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# The availability of land for perennial energy crops in Great Britain

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## Abstract

This paper defines the potentially available land for perennial energy crops across Great Britain as the first component of a broader appraisal undertaken by the ‘Spatial Modelling of Bioenergy in Great Britain to 2050’ project. Combining data on seven primary constraints in a GIS reduced the available area to just over 9 M ha (40% of GB). Adding other restrictions based on land cover naturalness scores to represent landscape considerations resulted in a final area of 8.5 M ha (37% of GB). This distribution was compared with the locations of *Miscanthus* and SRC willow established under the English Energy Crop Scheme during 2001–2011 and it was found that 83% of the planting fell within the defined available land. Such a correspondence provides confidence that the factors considered in the analysis were broadly consistent with previous planting decisions.

**Keywords:** geographical information systems, land availability, land use, landscape sensitivity, perennial energy crops, planting constraints

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## Introduction

There is a substantial degree of uncertainty regarding the long-term development of the global bioenergy sector and the capacity for sustainable increases in biomass supply. Recent estimates of global biomass potential vary at least six-fold (from ca. 100 EJ to over 600 EJ), with much depending on assumptions regarding the availability of current agricultural land and whether the focus is on what might be physically possible, socially acceptable or environmentally responsible (Slade *et al.*, 2011). Considerable efforts have also been expended in defining ethical principles and sustainability criteria for bioenergy policy (e.g. Nuffield Council on Bioethics, 2011; Department of Energy & Climate Change, Department for Environment, Food & Rural Affairs, Department for Transport, 2012). Nevertheless, there is also general recognition that bioenergy can be an important part of the solution in enabling many countries to meet future energy supply and climate change mitigation objectives (MacKay, 2009; Chum *et al.*, 2012; Valentine *et al.*, 2012). For instance, the recent UK Bioenergy Strategy predicts that bioenergy could sustainably provide around 12% of national primary energy demand in 2050 (Department of Energy & Climate Change, Department for Environment, Food & Rural Affairs, Department for Transport, 2012).

Bioenergy is generated by combusting solid, liquid or gas fuels made from biomass feedstocks (Department of

Energy & Climate Change, Department for Environment, Food & Rural Affairs, Department for Transport, 2012; p.77). These feedstocks can take a variety of forms, including algae, biodegradable wastes and residues, forestry products and agricultural crops (both food and nonfood). There are also many different ways in which these feedstocks can be converted into energy products such as heat, electricity or transport fuels (Chum *et al.*, 2012; Parliamentary Office of Science & Technology (POST), 2012). Indeed, it is this flexibility which is one of the attractions of bioenergy in terms of future energy supply.

Within the category of crops, a further distinction is often made between ‘first’ and ‘second’ generation combinations of feedstocks and conversion technologies. The former typically involve annually planted crops (e.g. cereals, oilseed rape and maize) which can be processed to provide food or energy products, while the latter include perennial rhizomatous grasses (e.g. *Miscanthus*) and fast growing tree species (e.g. short rotation coppice (SRC) willow) with a restricted range of alternate uses but greater energy generation efficiency and higher greenhouse gas (GHG) mitigation potential (Karp & Shield, 2008; Don *et al.*, 2012). These ‘dedicated’ energy crops account for only 3% of current European bioenergy production (Don *et al.*, 2012), but this is expected to increase as the pressures for decarbonization of energy supply intensify and technical advances allow the commercial use of lignocellulosic biomass for the production of a range of liquid or gaseous fuels in addition to combustion for heat and/or power (Chum *et al.*, 2012).

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*Miscanthus* and SRC willow are the dominant dedicated energy crops in Great Britain at present. There is good information on the planting initially supported by rural development programmes in England and Scotland (e.g. Natural England, 2013), but it is also known that some crops have been removed after the end of agreements and others have been established without grants. A similar system of financial support has not existed in Wales and current production is negligible (National Non-Food Crops Centre (NFCC), 2012). Since there is no definitive single source of data the estimates of planted area vary, but suggest that there are currently somewhere between 0.0078 and 0.0135 M ha of *Miscanthus* and 0.0022–0.0055 M ha of SRC willow in Great Britain, the vast majority of this occurring in England, particularly the East Midlands, South West and Yorkshire & Humber regions (Don *et al.*, 2012; National Non-Food Crops Centre (NFCC), 2012; Defra, 2013). This pattern reflects demand for cofiring products from several coal power stations, plus use in smaller combined heat and power (CHP) plants and local heating installations.

