1999 and involved farmers and rural communities in the development of a range of beneficial land management practices and programmes that could contribute to future rural support policies. The LMI study provided a good selection of contrasting rural landscapes, comparing similar agricultural activities in different geographical settings. It was concluded that the LMI study areas would provide a good basis for this research because of their landscape diversity and the existence of a range of reports on rural planning issues.

4. Creating local landscape change scenarios: Humberhead Levels LMI case study

One of the LMIs selected for particular attention was the Humberhead Levels. This area is predominantly a flat, open floodplain at the head of the Humber Estuary on the North Sea coast of England. The landscape has been transformed over several centuries by artificial drainage. Pump and gravity fed drainage ensures the continued existence of very low-lying land in the area (which would otherwise be flooded), and maintains the rich arable land which is one of the most productive cropping regions in Britain (Chamberlain, 2000). The arable landscape is dominated by very large, open fields but smaller hedge-lined fields can be found in some areas. The main crops are winter and spring-sown cereals, sugar beet, oil seed rape, vegetables and potatoes (Chamberlain, 2000).

The fragmentation of planning and regulatory responsibilities in the UK (see Cullingworth and Nadin, 2002) means that there are a wide variety of organisations with interests in the landscape of an area like the Humberhead Levels and a corresponding plethora of relevant local policy documents. These range in scale from Regional Spatial Strategies to Local Development Frameworks and also include reports on particular topics such as Catchment Abstraction Management Plans and Biodiversity Action Plans. The initial phase of the Humberhead research involved reviewing such documents. Further information on how the landscape might develop was obtained from interviews with local planners and stakeholder organisations. Examples of the policy prescriptions contained in these documents are given in Table 2. A report by Posford Duvivier Environment (2000) was particularly useful, containing details of over 100 separate projects, studies and relevant reports. From these, over 250 actions to be undertaken within the Humberhead Levels were stated.

Virtually none of the documents consulted made any more than scant reference to climate change, the exception being the recently published Regional Planning Guidance (RPG) (Anon., 2001) which is one of the first to incorporate concerns with respect to climate change (e.g. there are several measures in the RPG designed to enhance flood management). The RPG also acknowledges government policy to reduce greenhouse gas emissions and the need to work towards increasing energy supply from renewable resources. It is such responses to the climate change issue that will in time manifest themselves in landscape changes, whether it be through the granting of planning consents for wind farms, the creation of a market for energy crops, structural changes in coastal defences, etc.

Climate change impacts information came from a variety of reports. Although there have been many valuable studies over the last decade that have assisted our understanding of the potential impacts from climate change, information tends to be either very general (e.g. CCIRG, 1996) or very specific (e.g. Newman, 2005) and little is related to particular local areas or has defined time-scales. However, in the UK a series of regional climate impacts scoping studies have recently been carried out, and the document completed for the Humberhead area (Atkins, 2002) was a useful source of information for this study.

The information summarised in Table 2 formed the basis of the first of three scenarios. This 'unconstrained' scenario represents the desired outcome of current policy and the changes various organisations would like to see in the local countryside. The policy guidance documents mostly influence the establishment, retention or management of field margins, watercourses and other landscape features rather than actual land use. However, it is evident that the success of these policies is dependent on sympathetic land use changes. For example, in the absence of targeted

Table 2
Example of policy prescriptions used to compile an 'unconstrained' landscape change scenario for the Humberhead Levels, England

Feature	Prescription
Landscape	• Conserve the expansive, isolated and uplifting landscape typified by the Trent and Ouse Levels, whilst offering scope for localised landscape improvement and enhancement[a]
Arable land	• Encourage farmers to consider opportunities for winter storage reservoirs to reduce the level of summer abstraction from drains[b] and provide resource for wildlife and recreational use[c]
Field margins	• Maintain ditch water levels at as constant a level as possible and ensure that there is always water present in the ditches Particularly in the summer months[b] • Extend the amount of field margins (e.g. wildlife and sterile strips) throughout the county, through agri-environment schemes[d]
Hedgerows and hedgerow trees	• Ensure the protection and reinstatement of hedgerows where the hedgerow is adjacent to a highway or public right of way (where it does not affect safety), has historical significance and is a significant landscape feature or wildlife habitat[e] • Develop the linkage of hedgerows as wildlife corridors connecting to woodland, chalk grassland, other hedgerows, etc.[d]
Woodland and trees	• Encourage tree planting along road corridors where appropriate[a] • Restore 25% (approximately 800 ha) of ancient woodland sites to appropriate native broad-leaved woodland habitat, including liking to existing ancient woodlands, by 2010[d]
Designated areas	• Establish a buffer zone around SSSIs, such as the Hatfield and Thorne Moors and the Idle Washlands[b]
Marshland	• Rehabilitate areas of grazing marsh that have become too dry, or are intensively managed, favouring schemes that link or buffer existing sites, by 2005[d] • Restore 200ha of former grazing marsh, by 2005[d]
Peat/mire	• Expand the area of managed heathland and peatland/raised bog by 100 ha by 2005, where appropriate, by restoration or recreation of habitat. Make optimum use of grant-aid schemes for the purpose[d] • Through habitat management and extension of habitats, enable populations of endangered and vulnerable species associated with Lincolnshire heathland and peatland to expand where appropriate[d]
Wetland habitat	• Restore old and new wetland habitats[b] • Promote the use of agri-environment to re-wet flood meadows[b]
Ponds/pits	• Enhance the conservation value of ponds, lakes and reservoirs through appropriate management, especially sites supporting species/communities of conservation importance[d] • Create 100 new ponds (with aid of pond guidance leaflet) on land of low conservation importance in Lincolnshire by 2010[d]
Watercourses and water table	• Remodel river channels to create oxbows and offline channels to improve habitat for wildlife and to act as an escape reservoir from pollution incidents[f] • Develop more valuable river corridors through the creation of buffer zones and sensitive land management[b] • Maintain a permanent high water table in order to preserve waterlogged archaeological and paleo-environmental remains[b] • Review water abstraction to ensure that abstraction from the ditches is balanced by the need to keep sufficient water levels to maintain the nature conservation value of the ditches[b] • Manage and maintain water levels to ensure that inundation of undefended grassland areas of the floodplain and particularly SSSI areas should occur at least three times a year for a minimum of 7 days[b] • Develop wider more valuable river corridors through creation of buffer zones and sensitive land management[b] • Identify suitable locations and undertake bank side planting and fencing to create riparian buffer zones[b]
Settlement	• Proposals for new development within notified areas of flood risk or which would adversely affect the stability and continuity of tidal and fluvial defences will not normally be permitted[e]
Road/railway	• Seek to maximise local visual and ecological importance of roads constructed on raised berms. Encourage limited roadside planting, combined with verge management, to promote species richness[a] • Seek to encourage further tree planting along the highly visible M180 and M62[a]

