



# Bioenergy

review



Technical paper 2

## Global and UK bioenergy supply scenarios

Committee on Climate Change  
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**Photo credits:**  
Ute Collier, CCC

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# Introduction and key findings

The CCC's bioenergy review provides an assessment of the potential roles for bioenergy given lifecycle emissions and other sustainability concerns, and also considers alternative uses for bioenergy feedstocks. The main report is available on our website: <http://www.theccc.org.uk/reports/bioenergy-review>.

More detailed analysis on estimates of global and UK bioenergy supply is provided in this technical paper. Three further technical papers are available on the website covering:

Technical Paper 1. Lifecycle emissions

Technical Paper 3. Appropriate use of scarce bioenergy

Technical Paper 4. Biomass in power generation

Bioenergy is playing an increasingly important role in the UK's energy mix, with the share of the UK's primary energy coming from bioenergy, currently 2%, expected to rise significantly by 2020 to meet the UK's renewable energy target. Globally, bioenergy accounts for 10% of total primary energy supply, two-thirds of which comes from traditional biomass (small-scale, local harvested biomass used in cooking and heating). The International Energy Agency (IEA) predicts an increase of up to 26% in global bioenergy use by 2020<sup>1</sup>.

Tensions between bioenergy use and sustainability objectives are not new. The use of firewood has long been linked to deforestation, especially in the developing world. However, the potential scale of modern bioenergy development for meeting renewable energy and climate change mitigation targets, as well as addressing energy security, has raised new concerns over unsustainable land use. The recent and substantial increase in the consumption of liquid biofuels has escalated the debate, given competition of biofuels with land previously used to grow food crops.

Numerous studies have assessed the global potential for bioenergy resources, with many attempting to constrain resource potential by economic, social and environmental factors. The range of bioenergy estimates in the literature is thus very wide – 28,000 to 415,000 TWh (or 100 to 1,500 EJ)<sup>2</sup> per year in 2050 (on a primary energy supply basis):

- To put this into perspective, the current global consumption of bioenergy is around 14,000 TWh (50 EJ).
  - 10,200-12,000 TWh (37-43 EJ) from traditional biomass (e.g. firewood).
  - 3,100 TWh (11.3 EJ) from modern biomass (e.g. biofuels processes from food and fodder crops, landfill gas).

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<sup>1</sup> IEA (2011), World Energy Outlook, 450ppm Scenario.

<sup>2</sup> 1EJ = 277 TWh.

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- The equivalent heat content of all the biomass currently harvested worldwide for food, fodder and fibre is 60,700 TWh/year (219 EJ)<sup>3</sup>.

Considering the wide range of estimates and assumptions in the literature, we felt it was important to develop our own, transparent scenarios. Whilst we recognise that developing bioenergy resource potential estimates is a highly speculative and uncertain exercise, we needed to establish the potential range of resource available to the UK in the short, medium and long term in order to analyse the most appropriate uses of sustainable bioenergy supply, and draw out implications for near-term carbon strategies.

This technical paper sets out our approach to developing UK bioenergy supply scenarios (Figure 1). We have developed scenarios for global bioenergy resource in line with the general approach taken in the literature, but based upon our own assessment of key sustainability constraints relating to food supply, biodiversity, water stress and social issues. We have also benefited from a recent UK Energy Research Centre study<sup>4</sup>, which has assessed the current stage of knowledge about global biomass available for bioenergy.

The focus of our global scenarios is on bioenergy feedstocks that can be traded internationally (e.g. dedicated energy crops, forest biomass, and dry agricultural residues) and therefore accessed by the UK for use in its energy system. We assume that the UK will receive a pro-rata share of the global supply of tradable feedstocks on the basis of its share of global energy consumption.

The key findings from our analysis are:

- Our scenarios give estimates of 108, 213 and 504 TWh of UK bioenergy supply, or a bioenergy share representing 5, 10 and 22% of primary energy demand in 2050.
- However, it would be unsafe at present to assume any higher level than 10% of bioenergy supply, and even this level might require some trade-offs versus other desirable environmental and social objectives (e.g. through energy crop production encroaching on land of high biodiversity value).
- Our scenarios are at the low end of the range represented in the literature<sup>5</sup>, including a recent report by the Intergovernmental Panel on Climate Change (IPCC), which reflects our cautious approach given sustainability concerns.
- Domestic waste feedstocks, which are largely non-tradable, could contribute significantly to the UK's bioenergy supply. Of total bioenergy supply, domestic production could account for 100%, 65% and 40% in our scenarios.