The UK Biomass Strategy in 2007 included an aspiration for up to 0.35 M ha of perennial energy crops to be planted in the United Kingdom by 2020, with an additional 0.75 M ha for biofuel feedstocks (Department for Environment, Food & Rural Affairs, Department for Trade & Industry, Department for Transport, 2007). In the recent UK Bioenergy Strategy (2012), there is a more cautious tone with recognition that while there are some low-risk pathways (e.g. generation of heat and electricity through CHP processes) the use of bioenergy 'is not automatically low carbon, renewable or sustainable' (Department of Energy & Climate Change, Department for Environment, Food & Rural Affairs, Department for Transport, 2012; p.14). Estimates of potential future land use are also more nuanced, with the maximum extent not impinging on food production cited as 0.93–3.63 M ha in England and Wales, but acknowledging that the extent to which this is realized will depend hugely on factors such as the distribution and extent of demand, farm economics and public attitudes (Department of Energy & Climate Change, Department for Environment, Food & Rural Affairs, Department for Transport, 2012). Given current barriers to bioenergy deployment (Adams *et al.*, 2011), a low-end projection is for 0.007–0.05 M ha of perennial energy crops in England and Wales by 2020, with a 20% annual increase in current planting rates resulting in around 0.04 M ha by that date (National Non-Food Crops Centre (NFCC), 2012). It is also important to note that with the trend towards devolution in the past 15 years, there are increasing differences in policy implementation and data collection between the constituent parts of the United Kingdom. In particular, Northern Ireland is not considered further

in this study due to the difficulties of obtaining the necessary data sets in a form consistent with the remainder of the United Kingdom.

Previous studies that have sought to assess the availability of land for planting perennial energy crops in Great Britain have considered a range of factors relating to physical limits on production, existing land use and a variety of planning or landscape designations (National Non-Food Crops Centre (NFCC), 2012). Typically the possibility of planting has been excluded from urban areas, on slopes steeper than 10 or 15% and close to public rights of way, main roads, rivers or lakes (e.g. Land & Landscape Management Ltd, 2004; Lovett *et al.*, 2009; Aylott *et al.*, 2010). Other common environmental constraints have included elimination of existing woodlands, natural and seminatural habitats (including unimproved grasslands) and soils with high levels of organic carbon content (due to the GHG emissions during planting operations) (e.g. Bauen *et al.*, 2010; SQWenergy, 2010). There has also been a presumption against planting on sites designated on biodiversity or cultural heritage grounds. All of these considerations are reflected in the planting guidance and Environmental Impact Assessment requirements associated with the energy crop funding schemes (Coleby *et al.*, 2012; Natural England, 2013).

In addition to these restrictions there are other factors where the constraint is more relative than absolute. One issue concerns the alternative use of land for food production and this has been incorporated into several studies by exclusion of the most productive grades of agricultural land (e.g. Lovett *et al.*, 2009). In this study such a blanket approach has not been adopted in the initial assessment of availability and the land-use implications of different financial returns to farmers from food and nonfood crops are examined in subsequent economic modelling (Alexander *et al.*, 2014).

A second consideration is the limitation of potential planting on grounds of visual or landscape impacts. Crops such as *Miscanthus* and SRC willow are dense and taller (3–6 m high) than those they typically replace, so have the potential to obscure views and alter landscape character (Rowe *et al.*, 2009; Dockerty *et al.*, 2012). Some future energy scenarios have excluded perennial energy crops for this reason (e.g. Howard *et al.*, 2011), while others have used the boundaries of areas designated on grounds of landscape quality such as National Parks (NPs), Areas of Outstanding Natural Beauty (AONBs) or Scottish National Scenic Areas (NSAs) as a secondary constraint (e.g. Aylott *et al.*, 2010). Several regional assessments have implemented a more nuanced approach where descriptions of landscape zones (e.g. English Joint Character Areas, JCAs) have been translated into a ranked sensitivity scale (e.g.

Capener *et al.*, 2004; Thumin & White, 2007), though generating such appraisals is time consuming and it would require substantial time and expertise to complete a similar national coverage.

