Balancing UK Land Use

A Guide to Friends of the Earth's UK Land Calculator

Version: 1.2

23 November 2016

Document Version History

Version	Date	Author	Description
Working version (0.1)	18 June 2015	Kenneth Richter	Working Version of document (under previous 'competing demands on UK land' name)
Working / snapshot Version (0.2)	30 July 2015	Kenneth Richter and Chris Gordon-Smith	Working/ snapshot version. Introductory material added. Assumptions / calculations section restructured and material added / amended. References consolidated / added.
0.3 - Draft	3 September 2015	Chris Gordon-Smith	Version for discussion (KR / CGS), including updates and identifying discussion points
Several intermediate snapshot versions			
1.0 - Draft	3 January 2016	Chris Gordon-Smith	Draft for final review. Includes updates following feedback. Renamed "A Guide to the Friends of the Earth UK Land Calculator"
1.0 - Draft 2	5 February 2016	Chris Gordon-Smith	Review comments included
1.0 - Draft 3	4 April 2016	Chris Gordon-Smith	Points from Friends of the Earth Illustrative Scenario Review included
1.0 - Draft 4	11 April 2016	Chris Gordon-Smith	Minor updates
1.0 - Draft 5	13 April 2016	Chris Gordon-Smith	Preview Version – some text re-arranged for readability.
1.0	23 April 2016	Chris Gordon-Smith	First release
1.1	22 November 2016	Chris Gordon-Smith	Updated following pre-launch comments:- 1) Updated Biomass for Energy text to remove incorrect text referring to UK Bioenergy Strategy. Made minor change to Medium option as a result (from 1.87 to 2.05). 2) Made clear that options for land use factors have been chosen to be relevant for the purpose of illustrating, discussing and exploring land use issues 3) Removed statement that the Calculator assumes no increase in overseas land footprint. It doesn't (although the Friends of the Earth Illustrative Scenario does) 4) Updated to reflect changes to the Calculator itself. Eg more scenarios and comment area 5) Added text on simplified options for illustrative purposes, along with guideline on what to do if a preset option is too far from user's preferrence 6) Added suggestions on nature of material to be included in scenario explanatory text 7) Added clarification on primary land use 8) Added text on rewilding 9) Updated aviation biofuels calculation to use rapeseed rather than Jotropha. Also remove

			reference to Luftahsa document that is no longer available at the earlier URL 10) Reworded to avoid saying that land to be used for housing cannot be used for farming. Could be misunderstood – people can produce food in their gardens
1.2	23 November 2016	Chris Gordon-Smith	Minor correction

Contents

1 Introduction

1.1 Background

Demand for land in the UK is increasing. There are many different requirements for future land use, which often conflict or compete with one another. For example, residential land cannot be used for cattle grazing, and land dedicated to growing biofuels cannot be used to grow food crops. However, there are also opportunities to free up land from existing uses. For example, changes in diet, agricultural yield increases, or a reduction in the amount of food waste could lead to less land being required for agriculture.

But can we balance new demands for land with measures that would free up land? How do the various new demands for land compare in scale? What technological advances are realistic? What kind of policy changes may be necessary?

Friends of the Earth has produced a UK Land Use Calculator (referred to below as 'The Calculator') that illustrates the issues involved in these questions. This web based graphical tool provides a user friendly way to experiment with choices for future UK land use, and to visualise the nature and scale of their consequences. For example, the very large reduction in demand for agricultural land that would result from a reduction in human consumption of meat and dairy products can be seen. The large land use associated with high levels of biofuel and biomass for energy production is also made evident, along with the comparatively low land demand associated with solar electricity and onshore windpower.

1.2 Purpose of the UK Land Use Calculator

The purpose of the Calculator is to illustrate some of the issues that will affect UK land use over the next 15 years, and to encourage discussion and exploration of these issues. Ultimately such discussion should inform important policy decisions that affect land use in the UK.

1.3 Illustrative Scenarios

In addition to enabling experimentation, the Calculator also provides the capability to show various different pre-defined scenarios illustrating different ways in which land use could change by 2030. In its initial release, the Calculator includes a scenario produced by Friends of the Earth. Explanatory details of this are given in the document "Friends of the Earth's Illustrative Land Use Scenario" [1]. We aim to add a range of alternative scenarios from leading opinion formers.

1.4 Intended audience

The Calculator is aimed at anyone (specialists and non-specialists) with an interest in UK land use issues. Specialists may include researchers, thinkers/influencers, those working in the energy and farming industries, planners, policy makers, NGOs and others. Non-specialists could include anyone with an interest in land policy. For example, residents of areas affected by land issues, countryside lovers, people using land for recreational purposes (e.g. hiking, golfing, horse riding), and others.

We hope that specialists and non-specialists alike will find the Calculator useful as an illustration of land use issues and trade-offs, and as a focus for discussion and exploration of the issues.

1.5 Acknowledgements

As far as we know, Friends of the Earth's UK Land Use Calculator is the first tool of its kind for UK land. We took inspiration for the overall concept from the DECC 2050 CO_2 Calculator Tool [2] (Overview section). A Friends of the Earth example scenario is available for the DECC calculator [3].

For applying the concept to land, we took inspiration particularly from the paper "The best use of agricultural land" [4] from the University of Cambridge Institute for Sustainability Leadership. Several of the data values we have used also come from this paper.

Other sources of data and inspiration are too numerous to mention here. We thank the authors of all of the publications mentioned throughout this document and in the References section.

1.6 Comments

We welcome feedback on the Calculator and on this document. Please send any comments to: info@foe.co.uk

2 Document Overview

This document describes the problem of balancing UK land use and presents a guide to Friends of the Earth's UK Land Use Calculator. It includes:

- Section 1 – *Introduction*: Includes an outline of the problem of balancing UK land use and a description of the nature and purpose of the Calculator
- Section 2 – *Document Overview*: This section - indicates the overall structure and content of this document
- Section 3 - *Overview of the UK Land Use Calculator*: Gives a high level overview of the Calculator, including a screenshot with descriptions of the main features. Also discusses the simplified design approach for the Calculator
- Section 4 – *The demand and supply factors*: Describes each of the land demand and supply factors, and details the assumptions and calculations on which the alternatives provided for each factor are based
- Section 5 – *Appendix*: Provides additional details of assumptions and calculations
- Section 6 - *References*: Gives details of all sources referenced.

3 Overview of the UK Land Use Calculator

3.1 Overarching Assumption: All usable / productive UK land already in use

There is almost no spare productive / usable land in the UK that is not already in use for some purpose (e.g. agriculture, forestry, housing, infrastructure, providing support for biodiversity, recreation). The Calculator therefore assumes that if there is a demand for additional UK land for a particular purpose, this can only be met if an equivalent area of UK land is freed from its existing use.