3. North Lincolnshire Council, April 1999. North Lincolnshire Countryside Design Summary. Draft.

[a] Anon., Our Landscape, Today for Tomorrow. An Assessment of the Landscape North and South of the Humber with Management Guidelines for its Future (undated).

[b] See Posford Duvivier Environment (2000).

[c] Government Office for Yorkshire and the Humber, March 2001. Draft Regional Planning Guidance for Yorkshire and the Humber (RPG12). Public Consultation.

[d] Lincolnshire Wildlife Trust, May 2000. Lincolnshire Biodiversity Action Plan. Habitat Action Plans. Species Action Plans. Published by the Lincolnshire Wildlife Trust on behalf of the Biodiversity Action Plan Steering Group. ISBN 0-9538270-0-3.

[e] Selby District Local Plan, February 1999. Selby District Local Plan, Deposit Draft. Second Set of Proposed Pre-inquiry Changes, vol. 1.

[f] See Chamberlain (2000).

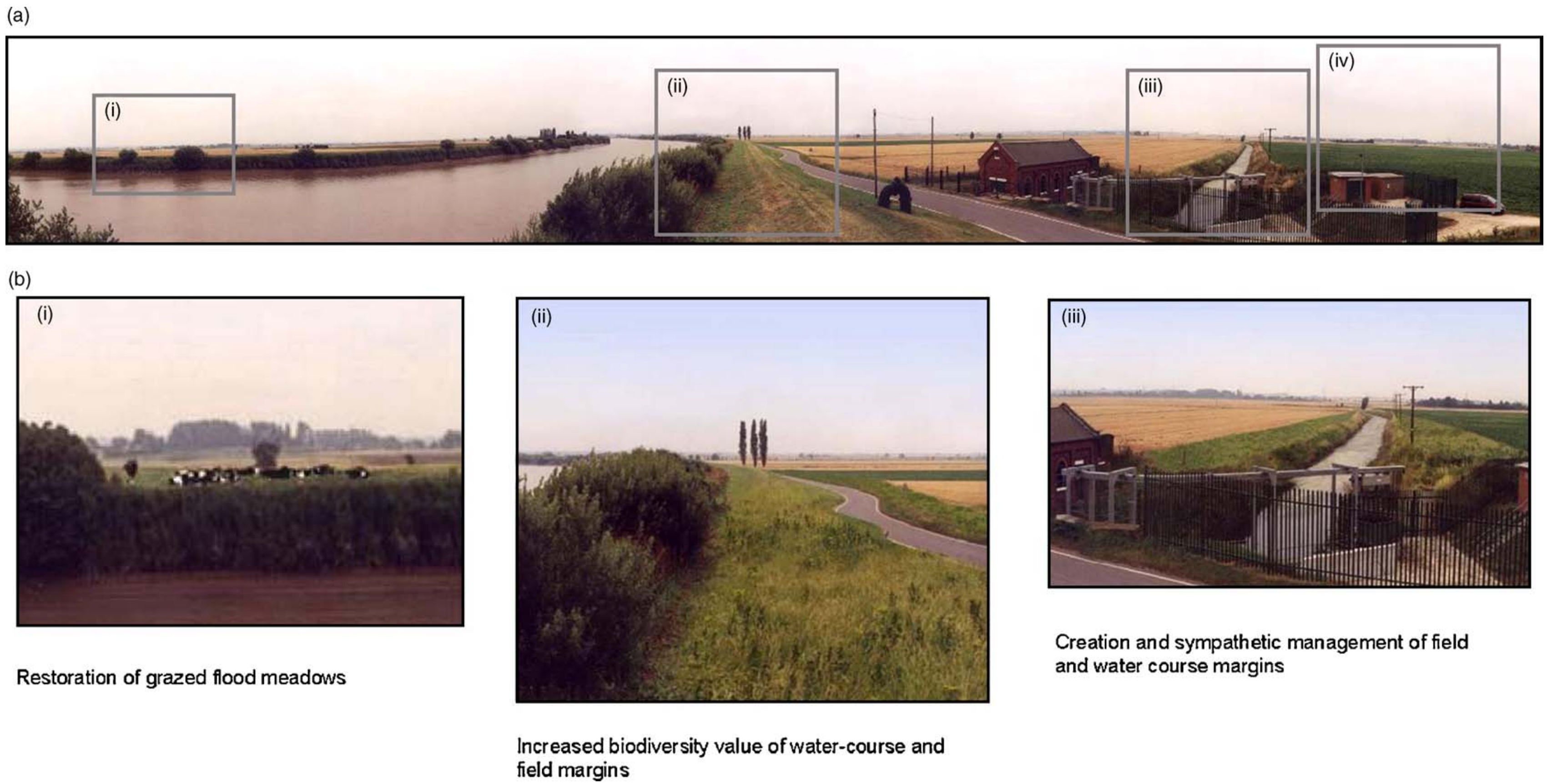

Fig. 3. Visualisations of the River Trent Floodplain near West Butterwick: (a) present-day landscape, pictured August 2001, and (b) 'unconstrained' current policy scenario.