In a context such as landscape impacts, it is also important to recognize that potential constraints can be dynamic rather than static and absolute (Department of Energy & Climate Change (DECC), 2009; p.82). Landscape preferences may well change as societal attitudes to different energy sources evolve (Selman, 2010) and although negative responses to perennial energy crops have been recorded (e.g. Upham & Shackley, 2007), another recent survey found that public response was more influenced by the prospective size of associated infrastructure than the actual planting of the crops (Dockerty *et al.*, 2012). Assuming a complete absence of planting in NPs, AONBs and NSAs also seem too pronounced a restriction when small areas are explicitly fundable under the English Energy Crops Scheme (Natural England, 2013) and already exist in places such as Exmoor. It therefore appears relevant to try to take into account the implications of different scales of energy crop planting by developing a more spatially detailed way of evaluating such landscape sensitivity issues.

The integration and analysis of spatial supply and/or demand distributions is central to the assessment of future scenarios regarding the use of perennial energy crops. Several previous studies of Great Britain have adopted such an approach, combining details of land availability with yield maps, potential supply for particular power stations and implications for food production or GHG emissions (e.g. Hillier *et al.*, 2009; Lovett *et al.*, 2009; Aylott *et al.*, 2010; Bauen *et al.*, 2010). However, these individual spatial studies had some limitations in scope, particularly in terms of incorporating the interactions between supply and demand at a national scale, farm economics and yield alterations under projected climate change (e.g. Hastings *et al.*, 2009; Sherrington & Moran, 2010). The aim of the 'Spatial Modelling of Bioenergy in Great Britain to 2050' project (Smith *et al.*, 2014) was therefore to provide such a broader 'whole system' perspective and identify the implications for national policy regarding perennial energy crops. This paper represents the first step in such a holistic analysis and focuses on defining the potentially available land across all of Great Britain as a basis for subsequent research to examine additional supply and demand issues (e.g. Alexander *et al.*, 2014; Hastings *et al.*, 2014; Wang *et al.*, 2014). Novel features of the approach include the incorporation of a measure of landscape naturalness as a constraint and a validation exercise through comparison of the final map with locations where planting has taken place under the Energy Crops Scheme in England.

## Materials and methods

Based on the literature reviewed above and discussions with stakeholders at project meetings, a series of data layers for England, Scotland and Wales were compiled in the ArcGIS software (ESRI, 2013). Table 1 summarizes the sources used and the organizations or websites that data were obtained from. It is worth noting that for several layers this required obtaining data from two or three different organizations (reflecting the devolution-related challenges noted previously) and then merging different attribute categorizations. For soil characteristics, it was decided to use information from a coarser resolution global database than two separate national ones because the former had a consistent classification with sufficient detail for the purposes required.

The data were obtained in a mixture of raster and vector formats which for the purposes of overlay analysis needed to be transformed into a consistent structure. A raster grid of 100 m resolution was used for this purpose, the choice reflecting compatibility with a number of the coarser source data scales. Where the source details were at higher resolutions (e.g. land cover and elevation databases), then summary parameters such as majority or maximum values for each 100 m grid cell were derived. In addition, a land/sea mask grid was generated from Ordnance Survey vector outlines and used to ensure consistency in layer extents during the subsequent overlay processing. As an initial definition of land availability, the factors listed in the first seven rows of Table 1 (i.e. from urban areas through to cultural heritage) were defined as primary binary constraints (i.e. suitable or not) and the raster grids overlaid to find the cells meeting all seven criteria.

Several different approaches were investigated as a means of mapping landscape sensitivity in a more detailed manner. Given that the height of perennial energy crops has been identified as an issue one possibility was to generate measures of visibility (e.g. Miller, 2001; Bishop, 2003) and restrict planting on the most open landscapes. However, while such calculations are quite feasible on a site or even regional basis they are also computationally intensive and a national assessment at sufficiently detailed resolution to be meaningful was not feasible within the resources available for the project. An alternative approach was suggested by findings that perennial energy crops are sometimes regarded as an 'alien' landscape feature (van der Horst & Evans, 2010) and the tendency for human preferences to be positively related to the naturalness of a scene (Purcell & Lamb, 1998; Ode *et al.*, 2009). Previous research by Jackson *et al.* (2008) on assessing landscape naturalness as part of a wider tranquillity mapping exercise was therefore adapted to apply scores on a 0–100 scale to classes from the CEH Land Cover Map 2007 (Centre for Ecology & Hydrology (CEH), 2013a). The final score for each 100 m cell was calculated based on a weighted average of 50% from the score of the land cover present there and 50% from the average score within a four cell (i.e. approximately 500 m) circular radius of the target cell (to take account of neighbouring land cover types).