Although this assumption is a simplification, we believe it is sufficient for the purpose of the Calculator.

With the above in mind, the Calculator displays a warning when choices would lead to a substantially larger demand for UK land than can be met by the supply.

3.2 What the Calculator does and how to use it

3.2.1 Web based application

The Calculator is a web based application that enables the user to try out choices for future UK land use, and to visualise their consequences. It is available at https://www.foe.co.uk/page/uk-land-use-calculator.

3.2.2 The Calculator display and user choices

Figure 1 shows the Calculator display. On the left there are 19 land demand factors, and on the right there are 5 land supply factors. For each factor, the user chooses from three alternatives (low, medium and high) for net change in land use by 2030. Users make their choices according to their land use preferences and priorities, and what they believe is feasible.

The low, medium and high alternatives have preset values, which are representative of the range of additional demand or supply relevant for the purpose of illustrating, discussing and exploring land use issues. The values have been chosen taking account of relevant research, the scale of potential demand / supply, and the ambitions of various parties / organisations[1]. For example, the low alternative for Woodland assumes that the current trend of increasing UK woodland continues at same rate into the future, and is also the low option selected by University of Cambridge report [4] (page 20). Our medium option corresponds to the high option from the University of Cambridge report [4] (which does not include a 'medium' case). Our high option is more ambitious, and is based on a doubling of UK woodland cover as envisaged by Zero Carbon Britain [8].

In the centre of the display are two vertical bars, one showing the breakdown of additional land demand resulting from the user's choices, and the other showing the breakdown of additional land supply. A pair of scales indicates whether land demand and supply are balanced (i.e. supply and demand are roughly equal).

If demand exceeds supply by more than 500,000 hectares a warning pops up. The user should attempt (through manipulation of the factors) to arrive at an overall scenario where supply and demand are roughly equal. Depending on the user's choices, the scale of changes will vary from moderate to dramatic on both supply and demand sides.

Below the Supply area on the right is a 'Select/reset button'. This enables the user to select from of a number of preconfigured scenarios contributed for use with the Calculator.

Warning: The basic functionality does not provide way for a user to save a scenario within the Calculator itself. Selecting a new scenario clears/resets any choices the user may have made. The best way to 'remember' user choices is to take a screenshot or photograph.

At the bottom right of the screen is an information panel giving details about the currently selected land demand / supply factor, or about the selected scenario (depending on the user's last selection).

[1] The intention is to encourage a wide ranging discussion between participants who may have different backgrounds and different points of view. As a result, there may be differences of opinion on the ranges. For example, some may feel that a particular High value is well above anything that should be envisaged, while others may consider the same value to be feasible and / or a realistic indication of potential demand or supply. This is to be expected in an area with so many potentially conflicting demands for land.

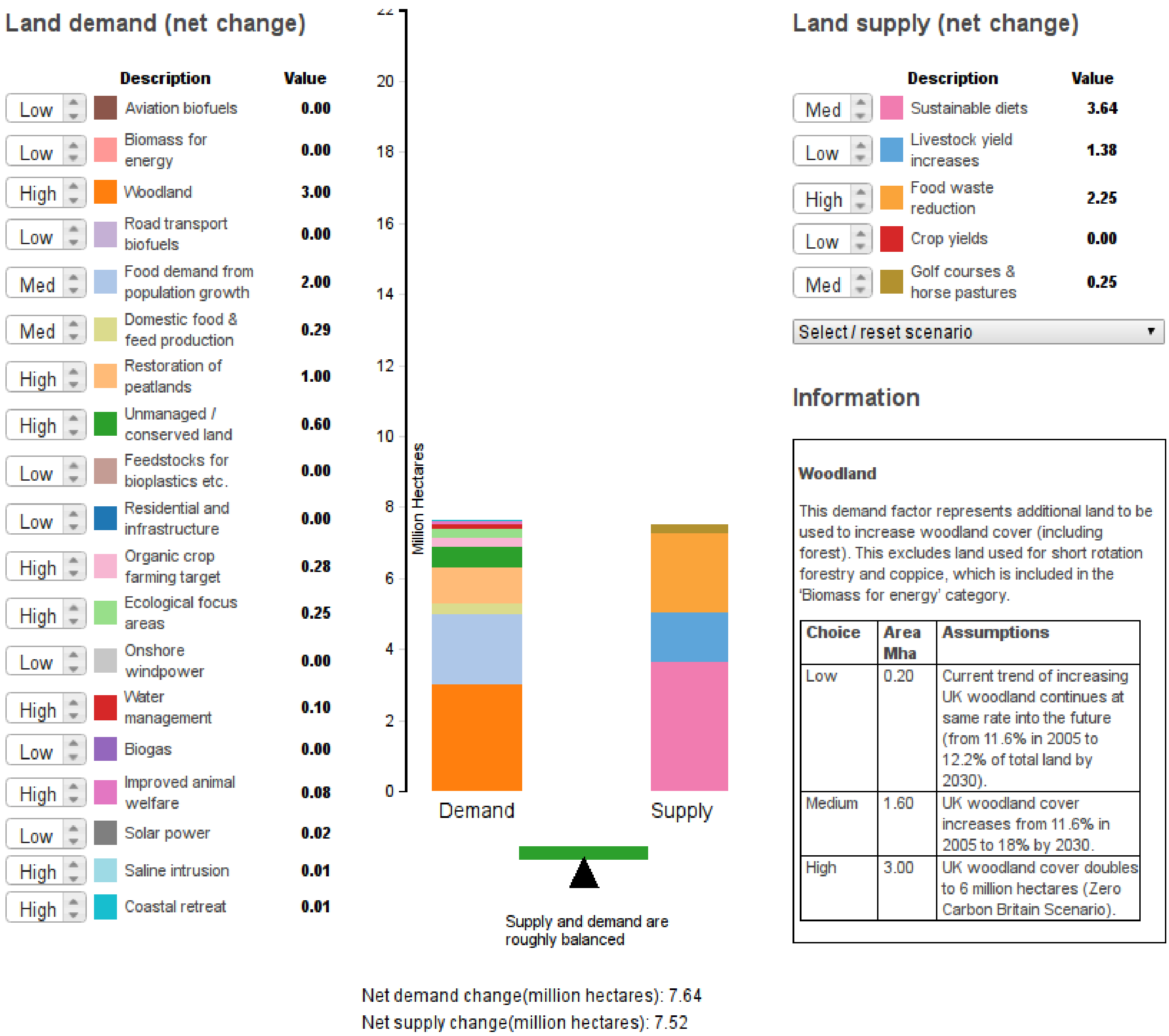

Figure 1 - The UK Land Use Calculator Display

3.2.3 Simplified options for illustrative purposes

As mentioned above, the preset values for each factor are limited to three options: high, medium, and low. The Calculator is intended to *illustrate* land issues in a simple and accessible way, and we believe that adding more options could make it more complicated to use, and potentially detract from its value as an illustration. See also section 3.3 on the simplified design of the Calculator.