financial incentives, hedgerows are unlikely to be restored or field sizes reduced where cereal crops continue to be grown, but they may be reinstated if economic conditions dictate a switch to livestock farming. So the 'unconstrained' scenario is thus termed because it assumes land owners are not constrained by economic conditions and would be willing to change land use accordingly. It therefore actually represents a 'wish list' or 'fantasy landscape' that could only be realised if it was economically viable. In reality land use decisions are based on the economic return available from the land. This is the reason that the other two scenarios include potential future land use changes projected by the CLUAM model. The way in which the CLUAM data have been combined with the policy information to produce the final landscape change scenarios is described below.

4.1. Implementation at the local scale

The landscape within the Humberhead Levels LMI selected for the visualisations falls within North Lincolnshire Council's Trent Levels landscape character area (Anon., 1999). It is an intensively farmed area alongside the River Trent, near the village of West Butterwick, and typifies the flat drained farmland that today forms much of the Humberhead Levels. Fig. 3(a) shows a panoramic image (covering a 250° field of view) of the landscape taken in August 2001. The centre of the image looks southwards along the engineered banks of the River Trent, whilst the village of West Butterwick is on the far right of the photo, screened by trees.

In the distant past, this area would have been a wet and marshy landscape of floodplain meadows, with possibly more tree cover than today. Attempts to drain the land date back to Roman times but the main drainage works were carried out by Dutch engineers in the early 17th century. In the past West Butterwick was a larger and busier place than today employing a range of agricultural workers and associated trades such as hemp spinners. Brickmaking was a major village industry in the mid-19th century with the bricks being transported away by river (see http://www.linktop.demon.co.uk/axholme/butterwick.htm). The agricultural land adjoining the village has been improved over many years, revitalised annually by the river through the process of 'warping' to allow the build up of rich alluvial soil.

The drainage systems and improvement of the soils have facilitated the intensive arable agriculture that is practised today. However, drainage and vastly increased water consumption for domestic, industrial and agricultural purposes in an area of low annual rainfall have led to a reduction in the water table and a loss of the natural vegetation that was dependent on it (Anon., 1999).

The Landscape Character Assessment values and seeks to preserve the openness of the present landscape, describing the area as follows—"an essentially flat open landscape with occasional rising ground and little vegetation cover . . . large open field structure defined by well-maintained drainage ditches . . . offers expansive views with very little diversity in character . . . woodland blocks, rising ground and settlements create distant enclosure . . . dominated by linear features, long narrow roads flanked by drainage ditches . . . field drainage systems . . . settlements adjacent to the banks of the River Trent . . ." (Anon., 1999, p. 17).

Objectives under the landscape strategy basically involve minor enhancements to the landscape, particularly with respect to ecological and wildlife potential (Anon., 1999). This theme is echoed in a variety of other policy guidance documents (see Table 2). CLUAM projections for potential land use change by the 2020s are shown in Table 3.

A full interpretation of the CLUAM output has not yet been published but the use of these data is primarily to illustrate an approach and we can to an extent surmise the reasons for the changes identified; in the 'economics-first' (A2) world production costs are likely to be cheaper in other parts of the world, which national protectionist policies may not be able to counteract, hence the dramatic drop in cereal production. With continued use of fossil fuels there is no incentive to diversify into non-food crops (e.g. energy crops) so land could be lost to built development. Under the B2 'Local Stewardship' scenario there may be more emphasis on valuing locally produced foods, rather than lowest priced foods, and so the declines in cereal production are not so drastic. However, under both of these scenarios, world trade influences combined with climatic stresses (e.g. insufficient water supply) serve to reduce yields in this area causing a decline in cereal production and a switch to other crops.

A notable feature of these scenarios is that they suggest some land could become surplus to requirements for

Table 3
Summary of land use changes projected by CLUAM

Scenario	Main land use changes identified by CLUAM
National Enterprise (A2) 2020s	This scenario shows a total collapse in cereal growing though around 50% of the land transfers to other crops such as sunflowers, oilseed, beet and vegetable production. Some 20% of land is surplus to requirements
Local Stewardship (B2) 2020s	This scenario also indicates a reduction in wheat growing, but with land transferring to the production of peas/beans and sugar beet. Again around 20% of land is surplus to current crop requirements

Source: Parry et al. (unpublished results).

Table 4
Examples of the filtering system used to allocate policy and land use information to landscape visualisations

Feature	Policy prescription	National Enterprise (A2) economic priority	Local Stewardship (B2) environmental priority	CLUAM suggested land use change	National Enterprise (A2) landscape scenario visualisation	Local Stewardship (B2) landscape scenario visualisation
Landscape	Conserve the expansive, isolated and uplifting landscape typified by the Trent and Ouse Levels, whilst offering scope for localised landscape improvement and enhancement	Requires no positive action but likely to be ignored in favour of economic development		Continued crop production favours maintenance of large field sizes	Virtually no change in landscape structure but evidence of economic development is included via new sports ground	
			Planning controls would restrict development. Agri-environment schemes would finance enhancement	Continued crop production favours maintenance of large field sizes		Little change in landscape structure but enhancements to field margins, etc.
Arable land	Encourage farmers to consider opportunities for winter storage reservoirs to reduce the level of summer abstraction from drains and provide resource for wildlife and recreational use	This would be left to individuals to finance and probably would be too expensive		Surplus land is available	A reservoir would not be considered a high priority and is not included in visualisation	
			If possible financial support would be provided to conserve water	Surplus land available for constructing reservoirs		A reservoir is considered unlikely in this location so not included in visualisation
Land use				Transfer cereal fields to sunflowers oilseeds, beet and vegetables. Surplus land available for economic development	Transfer cereal fields to sunflowers oilseeds, beet and vegetables	
				Reduction in cereals. Show beet. Surplus land could be used to grow energy crops		Reduction in cereals. Show beet and energy crop production
Ditches	Maintain ditch water levels at as constant a level as possible and ensure that there is always water present in the ditches Particularly in the summer months	With no water conservation effort and competing water demands this is unlikely to happen			Water levels in ditches are not maintained—ditches may dry in summer	
			Good water conservation and practice means that ditches and ditch margins are enhanced	Surplus land available for implementing margins		High water level and good bank side management are illustrated