Fig. 1 shows the results from this exercise with the blue shadings in Fig. 1a representing higher levels of naturalness and the light outlines depicting the boundaries of NPs, AONBs

**Table 1** Data sources used in the GIS analysis

| Layer names  | Definitions and data sources  |
|--|---|
| Urban areas, main roads, rivers, lakes                 | Ordnance Survey Meridian Data from the Edina Digimap Service, <a href="http://digimap.edina.ac.uk">http://digimap.edina.ac.uk</a>   |
| Slope > 15%  | Limit beyond which planting and harvesting crops is impractical. Calculated in ArcGIS using Ordnance Survey Panorama DTM from the Edina Digimap Service, <a href="http://digimap.edina.ac.uk">http://digimap.edina.ac.uk</a>  |
| Existing woodland                                      | Ordnance Survey Meridian Data from <a href="http://digimap.edina.ac.uk">http://digimap.edina.ac.uk</a> , plus ancient woodland and national forest inventory products from <a href="http://www.forestry.gov.uk/inventory">http://www.forestry.gov.uk/inventory</a> . Any woodland areas defined on these databases were excluded from planting. |
| Natural & seminatural habitats                         | Classified from Land Cover Map 2007 (including acid, neutral and calcareous grasslands), data from <a href="http://www.ceh.ac.uk/LandCoverMap2007.html">http://www.ceh.ac.uk/LandCoverMap2007.html</a>  |
| High organic carbon soils                              | Histosols and soils with TOC >30% from the Harmonized World Soil Database Version 1.2 from <a href="http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/">http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/</a>  |
| Designated areas                                       | LNR, NNR, RAMSAR, SAC, SPA and SSSI sites, boundaries from <a href="http://magic.defra.gov.uk">http://magic.defra.gov.uk</a> , <a href="http://jncc.defra.gov.uk">http://jncc.defra.gov.uk</a> , <a href="http://www.snh.gov.uk">http://www.snh.gov.uk</a> and <a href="http://www.ccw.gov.uk">http://www.ccw.gov.uk</a>                        |
| Cultural heritage                                      | Scheduled Monuments and World Heritage Sites, boundaries from <a href="http://magic.defra.gov.uk">http://magic.defra.gov.uk</a> and <a href="http://data.historic-scotland.gov.uk">http://data.historic-scotland.gov.uk</a>   |
| Landscape naturalness                                  | Calculated using values from Jackson <i>et al.</i> (2008) applied to Land Cover Map 2007 classes, data from <a href="http://www.ceh.ac.uk/LandCoverMap2007.html">http://www.ceh.ac.uk/LandCoverMap2007.html</a>   |
| National Parks and Areas of Outstanding Natural Beauty | Included National Scenic Areas for Scotland, boundaries from <a href="http://magic.defra.gov.uk">http://magic.defra.gov.uk</a> , <a href="http://www.ccw.gov.uk">http://www.ccw.gov.uk</a> and <a href="http://crtb.sedsh.gov.uk/spatialDataDownload/dload.asp">http://crtb.sedsh.gov.uk/spatialDataDownload/dload.asp</a>                      |
| Existing energy crop scheme planting                   | Areas of <i>Miscanthus</i> and SRC Willow planting supported by the English Energy Crops Scheme 2001–2011, polygon boundaries from <a href="http://magic.defra.gov.uk">http://magic.defra.gov.uk</a>  |
| Agricultural land classification                       | Five grades of agricultural land, plus nonagricultural and urban areas, boundaries from <a href="http://magic.defra.gov.uk">http://magic.defra.gov.uk</a> , the Welsh Assembly and Scottish Governments   |

and NSAs. A general tendency for the former to be higher within the latter is apparent, particularly in much of lowland England. More quantitatively, the mean naturalness score is 73.2 in NPs, 69.4 in AONBs or NSAs and 63.5 elsewhere, with no overlap between 95% confidence intervals around the three mean values. Figure 1b and c provides another comparison, with the former showing the results of the energy crop landscape sensitivity assessment for JCAs in south west England undertaken by Capener *et al.* (2004) and the latter the calculated naturalness scores for the same region. The 'high' sensitivity category has a mean naturalness score of 69.2, 'moderate-high' 61.4 and the remaining three a combined mean of 58.8, again with no overlap between the 95% confidence intervals around the three mean values. Moreover, the landscape scores in Fig. 1c highlight variations within sensitive areas such as Dartmoor and Exmoor that are obscured by the blanket classification of individual JCAs.