It is recognised that in some cases a user producing a scenario may feel that using a value different to those available would make for a significantly better illustration. If so, then it will be appropriate to select the closest value and mention the preferred alternative value in the explanatory text (see section 3.2.4).

3.2.4 Scenario explanatory text

When a pre-configured scenario is selected, the information area displays explanatory text provided by the author of the scenario. The material on the text is entirely the choice of the author. However, the following are suggestions for material that could be included:

- **Explanation of the key preferences, priorities and assumptions**
- **Identification and explanation of any preferred alternative value(s):** If it is felt that an alternative to a preconfigured value would significantly improve the usefulness of the scenario as an illustration of the user's view (see section 3.2.3), then this can be mentioned in the text.
- **Consequences for overseas land use if known / relevant:** The Calculator is intended as a simplified illustration of *UK* land use, and does not explicitely represent the consequences of UK choices for land overseas. In many cases, changes in overseas land use may not be entailed in the scenario assumptions or intended by the scenario author. However, in some cases the scenario may be based on an assumption that there will be a large increase in overseas land use. For example, a user envisaging an expansion in the use of biomass / biofuel in the UK might produce a scenario using a moderate amount of land in the UK for biomass / biofuel, and assume a large further use of land use overseas. Only the UK land use would be shown on the Calculator page. In such cases it will be helpful for the overseas land use to be mentioned in the scenario text so that the context can be better understood.

3.3 Simplified design

As indicated in section 1.2, the purpose of the Calculator is to illustrate the issues affecting UK land use, and to encourage discussion and exploration of these issues. Inclusion of a comprehensive and detailed land model covering all possible factors is not necessary for this purpose, and could detract from it. The following aspects of the simplified Calculator design are in line with this approach:

- The Calculator considers only *net changes* in land use. It does not show total land use, or attempt to show geographically where the changes would occur
- The Calculator does not model the suitability of land for particular purposes. For example, it does not check that an increased demand for crop land is met by a supply of land suitable for crop production. Changes specified in the Calculator simply represent a high level future scenario that balances total land use
- The Calculator does not attempt to optimise land use. It is left to the user to choose appropriate values for the demand / supply factors
- The Calculator does not model interdependencies between factors (see also section 4)

While Friends of the Earth believes that the Calculator is suitable for its intended purpose (see section 1.2), we recognise that far more work is needed. We support and encourage the development of comprehensive and detailed models to be used to help in making policy decisions.

4 The demand and supply factors

This section provides explanatory information regarding each factor on both supply and demand sides, and on the underlying assumptions for the low, medium and high choices. Where appropriate, calculations showing how the factor values are derived from the assumptions are given. Section 4.1 covers demand factors, section 4.2 covers supply factors.

All land demand / supply area figures in the tables are in millions of hectares (Mha), and indicate the change by 2030. Figures for demand / supply factors are rounded to two decimal places.

Most of the assumptions are based on published research; references are given throughout to research papers and other documentation. There are sometimes small differences between figures available from different sources. This is to be expected, and we have not attempted to determine which is more accurate, although we have in general preferred the latest figures. Some of the assumptions represent Friends of the Earth's own view of what is likely / feasible / illustrative, rather than being based on published research. Such cases are made clear in the text.

Each individual demand / supply factor would warrant a whole area of research on its own, and our alternatives represent simplifications. For example, the Calculator allows the factors to be varied independently, whereas a more sophisticated model would represent the interdependencies. Nonetheless, we believe that the Calculator is sufficient for its intended purpose (see section 1.2).

The shaded entries in the tables below indicate the choices of the Friends of the Earth scenario. Explanatory details are given in the document "Friends of the Earth's Illustrative Land Use Scenario".

Each land use factor refers to the *primary* use of land. In some cases, land can be used for multiple puropses. For example, private gardens on residential land can be used for food production, and biomass can be produced from sustainably harvested woodland. For the majority of cases, the Calculator accounts solely for the primary land use. In defining scenarios, it is possible to assume a certain level of secondary land use. This is done explicitly in the Calculator factors for onshore windpower and solar electricity; the high / medium / low options reflect varying degrees to which land used for power generation can also be used for other purposes, such as agriculture.There is no demand factor specifically for Rewilding. This is because it cuts across several land uses such as Woodland, Peatland, Unmanaged / Conserved and Ecological Focus Areas. It is possible however to produce a rewilding oriented scenario by prioritising such uses.

4.1 Demand side factors

4.1.1 Aviation biofuels

This demand factor represents land to be used to grow crops for use as feedstock for the production of aviation biofuel.

Currently, no land is used in the UK to grow crops for use in aviation biofuels on a commercial scale. See [9] (page 6) .

Possible alternatives include the use of wastes as feedstock.

Alter-native	**Land Demand** (Mha)	**Assumptions/Calculations**
Low	0	• No change to the current situation in which no UK land is used to grow crops on a commercial scale or use in aviation biofuels
Medium	1.07	• One fifth of the High scenario • The illustrative high alternative may be considered extremely challenging, and so for our Medium option we adopt a substantially lower figure, rather than simply the mid-point between low and high options

High	5.36	• The International Air Transport Association (IATA) has adopted a goal for a 50% reduction of CO_2 emissions by 2050, relative to 2005 levels [10]. This goal has been endorsed by the aviation industry
		• For our illustrative High alternative, we make the (probably more demanding) assumption of a target to achieve a 45% reduction by 2030, and we assume that the replacement fuel is based on UK grown crops. This may be considered extremely challenging. However, it provides an illustration of the scale of the UK land use that could be required should a target more ambitious/urgent than that of the aviation industry be put in place alongside a requirement to avoid increased overseas land use. See Friends of the Earth's Illustrative Scenario [1] and European Parliament briefing [7] (section 3) regarding concerns about overseas land use.
		• We assume that UK Aviation fuel demand for the year 2030 will be the same as in 2006 - 16 billion litres. See the parliamentary statement on 2006 UK aviation turbine fuel (Avtur) consumption in 2006 [11] (page 6). This is a 'minimum' figure, used here for the purpose of illustration, rather than as a forecast. Most forecasters expect that demand for aviation fuel will continue to increase in the period up to 2030 (as it has since 2006). See for example IATA forcasts [12] .
		• We assume that the UK grown feedstock used will be rapeseed
		• We assume that rapeseed oil is produced with an annual yield of 1342 Litres / hectare, consistent with the mid-point of the range shown, in US gallons per acre in Extension article [13]
		• We assume that 1 litre of rapeseed oil produces roughly the same volume of aviation biofuel. The fact that the energy densities of jet fuel / kerosene, rapeseed oil and biodiesel are roughly the same is supportive of this. See [14], [15] and [16]
		• Calculation:
		    ○ Aviation biofuel fuel requirement: 45% x 16 billion litres = 7.2 billion litres
		    ○ Land requirement: 7.2 billion litres per year / 1342 litres per hectare per year = 5.36 Mha

4.1.2 Biomass for energy

This demand factor represents land to be used to grow biomass for which the primary purpose is energy production. This may include land used for short rotation forestry and coppice.