Field margins	Extend the amount of field margins (e.g. wildlife and sterile strips) throughout the county, through agri-environment schemes	Maintaining cropping area to maximise profit and lack of financial support mean this would not happen	Surplus land is available	No change to marginal features
		Strong environmental policy plus financial support increase the prevalence of field margins	Surplus land available for implementing margins	Margins created around watercourses, fields and roads

growing the range of crops considered by CLUAM. This offers the potential for new crops to be considered or for land to come out of agriculture altogether. In our scenario visualisations we have therefore tried to represent some of the alternatives and opportunities that could arise.

Table 4 illustrates how policy information has been allocated to the National Enterprise (A2) and Local Stewardship (B2) scenarios and combined with the CLUAM predictions to arrive at the landscape changes shown in the visualisations. Taking as an example, the issue of field margins, column 2 of Table 4 indicates that current policy documents favour the extension or creation of this landscape feature. Column 3, however, indicates that this policy does not accord with the ethos of the National Enterprise (A2) world, which would be unlikely to allocate funding to agri-environment schemes, and in any case field sizes would be maximised to maintain profits. Although CLUAM output suggests land would be available (column 5) there is no economic incentive to create margins. As a consequence, the resulting visualisation of the National Enterprise (A2) scenario does not include any additional field margins. Here (A2) the surplus of land is used for sports fields instead. This contrasts with the Local Stewardship (B2) scenario. Although there is an issue of judgement in arriving at the changes to specific features within the visualisations, the SPRU scenarios framework makes it relatively easy to assess which policy prescriptions would be implemented in particular circumstances.

5. Visualisation of scenarios

Two approaches to visualising impacts of potential policy and climatic influences were investigated as part of the Humberhead study. The first of these was the development of digital photo-montages and the second focussed on the development of an interactive landscape model from GIS data.

5.1. Digital photo-montages

The production of a digital photo-montage is a relatively straightforward approach which makes use of image manipulation software. Several studies have used this approach for visualising policy options (e.g. Al-Kodmany, 1999; Simpson et al., 1997). Producing an altered landscape view in this way requires:

(1) a base-line landscape photograph;
(2) an appreciation (scenario) of how the view in the photograph is likely to be altered;
(3) suitable imagery to incorporate into the photo-montage to represent the scenario.

The requirement for 'suitable imagery', for example, photographs of novel crops that might be introduced as the climate changes, requires the compilation of an image library. A considerable amount of time was spent on this task during the research. The images collected were also of use in the GIS-based visualisation work, as this often also requires photographs of individual tree, plant or crop species that can be converted into models with which to 'populate' a field or provide a texture to represent a given land use. (Many of the currently available image libraries are based on vegetation from North America and consequently not especially applicable to the European context.)

Fig. 3(b) displays three extracts from the photo-montage for the unconstrained scenario based on prescriptions from a variety of policy documents (see Table 2). These extracts can be compared with the highlighted areas of the present-day landscape shown in Fig. 3(a). The policy prescriptions focus on conserving the expansive nature of the landscape whilst implementing localised enhancements. This is indicated in Fig. 3(b-ii and -iii) by the addition of uncultivated grass field margins and water course margins managed for wildflowers, insects and animals. In the distance, small blocks of woodland have been enlarged to increase overall woodland cover. Water is well managed and parts of the flood plain have been restored to a grazed flood meadow with livestock (Fig. 3(b-i)).

Fig. 4(a) illustrates how the agricultural landscape might look if world development follows the National Enterprise (A2) path where economic factors take priority over environmental protection. There is little concern about global issues, so few efforts are made to guard against climate change impacts and fossil fuels continue to be widely used. Under this scenario there are no incentives to implement the policies illustrated in the unconstrained scenario, so landscape character and biodiversity continue to diminish. Intensive farming continues with high use of pesticides and fertilisers. This means producing higher yields of crops off an increasingly smaller area of land (though with little regard to long-term damage to soils, etc.), meaning that some land is surplus to agricultural requirements. Under a changing climate CLUAM forecasts suggest that arable crops carry on dominating agricultural production but some new 'warm weather' crops such as sunflowers and grain maize (Fig. 4(a-ii)) could be introduced. However, agricultural production is threatened by summer droughts and poor water conservation and the water table drops further bringing further stress to remaining patches of woodland and other natural habitats which could die back due to water shortage. These trends could become critical issues in later decades affecting farming viability. As there is little concern for biodiversity or nature conservation any spare land is likely to transfer to new economic uses—e.g. more housing or industrial development or 'leisure landscapes' (illustrated by a new sports club and basketball courts; Fig. 4(a-iv)).