The use of naturalness scores as an indicator of landscape sensitivity was discussed at a project stakeholder meeting in January 2012 and agreed as an appropriate way forward so the scores were reclassified into a binary layer that could be overlaid on the seven primary constraints. To create this binary output, two reclassification thresholds were used, all scores of 85 or more being classified as unsuitable for planting as well as those of 65 or more inside a NP, AONB or NSA. This approach gave recognition to areas of high naturalness wherever they

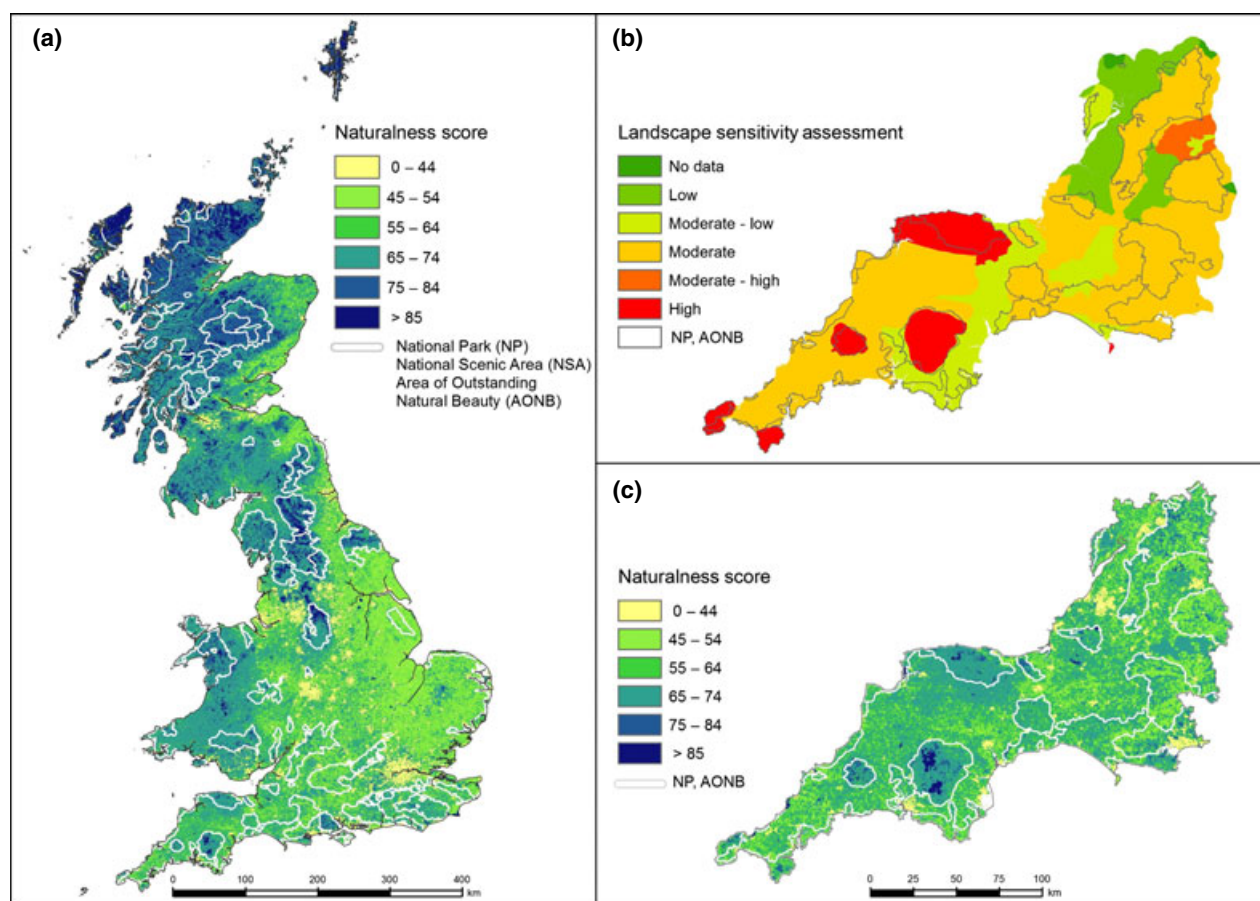
occurred and acknowledged the special landscape status of NPs, AONBs and NSAs without eliminating all land within such zones from possible planting.

It was also considered important to include some validation of the result from overlaying the eight factors described above by comparison with sites on which planting had already taken place. For this purpose, polygon boundaries of areas where planting was supported by the Energy Crops Scheme in England were obtained and converted to a 100 m resolution raster grid. All grid cells whose centre fell within one of the polygon boundaries were defined as planted areas in the raster grid. National agricultural land classification maps were also acquired so that the extent of different grades on the estimated available land for perennial energy crops could be assessed.