The 'biomass for energy' demand factor does *not* include woodland, which is covered by another demand factor (see Section 4.1.3). Although biomass from sustainably harvested woodland can be used for energy, that is not the primary/sole purpose of the woodland growth, and it is therefore not counted under 'biomass for energy'. This avoids 'double counting'.

Estimates for land needed differ widely. This is partly due to differing views on whether using land for biomass for energy is a sustainable solution to climate change, particularly where it competes with other land uses.

Alter-native	**Land Demand** (Mha)	**Assumptions**
Low	Zero	• • No change in land use • Note: This does not rule out production of bioenergy from feeedstocks not requiring additional use of land. See for example "Securing Biomass for Energy" [17] (page 8).
Medium	2.05	• Half way between the Low and High options
High	4.1	• Zero Carbon Britain [8] (page 83) advocates production of 237 TWh of biomass energy from various grasses, short rotation forestry and coppice. It indicates that this would require 4.1 million hectares. This equates to a land requirement of 0.017 million hectares / TWh • The ZCB model relies on large land areas (mainly grassland) being freed up as a result of substantial dietary changes.

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4.1.3 Woodland

This demand factor represents additional land to be used to increase woodland cover (including forest). This excludes land used for short rotation forestry and coppice, which is included in the 'Biomass for energy' category described in Section 4.1.2.

Alter-native	**Land Demand** (Mha)	**Assumptions**
Low	0.2	• Current trend of increasing UK woodland continues at same rate into the future (from 11.6% in 2005 to 12.2% of total land by 2030). See University of Cambridge report [4] (page 20)
Medium	1.6	• UK woodland cover increases from 11.6% in 2005 to 18% by 2030. See University of Cambridge [4] (page 20)
High	3.0	• UK woodland cover doubles to 6 million hectares. Zero Carbon Britain scenario [8] (chart on page 82)

4.1.4 Road transport biofuels

This demand factor represents land to be used to grow crops for use as feedstock for the production of road transport fuel. Examples of biofuel include ethanol, which can be blended with petrol, and biodiesel, which can be blended with conventional diesel fuel.

Alter-native	**Land Demand** (Mha)	**Assumptions**
Low	0	• In 2013, about 42,000 hectares in the UK were used to grow crops for transport biofuels [19]. The majority of crop-based biofuels currently used in the UK are made from imported feedstock. [20] [21] • Assume no change from current land use.
Medium	1.34	• Meet 5% of UK road transport energy (half of the EU target) with crop-based biofuels made from UK grown crops. See Section 5.2 for details of assumptions and calculations.
High	2.73	• Meet the EU target (see above) for 10% of energy used for transport to be renewable entirely from crop-based biofuels made from UK grown crops • See Section 5.2 for details of assumptions and calculations.

4.1.5 Food demand from a growing population

This demand factor represents additional crop and grazing land required due to the rising food demand of an increasing UK population. It does not reflect any change in diet or agricultural yield; these are handled separately as land supply factors.

Alter-native	**Land Demand** (Mha)	**Assumptions**
All		• Land use increases directly in proportion to population (no change in diet or agricultural yield) • Total UK crop and grazing land is approximately 16.5 million hectares. See Zero Carbon Britain – Rethinking the Future [8] (page 93) • Population in 2010 was 62.3 million. See Office for National Statistics data [22]
Low	1.5	• Population grows by 9%, broadly in line with International Futures forecast of 67.76 million [23].
Medium	2.0	• Population grows by 12% (midpoint between 'Low' and 'High' alternatives)
High	2.5	• Population grows by 15%, broadly in line with the 71.4 million projected by the Office for National Statistics [22]

4.1.6 Increased Domestic Food & Animal Feed Production

This demand factor represents land to be used to enable a larger proportion of the food and feed used to meet UK needs to be produced in the UK.

This would allow imports of food and animal feed to be reduced, with food security and other benefits (see section **Error! Reference source not found.**).

Alter-native	**Land Demand** (Mha)	**Assumptions and Calculations**
Low	0	• No change
Medium	0.29	• Friends of the Earth advocates replacing part of our imports of animal feed (primarily soy from S America) with home-grown alternatives. Here we assume that 50% of soy imports are replaced • According to calculations for Friends of the Earth, replacing 50% of soy imports with a range of UK grown crops would require 285,000 hectares. See 'Pastures New - A Sustainable Future for Meat and Dairy Farming' [24] (page 10)
High	1.5	• University of Cambridge research [4] (page 20), identifies a scenario in which the UK produces the equivalent of 100% of its fruit and vegetable consumption, and also replaces 70% of animal feed imports, and indicates that this would require 1.5 million hectares of additional land.

4.1.7 Restoration of peatlands

This demand factor represents damaged peat land to be restored. Governments around the world recognise the importance of peat lands for tackling climate change, and for water management and biodiversity conservation.

Alter-native	**Land Demand** (Mha)	**Assumptions**
Low	0	• No change – consistent with University of Cambridge research [4] (page 20), which does not identify a change for this factor
Medium	0.5	• Mid-point between Low and High alternatives
High	1.0	• IUCN UK Peatland Programme "1 million hectare challenge" to restore peat lands [25] is implemented • Note: Some of the restored peat land could continue to have other uses after restoration (e.g. low intensity grazing), so the total demand would in practice probably be less than 1 million hectares

4.1.8 Unmanaged/conserved land area for wildlife

This demand factor represents low productivity land (e.g. mountain slopes and heathlands, often currently used for low-level grazing) that is to be allowed to return to an unmanaged state. Due to its soil and other physiological qualities such land would not return to woodland, and could become an ideal haven for wildlife. This category excludes restored peatlands and woodlands

Alter-native	**Land Demand** (Mha)	**Assumptions**
Low	0	• No change – consistent with University of Cambridge research [4] (page 20), which does not identify a change for this factor (although it does include a factor for Ecological Focus Areas and set-aside)
Medium	0.3	• Half of the High alternative
High	0.6	• Zero Carbon Britain scenario [8] (page 82)

4.1.9 Biological feedstocks for plastics and other synthetic materials

This demand factor represents land to be used to grow biological feedstocks to replace fossil-based feedstocks in the production of plastics and other synthetic materials

Currently, little or no UK land is used to grow such feedstocks. The Joint European Biorefinery Vision for 2030 [28] (page 6) identifies the ambition that by 2030 "30% of overall chemical production is biobased."