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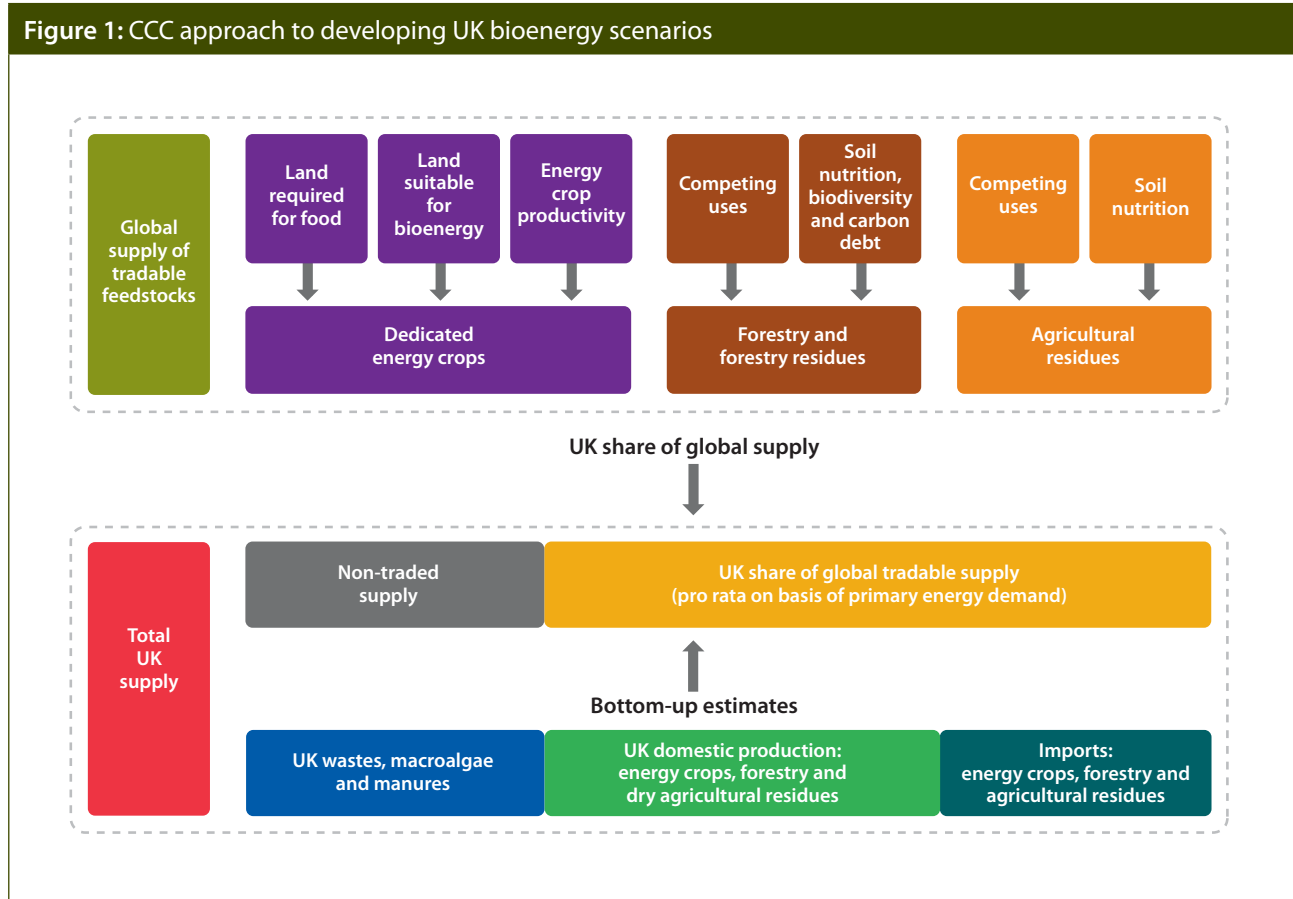
3 IPCC (2011), Special Report on Renewable Energy Sources and Climate Change Mitigation.