## Results

The total area of land in Great Britain (GB) using the 100 m mask grid was 22.9 M ha. Table 2 shows the areas of available land after each of the seven primary constraints was excluded. No single factor restricted the available land to less than 70% of the GB land area, although three (slope, soil type and natural and seminatural habitats) each excluded between 25% and 30%. When the seven were combined, however, the share of





**Fig. 1** Geographical variations in land cover naturalness scores and landscape sensitivity assessments. (a) National distribution of naturalness scores with outlines of National Parks, Areas of Outstanding Natural Beauty (AONBs) and NSAs, (b) Energy crop landscape sensitivity assessment for Joint Character Areas in south west England (data from Capener *et al.*, 2004), (c) Naturalness scores in south west England with outlines of National Parks and AONBs.

**Table 2** Overlay results using seven primary constraints

| Constraint layer                       | Land available (ha) | % available |
|--|---------------------|-------------|
| Natural & seminatural habitats         | 16 233 342          | 71          |
| Slope >15%                             | 16 704 785          | 73          |
| High organic carbon soils              | 16 794 958          | 73          |
| Urban areas, main roads, rivers, lakes | 20 289 135          | 89          |
| Designated areas                       | 20 469 186          | 89          |
| Existing woodland                      | 20 566 746          | 90          |
| Cultural heritage                      | 22 719 325          | 99          |
| All seven constraints                  | 9 086 465           | 40          |

land available was reduced to 40%, a total of just over 9 M ha.

As implied in Table 3 the land in NPs, AONBs and NSAs represent some 22% of GB. This constraint is of similar magnitude to that arising if all land with a

naturalness score of 75 or more is removed from consideration. Lowering the naturalness score threshold to 65 has a much more substantial impact and reduces the available land to just over 40% of GB. However, when these different landscape factors are combined with the seven primary constraints the impact is quite muted, implying that there is substantial overlap in the areas excluded. Supplementing the primary constraints with all land in NPs, AONBs and NSAs leaves 7.8 M ha of land available (34%), while using the naturalness score limits instead increases the total area to 8.5 M ha (37%). In essence, the two different definitions of more sensitive landscapes have quite similar effects, but using the naturalness scores allows less appropriate areas for planting to be identified with a higher degree of spatial detail.

Figure 2 shows where the addition of the land cover naturalness constraint has most impact. Fig. 2a illustrates the distribution of available land using the seven

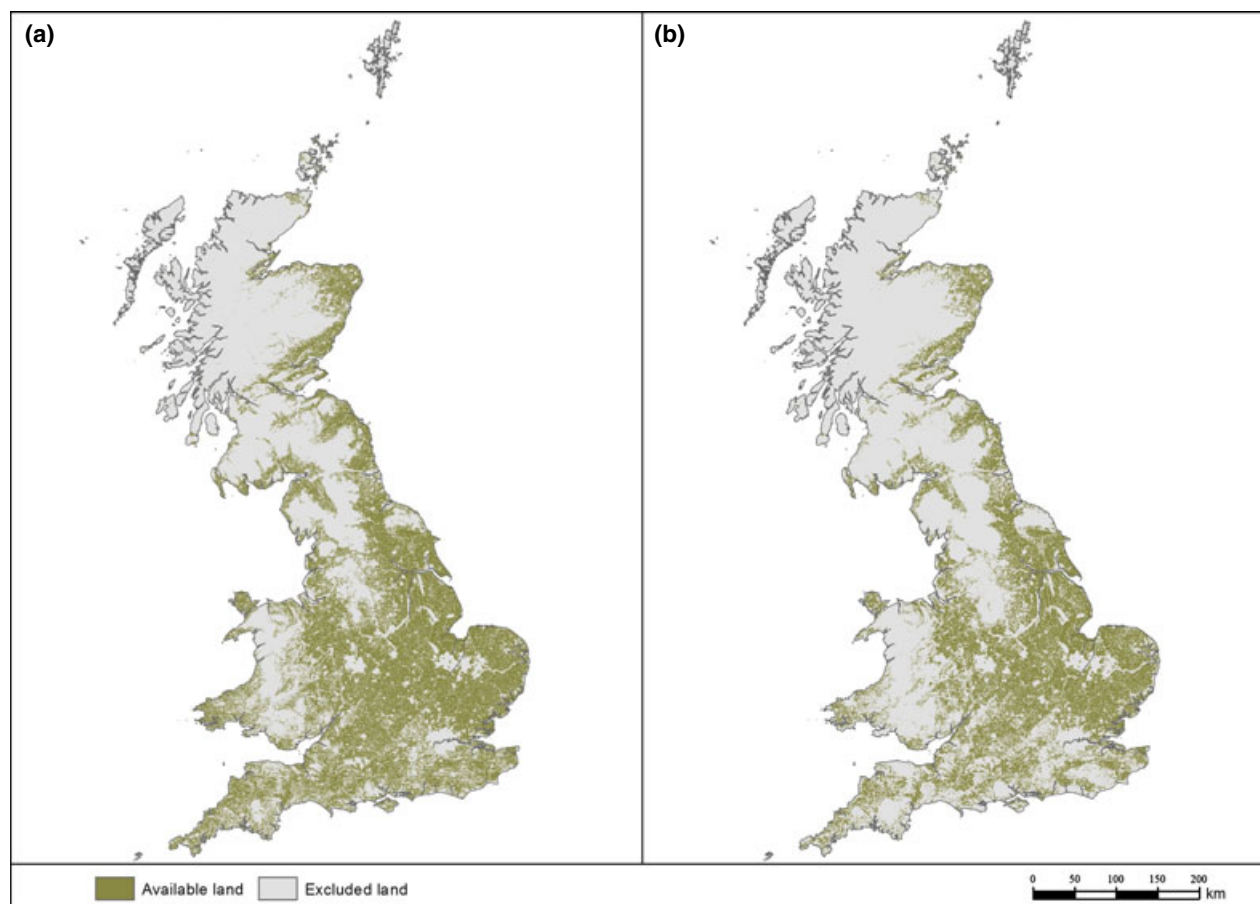
**Table 3** Overlay results after including landscape factors