Possible alternatives to growing biological feedstocks include the use of wastes as feedstock for biologically-based materials.

Alter-native	**Land Demand** (Mha)	**Assumptions / Calculations**
Low	0	• No change to the current situation in which little or no UK land is used to grow feedstock for bioplastics.
Medium	0.21	• Current UK plastic production: 2.5 million tonnes. See British Plastics federation website [26] • Target for 30% of overall chemical production to become bio-based is met… • … by producing feedstocks at a high yield (3.5 tonnes/hectare). See 'Bio-plastics in the context of competing demands on agricultural land in 2050' [27] (Table 2) • Calculation: 30% x 2.5 million tonnes / 3.5 tonnes per hectare = 0.21 million hectares
High	0.58	• As for Medium alternative, except that a low yield is assumed (1.3 tonnes/hectare). See [27] (Table 2)

4.1.10 Residential and infrastructure

This demand factor represents additional land to be used for dwellings, private gardens and transport infrastructure, as well as for commercial uses. See the University of Cambridge report 'The best use of agricultural land' [4] (page 20).

Alter-native	**Land Demand** (Mha)	**Assumptions**
Low	0	• Friends of the Earth's recommendation for 'compact cities' [29] (page 3), under which "over the next 10-15 years, the vast majority of new homes should be within existing towns and cities"
Medium	0.16	• Current land use is approximately 1.35 million hectares. Note: University of Cambridge research [4] (page 20) used this 2005 baseline due to lack of UK data for all categories for 2012 • Population growth of 12% by 2030, as in the medium alternative in the 'Food demand from a growing population' section below
High	0.4	• Increased area of land for settlements is consistent with the 'DECC 2050 scenarios', as mentioned by University of Cambridge research [4] (page 20)

4.1.11 Organic target for crop farming

This demand factor represents land to be used to enable increased organic farming.

Friends of the Earth advocates more planet friendly farming, including a higher percentage of organic farming. The Organic Target Bill that was campaigned for by a coalition of NGOs promoted a target that would ensure that 30% of agricultural land to be organic. See article 'Campaign for Organic Targets Bill' [30].

Alter-native	**Land Demand** (Mha)	**Assumptions and Calculations**
Medium and High		• Estimates of the impact of organic farming on crop yields vary widely. However an analysis of 362 studies by de Ponti and others suggests that, on average, organic yields per hectare are 20% lower than for conventional agriculture [31] • Area of crop land in the UK (2014) = 4.7 million hectares. See Defra Farming Statistics [32] (page 9). • Area of organically farmed cropland in the UK (2014) = 0.06 million hectares. See Defra Organic Farming Statistics [33] (page 6)
Low	0	• No change to current organic vs conventional split
Medium	0.14	• Half of the 'High' alternative
High	0.28	• The 30% target for organic use of agricultural land is achieved • Calculation: 30% (target) x (4.7 Mha – 0.06 Mha) x 20% (yield reduction) = 0.28 Mha

4.1.12 Ecological focus areas (EFA)

This demand factor represents arable land that is to be managed in a way that meets environmental / ecological needs.

Under current CAP regulations, every farmer in the European Union who claims a direct payment and has more than 15 hectares of arable land must have 5% of the arable land covered by ecological focus areas. These are areas which bring benefits for the environment, improve biodiversity, and maintain attractive landscapes (such as landscape features, buffer strips, afforested areas, fallow land, areas with nitrogen-fixing crops etc.). Some exceptions apply, for example to farmers who have more than 75% of their area under grassland. See European Commission Common Agricultural Policy (CAP) Glossary [35].

Alter-native	**Land Demand** (Mha)	**Assumptions / Calculations**
Low	0	• No Ecological Focus Areas
Medium	0.13	• Current 5% CAP EFA regulation (see above) • Friends of the Earth assumption that the introduction of EFAs will lead to an impact equivalent to reducing production by 50% (on the affected crop land) • Currently 5 million hectares are devoted to crops. See Zero Carbon Britain report [8] (page 82). • Calculation: 5 million hectares (total crop land) x 50% x 5% = 0.13 million hectares (after rounding)
High	0.25	• Because of the benefits for farm wildlife, Friends of the Earth supports a political push to increase EFAs to 10% of cropland. This would result in a demand for 0.25 million hectares of additional cropland. See Friends of the Earth Europe briefing [34] (page 4). Assume this is adopted • As for the Medium alternative, this figure assumes that crop land productivity is reduced by 50% as above

4.1.13 Onshore wind (for electricity)

This demand factor represents land to be used in the production of windpower.

Alter-native	Land Demand (Mha)	Assumptions / Calculations
		• Friends of the Earth believes that it is reasonable to expect 23 GW of installed onshore wind capacity in the UK by 2030 • Existing installed capacity is about 8.5 GW. See 'Onshore Wind Energy' [36] • This leaves 14.5 GW requiring additional onshore wind parks • According to David MacKay, 174 MW of onshore wind park capacity can be expected to have a land footprint of 1450 hectares [37]. This gives a land requirement of 8333 hectares per GW
Low	negligible	• Based on figures from David MacKay [37], about 2.5% of the land footprint of a wind park is used for hardware, foundations, or access roads • For the low alternative, we assume that the remaining 97.5% can be used for other uses such as livestock grazing and in some case even woodland. • Calculation: 14.5 GW x 8333 hectares / GW x 2.5% = 0.003 Mha
Medium	0.06	• For the medium alternative we assume that on average half of the footprint of a wind farm is unavailable for other uses
High	0.12	• For the high alternative we assume that all of the footprint of a wind farm is unavailable for other uses

4.1.14 Water management

This demand factor represents land that is to be used for the management of fresh water. For example, for increased wetlands and reservoirs.

There is wide agreement that climate change will lead to a demand for more land being used for such purposes. However, little work seems to have been done to estimate the land demand of this. University of Cambridge research [4] (page 20) estimates 0.1 million hectares.

Alter-native	Land Demand (Mha)	Assumptions
Low	0	• No change
Medium	0.05	• Midpoint between Low and High alternatives (rounded to two decimal placed)
High	0.1	• University of Cambridge study [4] estimate of 0.1 million hectares

4.1.15 Biogas

This demand factor represents land to be used for the production of organic matter (e.g. maize) that will be broken down to make gas for energy production.

Friends of the Earth opposes the expansion of maize cultivation for biogas, as maize is a crop that requires high inputs of fertilizers and pesticides that damage biodiversity. Maize crops also facilitate soil erosion which can lead to flooding. See article 'How we ended up paying farmers to flood our homes' [38] and Defra report 'Controlling soil erosion' [39]). In addition, maize crops for biogas compete with food production [40].