In the Local Stewardship B2 world (Fig. 4(b)) the will and resources to protect the environment are strong. Agriculture is subsidised to promote nature and landscape conservation, low input farming systems are encouraged—fields margins are likely to be filled with wildflowers. With the B2 ethos, many of the improvements seen in the unconstrained scenario are likely to be implemented. As a response to climate change, new clean sources of energy are sought (e.g. the wind farm in Fig. 4(b-i), though recent policy moves suggest such developments may more frequently be located off-shore). Although summer droughts become more frequent, measures have been put in place to prepare for and lessen the impacts of climate change—e.g. water use efficiency measures, the construction of farm reservoirs to hold up winter rainfall, the introduction of trickle irrigation, etc. Therefore, water is well managed and available to agriculture. CLUAM output indicates a reduction in the amount of cereals grown in the area and therefore there are possibilities for new crops to be introduced. The photo-montage shows *miscanthus* (Fig. 4(b-ii)), a biomass crop that is harvested as a fuel to supply the local biofuel power station (Fig. 4(b-iv)). Biodiversity and landscape enhancement measures are likely to be implemented under this regime as financial support is provided.

One benefit of photo-montages as a visualisation technique is that, once an image library has been created, it is relatively cheap and straightforward for a person competent in using the relevant software to produce representations of altered landscapes. However, because these products are simply illustrations, there is no analytical capability, whereas GIS-based techniques offer the ability to quantify potential landscape change. In addition, however, the landscape change is depicted, the photo-montage is limited to the field of view obtained in the original image.

A photograph at ground level will often provide only a partial impression of the landscape, particularly in areas with little relief. In many lowland regions an understandable impression of the landscape might only be achieved through an aerial view. In England's Norfolk Broads, for example, which is a region of man-made waterways in a flat fenland area, it is perfectly possible to travel by road well within the Broadland area, looking over a countryside of wide arable landscapes and be completely unaware of the vast network of surrounding waterways—until the sail of a boat is spotted apparently traversing across a field. Conversely, from the waterways, the view is of reed beds and lagoons and the agricultural landscape provides only the background setting, if it can be seen at all.

In more mountainous terrain a ground-level view might be limited to the slopes presented to the camera, which may mask settlements or alternate land use patterns on slopes of other aspect within the same landscape. Even in the very best of photographs therefore, the image can provide only a single view of a landscape. It is much more difficult to provide an impression of the landscape itself.

In addition, as Al-Kodmany (1999) indicated, there is very little scope for interactivity with this technique. Both Berry et al. (1998) and the Landscape Institute and Institute of Enviromental Management and Assessment (2002) recognise that photo-montages are increasingly being

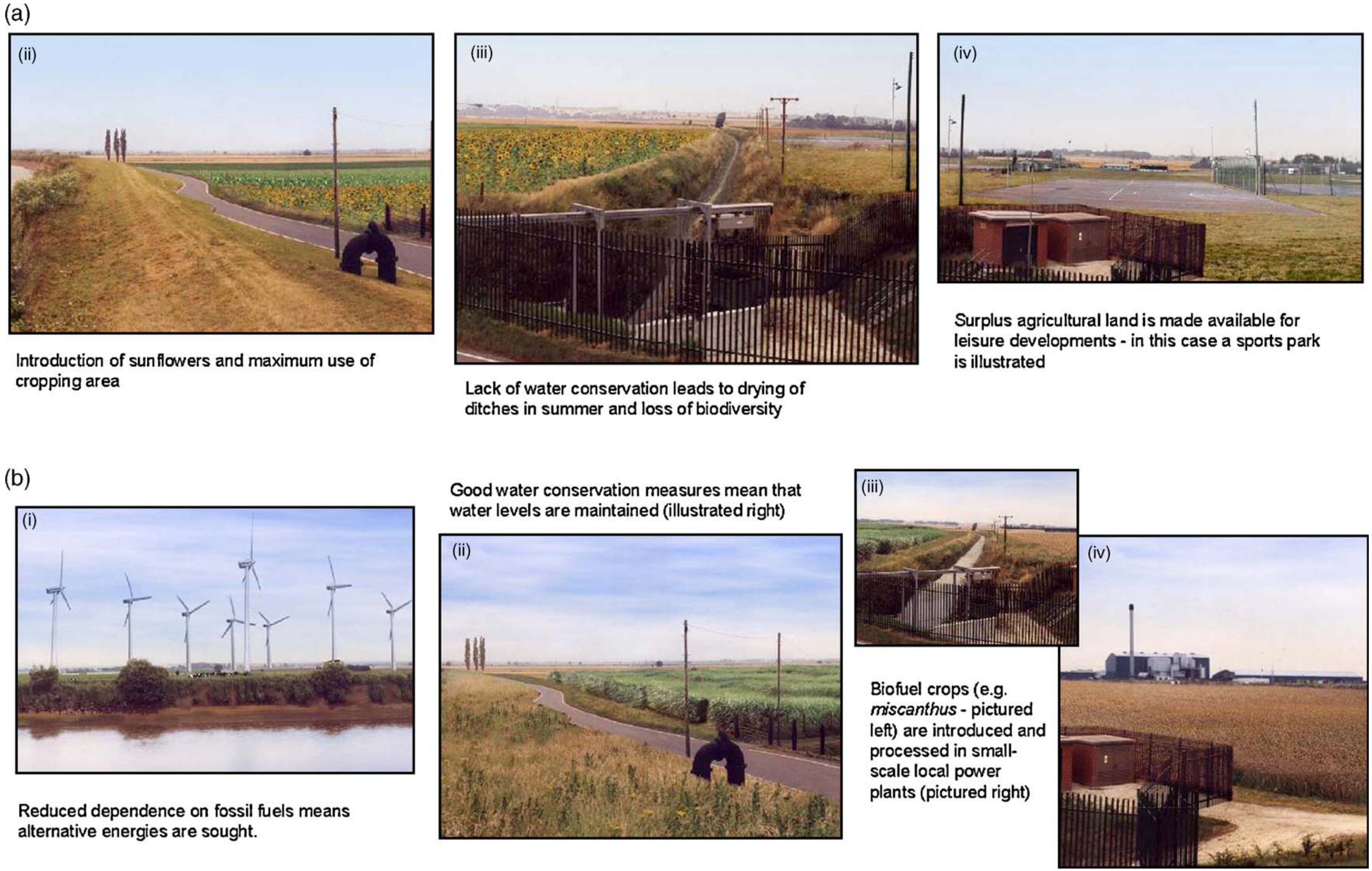

Fig. 4. Visualisations of the potential future landscape near West Butterwick: (a) 'National Enterprise' (A2) scenario for the 2020s under climate change and (b) 'Local Stewardship' (B2) scenario for the 2020s under climate change.