| Constraint layer   | Land available (ha) | % available |
|--|---------------------|-------------|
| Land in NPs, AONBs or NSAs   | 17 888 285          | 78          |
| Land Cover Naturalness Score $\geq 75$   | 18 128 958          | 79          |
| Land Cover Naturalness Score $\geq 65$   | 9 247 722           | 40          |
| All Seven Primary Constraints  | 9 086 465           | 40          |
| Seven Constraints + (NPs, AONBs or NSAs)   | 7 849 435           | 34          |
| Seven Constraints + (Score $\geq 75$ ) + (Score $\geq 65$ and in NPs, AONBs or NSAs) | 8 505 366           | 37          |

primary constraints and Fig. 2b depicts the consequences of also including the naturalness score thresholds. Comparing the two maps indicates that there is relatively little change in Scotland or northern England,

though the exclusion of some upland areas becomes more clearly defined. More substantial alterations are apparent in southern England, reflecting the number of NPs or AONBs present and the use of a lower naturalness score threshold in these areas. Table 4 summarizes the distribution in Fig. 2b on a regional basis, using government office regions (GORs) for England and amalgamations of local authorities for Wales and Scotland. Much of the available land is concentrated in six GORs within England, each with over 45% of their land area potentially available. These six regions account for just over 6 M ha of the 8.5 M ha total (71%).

The distribution of available land in Fig. 2b also corresponds with many parts of the country that are important for food production, particularly arable farming. Overlaying agricultural land classification maps indicates that 21% of the 8.5 M ha is categorized as Grade 1 or 2 (the most productive and versatile groups), 59% as Grade 3 and 20% as poorer or nonagricultural land. Following the approach in some previous studies of considering only agricultural land in Grades 3–5



**Fig. 2** Geographical distributions of potentially available land for perennial energy crop planting. (a) Result using all seven primary constraints, (b) Result with additional landscape naturalness constraint.

**Table 4** Regional distribution of available land

| Region                         | Land available (ha) | % of region |
|--------------------------------|---------------------|-------------|
| East of England                | 1 310 115           | 69          |
| English East Midlands          | 1 065 476           | 68          |
| English West Midlands          | 780 063             | 60          |
| Yorkshire and the Humber       | 772 066             | 50          |
| South East England             | 956 116             | 50          |
| South West England             | 1 139 518           | 48          |
| North Eastern Scotland         | 303 760             | 41          |
| South Eastern Scotland         | 338 306             | 39          |
| Wales West                     | 209 344             | 36          |
| North West England             | 463 488             | 33          |
| Wales South                    | 95 189              | 26          |
| Wales North                    | 152 782             | 25          |
| Eastern Scotland               | 450 379             | 25          |
| Wales East                     | 95 707              | 18          |
| South Western Scotland         | 224 077             | 17          |
| London                         | 22 501              | 14          |
| Scottish Highlands and Islands | 126 151             | 3           |

reduces the available area to 6.4 M ha and if Grade 3 is also excluded the total remaining is 1.4 M ha (6% of GB).