Alter-native	**Land Demand** (Mha)	**Assumptions**
Low	0	• Currently around 30,000 hectares are used to grow energy crops, primarily maize, for anaerobic digestion • Assume no change to this. See above regarding the damaging effects of maize
Medium	0.05	• Mid-point between high and low alternatives
High	0.1	• The National Farmers Union (NFU) advocates that 1000 medium-sized biogas plants are built by 2020 [41] [42], with maize supplementing the slurry and manure they process. That would mean the use of between 100,000 and 125,000 hectares • Assume (conservatively) the lower figure

4.1.16 Improved animal welfare

This demand factor represents land to be used to enable the adoption of farming techniques that improve animal welfare.

Friends of the Earth advocates improvement of the living conditions of livestock that are currently raised in intensive factory farms. Drawbacks of factory farming include (but are not limited to):

- Use of antibiotics and pesticides to mitigate the spread of disease exacerbated by crowded living conditions. The large amount of antibiotics used in factory farming is a significant cause of the resistance of many common pathogens to the antibiotics used to treat infections in humans [43] [44].
- The crowded living conditions of intensive factory farming also exacerbate the dangers of manure pollution of the environment [44]. According to work in the USA by the The Johns Hopkins Bloomberg School of Public Health, "Both animals and their waste are concentrated and usually exceed the capacity of the land to produce feed or absorb the waste. Consequently, the rapid ascendance of IFAP [factory farming] has produced an expanding array of deleterious environmental effects on local and regional water, air, and soil resources" [45] (page 9).

Alter-native	Land Demand (Mha)	Assumptions/Calculations
Medium and High		• Our Medium and High alternatives assume an increase in humane (e.g. free range) farming • Our assumption below on increased land demand for humanely reared (e.g. free range) livestock is based on work commissioned by Friends of the Earth and Compassion in World Farming [46]. This indicates (on page 18) relative feed input requirements for intensive, humane (e.g. free range), and organic livestock rearing. Producing meat, eggs and dairy product requires 10% more feed input under humane conditions than under intensive conditions. (A higher figure applies in the case of organic farming, which requires stricter standards) • Currently 2.5 Mha is used to grow crops for livestock. See Zero Carbon Britain [8] (page 93)
Low	zero	• No change
Medium	0.04 (rounded)	• An additional 15% of all livestock will be reared under humane (e.g. free range) conditions • Calculation - Estimate of additional farmland required to grow feed: 2.5 (current area used to grow crops for livestock) x 10% (additional feed required for humane conditions) x 15% (increased percentage of humane livestock farming) = 0.0375 Mha
High	0.08 (rounded)	• An additional 30% of all livestock will be reared under humane (e.g. free range) conditions • Calculation - Estimate of additional farmland required to grow feed: 2.5 (current area used to grow crops for livestock) x 10% (additional feed required for organic conditions) x 30% (increased percentage of humane livestock farming) = 0.075 Mha

4.1.17 Solar (for electricity)

This demand factor represents land to be used in the production of solar electricity.

Alter-native	Land Demand (Mha)	Assumptions / Calculations
All		• The rise of solar power in recent years has been dramatic. Friends of the Earth believes that it is now reasonable to expect 60 GW of installed capacity in the UK by 2030 • Assume that this will be achieved, and... • Assume that some solar park land can also be used for other purposes • According to estimates by the National Solar Centre [47], covering just 5.2% of commercial, domestic and industrial roof space with solar could account for 20GW. We assume that this will be installed, thereby reducing the capacity needed in solar parks • See the Appendix for full assumptions and calculations
Low	0.02	• 33% of the land used for a solar park is unavailable for other production (e.g. livestock grazing)
Medium	0.03	• 50% of the land used for a solar park is unavailable for other production (e.g. livestock grazing)
High	0.06	• Full footprint of a solar park is unavailable for other production (e.g. livestock grazing)

4.1.18 Saline intrusion

This demand factor represents coastal land that becomes unviable for conventional agriculture due to the movement of saline water into freshwater aquifers, for example due to climate change.

Alter-native	Land Demand (Mha)	Assumptions and Calculations
Low	Zero	• No change
Medium	0.01 (rounded up from 0.005)	• Half of the 'High' alternative
High	0.01	• According to the Committee on Climate Change (CCC), 10,000 hectares of agricultural land are at risk of saline intrusion due to climate change. For our High alternative, we assume that all of this land becomes unviable for conventional agricultural production. See CCC report [48] (page 102).

4.1.19 Coastal retreat

This demand factor represents coastal land to be managed in a way that helps adaptation to rising sea levels.

The Committee on Climate Change (CCC) warns that due to climate change, protecting coastal areas from flooding and erosion in the face of sea level rise will require greater effort in the future. Setting back the defences and restoring coastal habitats, known as 'managed realignment', is an important adaptation to rising sea levels. Managed realignment gives coastal habitats space to migrate inland as sea levels rise. Not adopting this realignment approach has a cost - either more flooding of coastal areas, or the need to build more expensive and intrusive hard flood defences, such as concrete sea walls.

Alter-native	**Land Demand** (Mha)	**Assumptions and Calculations**
Low	0	• No change
Medium	negligible	• Half of the 'High' alternative
High	0.01 (rounded)	• The Committee on Climate Change (CCC) identifies a goal of creating 6,200 hectares of coastal habitat by 2030 through a process of managed realignment involving breaching or removing some flood and erosion defences. See CCC report [48] (page 93); the report notes that this could be achieved without losing a single property. • The 'High' alternative assumes that the above goal is adopted

4.2 Supply-side factors

4.2.1 Sustainable diets

This supply factor represents land becoming available due a change in the UK towards healthier diets that require less livestock production.

Such a change towards diets lower in meat and dairy product content has a huge potential to free up land in the UK. This is because livestock requires, very approximately, 10 times as much land as arable crops to produce protein for human consumption. See University of Cambridge report [4] (page 21), which also notes that a reduction in meat and dairy consumption is in line with the UK Government's healthy eating advice.