4 Slade, R. et al. (2011) Energy from biomass: the size of the global resource. Imperial College Centre for Energy Policy and Technology and UK Energy Research Centre, London. Available to download at [www.theccc.org.uk/reports](http://www.theccc.org.uk/reports)

5 IPCC (2011) Special Report on Renewable Energy Sources and Climate Change Mitigation, IPCC, Geneva.

The evidence and analysis underpinning these conclusions is set out in four sections:

1. Global supply of dedicated energy crops
2. Global assessment of bioenergy from forestry, agricultural residues and waste
3. UK bioenergy supply scenarios
4. Summary of UK bioenergy supply scenarios and conclusions



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# 1. Global supply of dedicated energy crops

There is a wide range of estimates in the existing literature of the potential for growing crops for energy purposes (discussed at length in Slade, et al. (2011)). Reflecting this wide range and the complex nature of the forecasting, we have chosen to develop our own scenarios of the potential sustainable supply from dedicated energy crops so that our assumptions are transparent. We compare our scenarios to the literature below.

Bioenergy resource assessments, while relying on different models and underlying data sources, largely adopt similar approaches to estimating global bioenergy supply. They focus on the amount of land which could be available for growing biomass for bioenergy in the future given:

- Competition for land between food and fuel. This suggests a need to focus on energy crops, including fast-growing trees and perennial grasses that can be grown on land which minimises competition with food production (e.g. low-productive agricultural land, land abandoned from agricultural production for a host of reasons including soil degradation, and/or land released from agricultural production due to improvements in productivity). These studies often use spatially explicit global land use and cover databases as well as satellite mapping to identify suitable land areas.
- A range of demand and supply factors determined by each study's own scenario design (e.g. population growth, diets, demand for agricultural land for food production, value placed on environmental objectives).

In developing our scenarios for the potential global bioenergy resource from dedicated energy crops, our starting point is the amount of land that might be available for bioenergy. In a world where we have a growing population, a move towards high-protein Western diets, and potentially adverse impacts on agricultural production due to climate change, we explore the evidence of the types and quantities of land that might be available and suitable for growing dedicated energy crops.

## **Land required for food production**

There is increasing concern over the impact of bioenergy on food availability given a fixed stock of land in the world, and acknowledging that providing enough food for people is a priority. This limits the amount of land available for growing bioenergy crops.

Establishing the amount of land that will be required in the future to provide enough food and fodder is difficult; it will depend on a number of complex and inter-connected factors and relies on data on land use and land cover which are inherently uncertain and unreliable (see Box 1 for discussion).

### Box 1: Land use data limitations

There are a number of limitations to the current knowledge base concerning land cover and land use, which means that assessments of bioenergy potential are constrained by poor quality and inconsistent data:

- There are few data sources (with most relying on the FAO's statistical database)
- Classification of land cover varies widely between sources, and different definitions apply to the same category of land use, e.g. 90 different definitions of 'forest'
- Remote sensing data relate only to the topmost layer of vegetation, while multifunctional land use is not captured
- Spatial resolution and timing differs across sources
- Notable shortcomings of developing country (reported) data include: incomplete or limited range of variables, incomplete coverage of all regions, questionable reliability and inconsistent definitions of land use terms.

There is now a range of models/suites of models that attempt to simulate the complex range of factors that influence land supply and demand over time – e.g. IMAGE, GLOBIOM, LPJmL, and IMPACT (see Smith, et al., (2010) for further discussion). However, it may be that more region- or country-specific studies are required in order to improve the accuracy of such assessments, as well as greater investment in consistent reporting of land use across regions and sources, as proposed in the recent Foresight review .

**Sources:** German Advisory Council on Global Change (WGBU), 2010. Earthscan; Smith, P., Gregory, P., van Vuuren, D., Obersteiner, M., Havlik, P., Rounsevell, M., Woods, J., Stehfest, E. and Bellarby, J., (2010); Competition for land. 365, 2941-2957. Foresight (2011) . The Government Office for Science, London.

Estimating future agricultural production requires assumptions to be made on a number of key variables, including:

- Population growth: The United Nations estimate that the global population will increase from its current level of around 7 billion to 9.1 billion in a central case in 2050, with a range of 8.7-11.3 billion.
- Diet change: It is likely that income growth will drive diet change in emerging economies, where demand for meat and dairy is expected to increase. Red meat and dairy production are particularly land-intense, both as regards land for grazing and for growth of animal feed (e.g. the land requirement for cattle can be up to thirty times that of cereals to produce the same calorie content). Therefore, increasing demand for meat and dairy products in emerging economies will result in increased demand for grassland and cropland for feed production.
- Agricultural productivity growth: In the past, agricultural productivity improvements have been sufficient to provide food for a growing population without significantly increasing the amount of farmed land. To achieve sustained productivity improvement and a convergence in best practice worldwide, significant investment in knowledge transfer and improved management practices in low-yield areas such as Sub-Saharan Africa will be required<sup>6</sup>.
- Climate Change: The impact that future climate change will have on agriculture is uncertain – in some regions, moderate temperature rise may improve yields whilst in others rising temperatures will have a negative effect<sup>7</sup>. However, a significant proportion of past productivity improvement has resulted from the use of carbon-intense fertilisers and irrigation and scope for further such improvement may be limited in a carbon- and water-constrained world.