Data on 1562 *Miscanthus* and SRC willow planting agreements funded by the Energy Crops Scheme in England during 2001–2011 were used to evaluate the results of the land availability analysis. In this time period, some 0.0090 M ha of planting was supported and when the associated land parcel polygon boundaries were converted to 100 m grid cells the area encompassed was 0.0147 M ha. This increase was partly due to the generalization associated with the conversion process, but also because some planted areas covered only part of the smallest digital parcel boundaries held by Natural England. Of the 0.0147 M ha 83% occurred on the 8.5 M ha of identified available land. Of the remaining 0.0025 M ha of planting, some 0.0018 M ha (i.e. another 12% of the total) was on areas classified as arable farming or improved grassland in land cover mapping dated at 2000 or earlier (Centre for Ecology & Hydrology (CEH), 2013b), leaving just 0.0007 M ha (i.e. 5% of the total) on urban or less intensive categories.

## Discussion

The aim of this study was to define the potentially available land for planting of perennial energy crops in Great Britain. Seven individual primary constraints each excluded no more than 30% of GB, but when combined together reduced the available area to just over 9 M ha (40% of GB). Adding other variables to represent

landscape considerations further constrained the area to 34–37% of GB, the selected approach of naturalness score thresholds resulting in a final area of 8.5 M ha. This distribution encompassed 83% of the land planted under the English Energy Crop Scheme during 2001–2011. Given the uncertainty generated through the aggregation and conversion of different spatial data formats and supports (Cressie, 1996), the fact that 83% matched identified available land when the latter represented 53% of England (i.e. a ratio of 1.6–1) implies quite a strong validation of the analysis approach in terms of correspondence with the independent crop scheme data.

Of the 8.5 M ha total, just over 7 M ha is in England (6.5 M ha) and Wales (0.5 M ha). Not surprisingly, this figure is rather larger than a range of 0.93–3.63 M ha cited by Department of Energy & Climate Change, Department for Environment, Food & Rural Affairs, Department for Transport (2012) because the latter represents the maximum extent not impinging on food production. Making a direct comparison of the two estimates is complicated by the fact that nearly 60% of the available area identified in this study is Grade 3 agricultural land and the distinction made between Grades 3a and b in many policy documents (e.g. Natural England, 2012) is unfortunately not incorporated in currently available mapping. Nevertheless, if a conservative assumption is made that half of the estimated available land is Grade 3b or poorer then this gives a figure of 3.5 M ha which is close to the top end of the range mentioned in the Bioenergy Strategy (2012). Even if only Grade 4 or 5 land is considered then this is certainly sufficient to meet the low-end projections of planting through to 2020 made by National Non-Food Crops Centre (NFCC) (2012). The implication therefore is that the estimates of land availability made here do not contradict current policy aspirations and that the actual extent of future planting is much more likely to depend on economic considerations than any planning system constraints.

In terms of methods to map potentially available land for perennial energy crops, there were two main innovations in this study. The first was to use thresholds of land cover naturalness scores instead of simply excluding all areas within NPs, AONBs or NSAs. This approach was adapted from previous research on tranquillity mapping and while admittedly simple had the advantages of being readily implementable on a national scale and corresponding well to recognized zones of landscape value while making some differentiation within them. Future research could undoubtedly refine some aspects of the weightings involved, for instance by including estimates of the visibility of different types of land cover.



The second advance was to use data on existing planting to assess the outcome of the availability assessment. In this instance, the correspondence was good which provided confidence that the factors considered in the analysis were broadly consistent with previous planting decisions. Such a comparison is obviously dependent on the availability of suitable information, but in an era of rapid advances in remote sensing capabilities and moves towards open access data (e.g. European Commission, 2013) these restrictions are likely to become less in the future. In the particular context of GB-wide studies, it is also to be hoped that some of the current difficulties in combining data from different agencies in England, Scotland and Wales are reduced because this was a time-consuming aspect of the analysis. Nevertheless, the research presented in this paper demonstrates how a diversity of data can be integrated together in a GIS and used to map out potentially available land for perennial energy crops in a form that provides a robust foundation for subsequent components of the 'Spatial Modelling of Bioenergy in Great Britain to 2050' project.

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