superseded as a tool for Visual Impacts Assessment by 3D interactive techniques such as those being developed through integration with GIS.

5.2. GIS-based landscape models

Map information can be compiled in digital form within a GIS and then processed within linked visualisation software to generate a variety of outputs including still images of the view from a particular point, animated sequences (such as a flythrough of an area) or a real-time model where a mouse or joystick can be used to interactively navigate around a landscape (Ervin and Hasbrouck, 2001; Appleton et al., 2002). Recent years have seen rapid development in such GIS-based techniques, particularly with respect to the incorporation of levels of feature realism in real-time models that were previously only possible in still images (see examples in Bishop and Lange, 2005; Buhmann et al., 2005). However, it is also important to recognise that the pace of technical innovations has yet to be matched by advances in understanding as to how such virtual worlds are perceived by public audiences and the implications of using them in decision making contexts (Orland et al., 2001; Bishop, 2005). In our previous work visualising climate change scenarios in part of Norfolk (Dockerty et al., 2005) we concentrated on generating still images from GIS information, but by the time of the Humberhead study real-time models were feasible so we decided to generate these for the different scenarios and assess how they were perceived by a local audience.

The GIS information used in the Humberhead research consisted of a 10 m resolution elevation model (Ordnance Survey Profile®) and Ordnance Survey 1:2500 scale Master Map® data for the same area as shown in the photo-montages. The MasterMap® data showed the layout of fields, water, buildings and built-up areas as well as the location of electricity pylons. Crop information was derived to a basic level from aerial photography online at Multimap (http://www.multimap.com) and supplemented by information obtained from photographs taken in the area.

Landscape models were constructed using Visual Nature Studio (VNS) Version 2 from 3DNature (http://www.3dnature.com), with the additional Scene Express real-time export extension. GIS information in the form of ESRI shapefiles and grids was imported, and the VNS package was used to assign visual properties to all landscape features. As the aim was to produce a model suitable for real-time display on a PC, the level of feature detail was kept relatively simple. For example, buildings were shown using simple extrusions with flat roofs instead of importing full 3D geometry; the river was represented by a bluish-grey flat colour on the land surface, rather than simulated water with reflectivity, transparency and rippled surface; and instead of many individual items of vegetation, procedural textures were used to represent arable crops and other land cover. The Humberhead landscape has few trees, but a set of three distinctive poplars visible in the initial photo-montage was shown, and garden or street trees were also included in the village area by using two-dimensional ‘billboards’ based on photographic images.

Separate landscape models were developed for the National Enterprise and Local Stewardship scenarios by downscaling CLUAM predictions of agricultural change (in the same way as described by Dockerty et al., 2005 for the Norfolk work) and creating two scenario landscape shapefiles that could be imported into VNS. In both of these models, there was also a need to add in a small number of more specific structures (e.g. wind turbines and a sports ground) than the simple, extruded houses and farm buildings. All three landscapes contained a model of the pumping station which is prominent in the initial photo-montage (Fig. 3(a)). These more detailed buildings were created using the Wings3D software (http://www.wings3d.com).

As the 10 m resolution of the elevation data was insufficient to show the river embankments and field ditches, these were added in at the visualisation stage using the ‘Terraffector’ feature in VNS. This allows for local terrain modification according to a user-defined elevation profile, applied symmetrically along a vector. Similarly, an area-based Terraffector was used to raise the surface height of fields containing tall crops such as miscanthus and maize, since the inclusion of thousands of items of vegetation would have made the real-time model unusable.

In preparation for export to a real-time format, a number of pre-set fixed and animated cameras were set up. These consisted of an overhead view, a circling camera at an altitude of approximately 500 m, a stationary ground level view and a panning ground level view sweeping through the arc visible in the photographic panorama. Such cameras give an alternative overview of the model for audience members who do not wish to navigate interactively, without affecting the ability of other viewers to take control if they wish.

3DNature’s own NatureViewExpress format was used to export and view the landscape models. This was chosen for ease of export and the speed of interaction, as well as the variety of control methods and the ability to use the pre-set cameras discussed above. Furthermore, the viewing software for this format is free to distribute, allowing the model files and viewer to be downloaded or received on CD by anyone who wishes to view the scenarios.