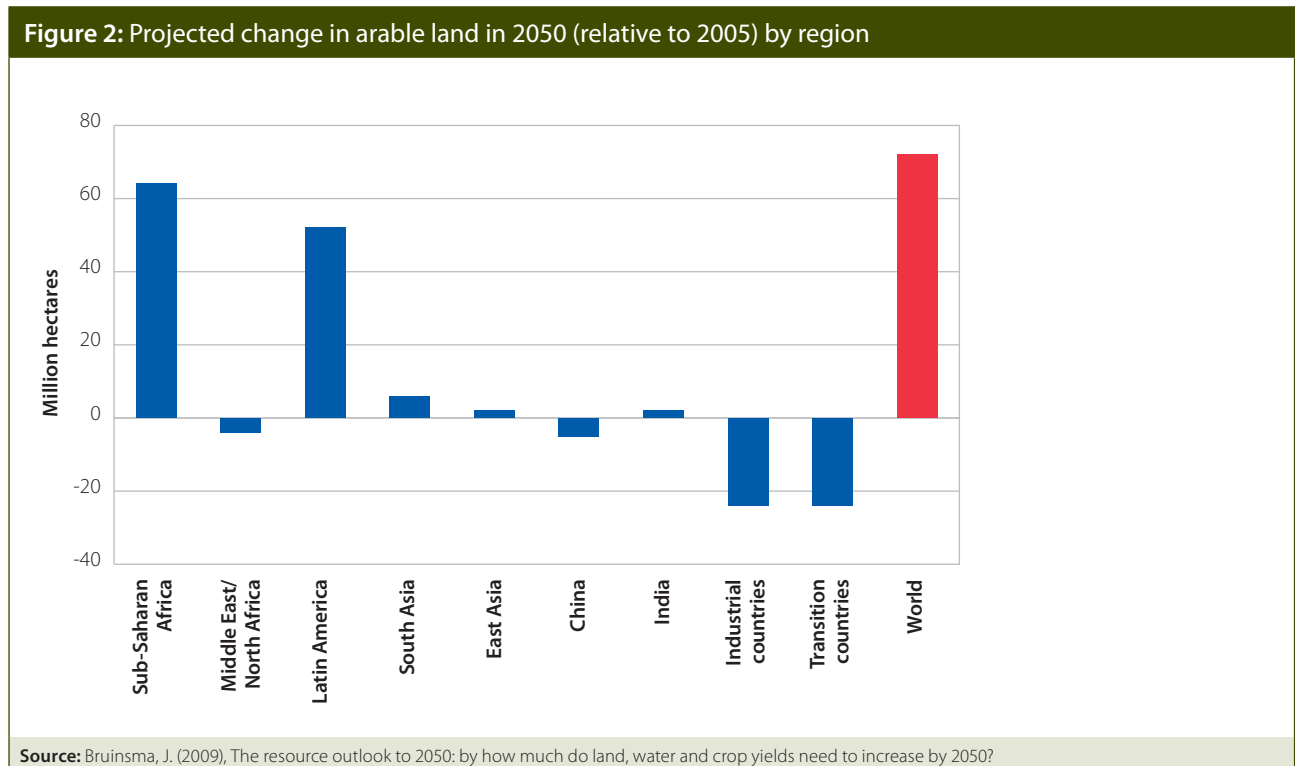
<sup>6</sup> Godfray, et al., (2010) Food Security: the challenge of feeding 9 billion people. *Science* 12 February 2010: Vol. 327 no. 5967 pp. 812-818.

<sup>7</sup> IPCC (2007), Fourth Assessment Report: Climate Change (AR4).

The United Nations Food and Agriculture Organisation (FAO) suggests that growing demand for agricultural products, due to increasing population and changing diets, will require a 70% increase in agricultural production by 2050<sup>8</sup>. The FAO forecast a net increase of 72 Mha of land for growth of food to meet this demand, which is achieved by a combination of land expansion in developing countries (120 Mha) and a contraction of agricultural area in developed countries (48 Mha) (Figure 2). Land expansion could contribute 20% to the production increase by 2050, with the majority being fuelled by additional yield growth (67%) and cropping intensity (13%)<sup>9</sup> (see Box 2 for further discussion of the FAO forecasts).