Alter-native	**Land Supply** (Mha)	**Assumptions and Calculations**
Low	0.6	• Continuation of the trend over last 30 years of falling meat consumption, with a further 5.9% reduction by 2030 (this is being replaced by greater vegetable & fruit consumption). See University of Cambridge report [4] (page 21)
Medium	3.64	• Similar to Zero Carbon Britain 'High; alternative below, but assume 30% reduction in meat and dairy production • Calculation 8.5 x 30% / 70% = 3.64 Mha

High	9.71	• Assume an 80% reduction in meat and dairy production
		• Take 'average' diet suggested by Zero Carbon Britain (ZCB) report [8] (page 92) as a starting point: Beef and lamb products are reduced by 92%, pig and chicken products (including eggs) are reduced by 58%, and dairy consumption is reduced by 59%.
		• Simplify by taking the (rounded) average of the three above figures, and assume this is equivalent to an overall 70% reduction in meat and dairy production
		• Calculation for this 70% reduction, based on [8] (page 93)
		  o Current land for Food/grassland for livestock: 14 Mha
		  o ZCB scenario land for Food/grassland for livestock: 4.25 (a 70% reduction from current situation)
		  o Current land for human consumption: 2.5 Mha
		  o ZCB scenario land for human consumption: 3.75 Mha (a 50% increase from the current situation)
		  o ZCB land saving = (14 - 4.25) + (2.5 - 3.75) = 8.5 Mha
		• Scale-up for 80% (rather than 70%) reduction:
		8.5 Mha x 80%/70% = 9.71 Mha

4.2.2 Livestock yield increases

This supply factor represents land becoming available due to increased livestock yield (increased livestock production per hectare).[2]

As with crop yields, predictions on livestock yields also vary significantly.

Alter-native	Land Supply (Mha)	Assumptions / Calculations
All		• Current total land for livestock is approx. 12.5 Mha. See [4] (page 21)

Low	1.38	• No increase in factory farming
		• Friends of the Earth believes that if there is no further increase in factory farming, livestock yields will not increase as fast as has previously been the case. We assume that livestock yield growth will be broadly consistent with the historical rate of milk yield increase in New Zealand, where farming is less intensive. See the paper by Capper and others for historical milk yield data [49] (Figure 5).
		• Calculation:
		  ○ NZ milk yield in 2007: 8300
		  ○ NZ Milk yield in 1961: 6000
		  ○ Assume year on year increases are compounded (i.e. like compound interest)
		  ○ Year on year rate of growth = $(8300/6000)^{1/(2007-1961)} - 1$
		  $= 0.7\%$
		  ○ Additional land required = 12.5 Mha x $(1.007)^{15}$ – 12.5 Mha
		  = 1.38 Mha

Medium	3.13	• Large-scale transition from grazing livestock to intensive, indoor production systems (so called “factory farming”) • Continuation of current trend of increased dairy, pig and broiler production yield • 1.5% year-on-year increases in livestock yields. See University of Cambridge report [4] (page 21). Note that our figure for land supply is different to that in the Cambridge report. This is because the Cambridge calculation includes the effects of population growth, whereas we use a separate land demand factor for that.

[2] This land supply factor is to some extent related to the ‘improved animal welfare’ demand factor. Overall, improved animal welfare may be associated with less intensive farming and lower yield. However, it is possible that animal welfare could increase in some sectors of farming, but that intensification could increase in other sectors. If so, there could be both an element of land supply (due to intensification), and of land demand (due to improved animal welfare).

High	5.08	• Transition to factory farming as above • Adoption of new technology in addition, resulting in... • 2.3% year-on-year increases in livestock yields. See University of Cambridge report [4] (page 21) • See note regarding Medium alternative, which also applies here.

4.2.3 Food Waste reduction

This supply factor represents land becoming available due to reduced food waste resulting in reduced demand for food.

Alter-native	**Land Supply** (Mha)	**Assumptions and Calculations**
Low	0.5	• The current trend of reductions in household food waste continues, with waste declining from 18.5% to 15.4% by 2030. See University of Cambridge report [4] (page 21)
Medium	2.0	• The UK achieves zero 'avoidable' household food waste, i.e. a reduction from 18.5% to 6.6% by 2030. See University of Cambridge report [4] (page 21)

High	2.25	• Food waste from households, food manufacture and retail is reduced by 9 million tonnes. Research by WRAP [50] (page 1) indicates that the total waste is 12 million tonnes, of which 75% is avoidable
		• Calculation: Extrapolate from the Low and Medium alternatives above:
		    • Low alternative represents a 16.76% reduction in waste: (18.5% - 15.4%)/18.5% = 0.1676. This corresponds to 0.0298 Mha (0.5/16.76) land freed for each percentage waste reduction
		    • Medium alternative represents 64.32% reduction (similar calculation). This corresponds to 0.0311 Mha land freed for each percentage waste reduction
		    • Using 0.03 Mha per percent waste reduction gives 2.25 Mha for the High alternative. I.e. 75% waste reduction x 0.03 Mha per % waste reduction = 2.25 Mha

4.2.4 Crop yields

This supply factor represents land becoming available due to increased crop yield (increased crop production per hectare).

Estimates of future crop yields in the UK vary widely. There is potential for significant yield increases in some regions of the world. Factors that can improve yield include improved stress tolerance, avoidance of nutrient and water shortages, and improvements in pest control. However, there is much less potential in the UK.

It has been argued in research commissioned by Compassion in World Farming and Friends of the Earth that "…in Western Europe and North America, cropland yields have already reached very high levels. It is difficult to judge to what extent … yield gains can be realized and what the environmental costs of trying to achieve these yields might be (e.g. soil erosion, nitrogen leaching, water pollution or GHG emissions). It has been argued that many options to achieve yield gains have already been discovered and are approaching physiological limits..." See 'Eating the Planet' [46] (page 17).

There is also little agreement on the net impact of climate change on yields in the UK by 2030. An increase in mean temperatures could have both positive and negative effects on crop yields, depending on crop type. Pathogens and pests are likely to benefit from increase temperatures. There is an ongoing discussion on whether increased CO_2 levels could have a positive fertilizer effect on plant growth.

Water stress is likely to have a negative effect on crop yields.

Air pollution also has a substantial and likely future impact on crop yields. See Friends of the Earth's "Summary synthesis of literature review on bioproductivity" [51] (Section 2), and research by Shiri Avnery and others regarding the effects of ozone (O_3) pollution on crops [52] (Abstract). The results "...suggest that O_3 pollution poses a growing threat to global food security even under an optimistic scenario of future ozone precursor emissions."

Alter-native	Land Supply (Mha)	Assumptions / Calculations
All		• Area of crop land in the UK (2014) = 4.7 million hectares. See Defra Farming Statistics [32] (page 9). • Ignore population growth (this is handled by the "Food demand from a growing population" demand factor) • Ignore changes in diet (this is covered by another land supply factor)
Low	0	• Assume that previous year-on-year increase in crop yields in the UK will not continue, due to the impact of factors including climate change and air pollution • There is considerable uncertainty over the effects of these factors. The possibility of yield *reductions* cannot be ruled out

Medium	0.76	• Continuation of 1% year on year historic increase of crop yields in the UK. See University of Cambridge research [4] (page 21).
		• Calculation:
		  ○ Overall yield increase = $1.01^{15} - 1 = 16.1\%$
		  ○ Change in land supply = 4.7 Mha x 16.1% = 0.76 Mha

High	1.42	• 1.78% yearly yield increase. See University of Cambridge paper [4] (page 21): "Faster adoption of new crop varieties and technology, including hybrid crops and precision farming delivers yield increases of 1.78% per year" • Calculation: Similar to above

4.2.5 Golf courses & horse pastures

This supply factor represents land becoming available due a reduction in the amount of land used for golf courses and horse pasture.