The landscape models were exported with a terrain resolution of approximately 2.5 m and a drape image resolution of around 1.5 m (a limitation within the software currently prevents the drape image being more than 4096 pixels in either dimension, making this resolution the maximum possible). These settings are the primary determinant of the resulting file sizes; the total archive, including elevation files, drape images, foliage images and 3D object files as well as the main model file, was approximately 56 Mb. As an example, halving the resolution of both the terrain and the drape image leads to a total size of 30 Mb. The models ran smoothly on a laptop computer with

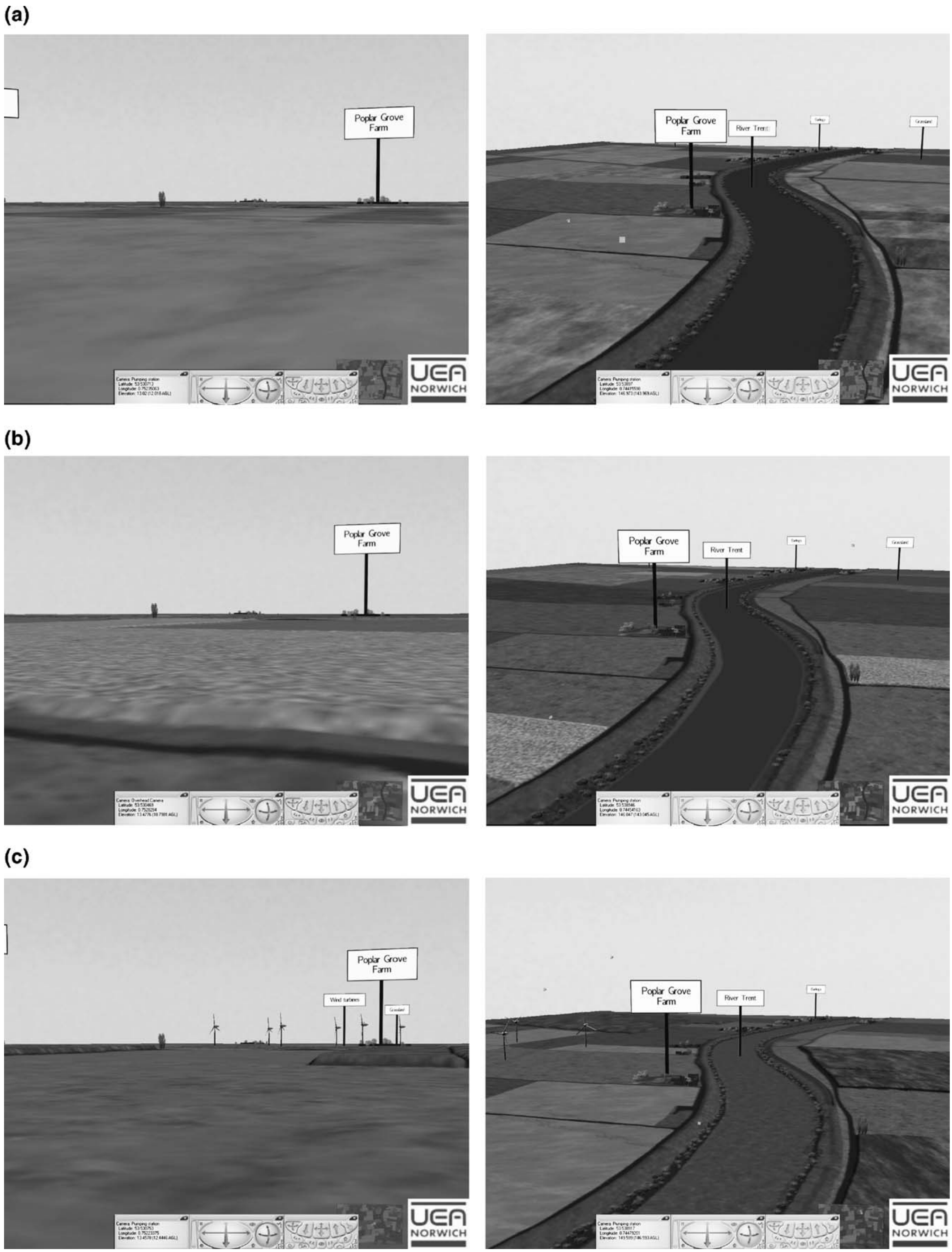

Fig. 5. Screenshots from the real-time landscape models. Views of the: (a) present-day landscape model, (b) A2 National Enterprise scenario and (c) B2 Local Stewardship scenario.

1 Gb RAM, a 2.4 GHz processor and a 64 Mb GeForce video card.

Fig. 5 illustrates screenshots from the present-day landscape model (a), as well as the A2 National Enterprise (b) and B2 Local Stewardship (c) scenario models, from both a low and a high level perspective. Although it is difficult to appreciate from the limited views presented here, compared with the photo-montages the expansive open nature of the landscape is very well represented in the real-time model and land use changes are easily seen. This is greatly facilitated by the ability of the viewer to change both viewpoint and perspective. The group of three poplar trees that are a distinctive feature in the photo-montage (Fig. 3(a)) can be seen on the horizon in the low level view, and to the right of the river in the high level view. The wind turbines in the Local Stewardship scenario become a much more prominent feature than they appear in the whole landscape view of the photo-montage.

At the bottom of each screen (see Fig. 5) can be seen two navigation toolbars and an overview map (next to the UEA logo)—a small red arrow is constantly updated to show the viewer's position and orientation within the landscape. Navigation is via a conventional mouse with a scroll wheel, with three different control modes available via the buttons on the toolbars. Other buttons offer functions such as "stop", "return home", "go to feature", next and previous cameras, and single-step movement for fine positioning. Labels (tall "signs" anchored to a specific surface point) were used to inform viewers of the field contents as well as to identify points of interest (the river, village and specific farms) to help viewers locate themselves. A menu can also be accessed with the right mouse button, allowing features to be turned on and off by type (e.g. all labels and all buildings) and an automatic tour of all pre-set cameras to be started.

5.3. Public evaluation of visualisation techniques

Several studies (e.g. Lange, 2001; Appleton and Lovett, 2003) have evaluated public responses to different display formats and levels of detail in computer-generated visualisations. To date, however, most of this research has been based on still images (rather than real-time models) and relatively few studies have involved participants actually familiar with the visualised locations (e.g. many are based on audiences of university students or staff). In addition, as noted by Sheppard (2004), there is currently very little information on public responses to visualisations of potential climate change impacts on landscapes.

An opportunity to address some of these knowledge gaps in a small way occurred when the Humberhead visualisations were displayed to local people familiar with the area during a 1 day conference organised within the region by the Countryside Agency in November 2004. As part of the event the photo-montages shown in Figs. 3 and 4 were presented on a large (A0) format poster and the real-time landscape models were displayed on a 1.5 m diameter Elumens VisionStation (http://www.elumens.com). To view the latter the user sits in front of the screen at a small desk containing a data projector with a specialised short-throw, wide-angle lens. A laptop computer used to run the model is connected to the projector via a standard video cable. The lens allows the image to be projected on to the curved screen, thus filling more of the user's peripheral vision than a standard monitor.

Delegates attending the conference were asked to complete a short survey which asked the following questions:

- How well do you feel the visualisations represent possible landscape changes?
- Which visualisation method do you prefer?
- Which of these future landscapes do you think we should be working towards?

Although only a small sample of survey forms were completed ($n = 23$), 78% of respondents found the photo-montages helpful or very helpful in representing possible landscape change, compared with 65% for the real-time models. More people found the real-time model difficult to appreciate or use—17% found this method 'not at all helpful', compared with only 4% for the poster images. However, there is a learning curve associated with navigating a real-time model and those who are less familiar with computer technologies may have found this intimidating. It is interesting that about half of the respondents favoured the real-time approach model and half favoured the photographic images when asked which method they preferred.

Despite these variations in attitudes to display methods, there was considerable consensus in response to the third question. Ninety-one percent favoured the Local Stewardship (B2) landscape. This scenario supports policies that switch away from fossil fuels, placing stronger environmental controls above economic objectives, resulting in a lower level of global warming than the National Enterprise (A2) scenario. Overall, although this needs further evaluation, the results of this small study suggest that representing potential climate change impacts through landscape visualisations can help to make the complex effects of increases in global mean temperatures more tangible. Nevertheless, it is also clear that the manner in which visualisations are presented can be influential and that a real-time approach may not always be beneficial. Bishop (2005) draws similar conclusions on the latter point and it is evident that the merits of different display methods require further research.

6. Discussion

It is important to recognise that visualisations are simply 'plausible representations' of possible futures and should not be taken too literally. The approach we have taken to scenario construction incorporates both policy documents and modelling outputs (CLUAM); each has elements of uncertainty and the images are the result of further interpretation of these data. However, by using multiple scenarios and setting them within recognised international (IPCC) and national (SPRU) frameworks, this ensures a degree of consistency and continuity with other research. The representation of uncertainty in landscape visualisations is itself a technical challenge and some possible approaches are discussed by Appleton et al. (2004).

The two 'climate change' visualisations presented here (Fig. 4) are derived from scenarios that are based on current policy, some of which are already reflecting concerns about possible climate change impacts. These futures are based on two contrasting paradigms, one of which furthers these fledgling policy responses to climate change (reducing dependence on fossil fuels, introducing water conservation measures, etc.). Both include land use changes that specifically incorporate a response to climate change and suggest that even by the 2020s crop growing zones will begin to shift in response.

The variation between scenarios illustrates the point that it is the choices that are made now regarding the development of our society, that will determine how robust future rural landscapes will be against the challenges posed by climate change. This is an important message. Without providing a real impression of how particular places might be altered by climate change it will remain difficult for individuals to engage with the issue and consider whether they might be willing to modify their own behaviour to mitigate against its effects, or link their own actions to the consequences, as Hardin (1968) expressed so well in 'The Tragedy of the Commons'. The soft-option is to decide that climate change is not an issue requiring immediate policy consideration. A key benefit of the approach described here, considered essential by the IPCC in climate impacts assessment (Parry and Carter, 1998), is the presentation of alternative potential future visions as a single 'most likely' pathway does not exist.

More work is required to evaluate how people respond to images of potential climate change impacts (Sheppard, 2004; Nicholson-Cole, 2005), but it is apparent from the preliminary survey described in this paper that people can distinguish between scenario images and select a preferred future state. The potential exists, therefore, for visual representations of scenarios to be constructed using a method that can be fully described and opened to scrutiny, which can contribute to the communication and formulation of future policy options without resorting to sensationalism.

An important benefit of the approach to creating landscape-scale scenarios discussed in this paper is that it is not expensive to undertake and it is transferable, making it possible to evaluate impacts and landscape change at any location where suitable information (i.e. policy documents and modelling results) exists. A Europe-wide climate change impacts evaluation was presented in Parry (2000), and Rounsvell et al. (2005) have modelled agricultural land use change across Europe under IPCC climate change scenarios. EU Directives now exert a substantial influence on many aspects of agricultural and environmental policy across Europe and these provide a framework within which national sources of policy guidance can be set. There are also suitable sources of GIS data in many countries and the GIS-based visualisation techniques described in this paper are becoming increasingly common (see examples in Bishop and Lange, 2005; Buhmann et al., 2005).

Further work is required to add more detail, that will help to inform on more subtle, smaller-scale changes that are likely to take place as the climate warms, e.g. reductions in the water table and changes in biodiversity. The potential for this will undoubtedly improve in the future as more information becomes available on time-dependent climate change impacts at the local scale (which is currently lacking) and as climate change becomes more evident. This is where the use of digital landscape models will really be of benefit, since continued advances in computing power and modelling/visualisation integration open up the prospect of users being able to pose 'what if' questions and see the answers in real-time (rather than as at present having to switch between pre-defined scenarios). Operationalisation of such decision support tools may be several years ahead, but it is evident from the research discussed in this paper that feasible and transferable methodologies exist to develop scenarios and translate these into landscape visualisations, and that such representations offer new opportunities for the communication and formulation of policy options with respect to future patterns of land use across Europe.

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