Large areas in the UK are used for golf courses and horse pastures, although precise figures are difficult to come by. For example, Paul Cheshire of the London School of Economics estimates that more of Surrey is now under golf courses – about 2.65% – than has houses on it." [53] (page 17).

It can be argued that some of this land should be used for more essential purposes. Land in England used for horses has been estimated as at least 600,000 hectares (see 'Inside Housing' [54]), and land used in England for golf courses has been estimated as 270,000 hectares (see Huffington Post [55]). Corresponding estimates for other parts of the UK are not easily available. Therefore, for the purpose of the Calculator, a conservative estimate of 1 million hectares for golf courses and horse pastures combined in the UK as a whole.

Friends of the Earth does not have a position on this. Our illustrative scenario assumes that 25% of golf course and horse pasture land is converted for other use (e.g. agricultural), but alternative sources of land could be found instead.

Alter-native	**Land Supply** (Mha)	**Assumptions and Calculations**
Medium and Low		• Make conservative estimate that 1 million hectares is used for golf courses and horse pastures combined.
Low	0	• No change
Medium	0.25	• 25% of the land is converted for other use (e.g. agricultural)
High	0.5	• 50% of the land is converted for other use (e.g. agricultural)

5 Appendix

5.1 Solar (for electricity) assumptions and calculations

The full assumptions and calculations for land use for the generation of solar electricity are shown below:

Alter-native	**Land Demand** (Mha)	**Assumptions / Calculations**
All		• The rise of solar power in recent years has been dramatic. Friends of the Earth believes that it is now reasonable to expect 60 GW of installed capacity in the UK by 2030 • Assume that this will be achieved • The Solar Trade Association estimates [56] that 25 acres of land is required for every 5 MW of ground mounted solar capacity. This equates to 2020 hectares / GW • According to DECC statistics, at the end of November 2015, overall UK solar PV capacity stood at 8,437 MW [57] • This means that in order to reach 60GW installed capacity, an additional 51.6 GW are required • According to estimates by the National Solar Centre [47], covering just 5.2% of commercial, domestic and industrial roof space with solar could account for 20GW. We assume that this will be installed. This would leave another 31.6 GW to be installed in ground-mounted solar parks by 2030 • Calculation: The additional land required to reach 60GW installed capacity is: ○ 31.6 GW (additional ground mounted capacity) x 2020 hectares /GW = 0.06 Mha • However, this is not necessarily all lost to agricultural production. David MacKay [37] estimates that in a 924 hectare solar park, only 308 hectares (i.e. one third) would be occupied by hardware, foundations, or access roads (infrastructure) • We assume that land not used for infrastructure could be used for other purposes such as livestock grazing.
Low	0.02	• 33% of the land used for a solar park is unavailable for other production (e.g. livestock grazing) • This is equivalent to assuming that all of the 'non-infrastructure' land is used for other production • Calculation: 33% x 0.06 = 0.02 Mha
Medium	0.03	• 50% of the land used for a solar park is unavailable for other production (e.g. livestock grazing) • Calculation: 50% x 0.06 = 0.03 Mha

High	0.06	• Full footprint of a solar park is unavailable for other production (e.g. livestock grazing) • Calculation: 100% x 0.06 = 0.06 Mha

5.2 Road transport biofuels assumptions and calculations

The full assumptions and calculations for land to be used to grow crops for use as feedstock for the production of road transport fuel are shown below:

Alter-native	**Land Demand** (Mha)	**Assumptions**
Low	0	• In 2013, about 42,000 hectares in the UK were used to grow crops for transport biofuels [19]. The vast majority of crop-based biofuels currently used in the UK are made from imported feedstock. [20] [21] • Assume no change from current land use.

Medium	1.34	• Meet 5% of UK road transport energy (half of the EU target) with crop-based biofuels made from UK grown crops. See calculation below
		• See 'Renewables in Transport: Directive 2009/28/EC - Devils in its Details' [58] regarding the EU target
		• Additional land required:
		    ○ 1.15 Mha (biodiesel) + 0.229 Mha (bioethanol) - 0.042 Mha (already in use – see Low alternative above) = 1.34 Mha
		    ○ See High calculation for details

High	2.73	• Meet the EU target (see above) for 10% of energy used for transport to be renewable entirely from crop-based biofuels made from UK grown crops. • Note: This assumption is made for illustrative purposes for the high alternative. In practice, some of the 10% requirement may be met using non crop-based biofuels (e.g. waste biodiesel and advanced biofuels). See Transport Energy Task Force paper [59] (page 10) • Energy used for road transport in 2014 was 40Mtoe (= 465200 GWh). See Department of Transport paper [60] (Chapter 2 – page 5). Assume this rate of use continues • Ratio (in 2015) of diesel energy (for transport) to petrol energy (for transport) is about 2.16. See Transport Energy Task Force report [59] (page 14) [3] • Assume that the ratio (by energy content) of biodiesel to bioethanol in 2030 will be the same as for diesel to petrol in 2015 as above • Energy content of biodiesel is about 33MJ / Litre [61] (Box 1) • Energy content of bioethanol is about 21MJ / Litre [61] (Box 1) • The ratio (by volume) of biodiesel to bioethanol in 2030 will therefore be 2.16 x 21/33 = 1.37 • Use the medium yield scenario for the amount of land required to produce ethanol and biodiesel (See research from Loughborough University [27] (Table 2)

[3] Label on vertical axis is shown as kilotonnes rather than megatonnes, but this does not affect the ratio above

		◦ Ethanol yield 0.55 l/m^2 (Mid) = 5500l per hectare ◦ Biodiesel yield 0.15 l/m^2 (Mid) = 1500l per hectare • Calculation: ◦ Energy to be produced from biofuels per year = 10% x 465200 GWh = 46520 GWh ◦ Using the figure of 1.37 for the ratio (by volume) of biodiesel to bioethanol, this gives a consumption of 3.47 billion litres of biodiesel, plus 2.52 billion Litres of bioethanol. Check: 3.47 billion litres (biodiesel) x 33MJ/Litre + 2.52 billion litres (bioethanol) x 21 MJ / Litre = 167.5 billion MJ ≈ 46520 GWh (1GWh = 3600000 MJ) ◦ Using the land yield figures gives: Land used for biodiesel crop growth = 3.47 billion litres / 1500l per hectare = 2.31 million hectares, and land used for bioethanol crop growth = 0.459 million hectares ◦ Total additional land required = 2.31 Mha (biodiesel) + 0.459 Mha (bioethanol) - 0.042 Mha (already in use for biofuels – see Low alternative above) = 2.73 Mha

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