While there is debate about the rates of yield improvement in the FAO forecasts and their potential environmental impacts (e.g. the crop projections imply slower growth in the use of fertiliser than in the past, but the increase could still be significant for pollution as well as CO<sub>2</sub> emissions), the FAO provides the most authoritative assessment in this area.

We therefore reflect the FAO findings of the amount of additional land required for agricultural production in two of our four scenarios of land available for dedicated energy crops.



<sup>8</sup> FAO (2006), World agriculture: towards 2030/2050.

<sup>9</sup> FAO (2006).

## Box 2: FAO Agriculture Outlook 2030/2050 – key assumptions

FAO analysis projects that an additional 72 million hectares (a 5% increase in arable land) will be required to meet food demand in 2050. This analysis is based on an assessment of future population growth, diet change, and improvements in agricultural productivity.

### ***Demand assumptions***

The FAO assumes a rising and increasingly wealthy global population, with both of these contributing to an increase in food demand of 70% over the next four decades:

- Population will grow from 7 billion now to over 9 billion by 2050, in line with UN projections.
- Average daily consumption per capita will rise from 2820 to 3130 kilocalories, representing an 11% increase between now and 2050.
- Meat consumption is projected to increase from an average of 37 kg/capita/year to 52 kg/capita/year between now and 2050. This increase is due to a move towards high protein Western diets in the developing world.
- 45% of projected cereal demand increase is for direct food consumption and 40% for livestock feeding (with the remainder for other uses, including industrial uses, seeds, etc.).

### ***Agricultural productivity assumptions***

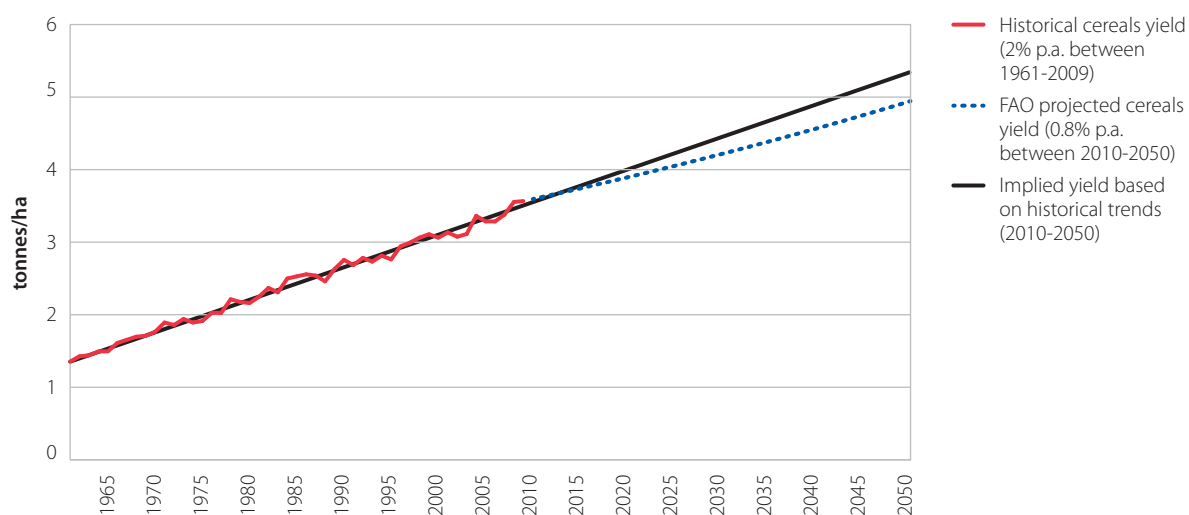
A small increase in land required for food production is projected on the basis that increased demand can largely be met through productivity improvement:

- Agricultural productivity increased by between 150 and 200% between 1960 and 2010 (e.g. global cereal yields grew by 2% per year), which allowed production to keep pace with growing demand without large amounts of new land being brought under production (e.g. the area of land under cultivation has increased by 12% while agricultural production has grown by 2.5 to 3 times).
- Much of this increase was fuelled by the 'green revolution' where advances in crop breeding, seed technology, and improvements in management practices allowed yields to improve, particularly in India and central Asia.
- The FAO notes that in many places productivity achievements have been associated with management practices that have degraded the land and water systems upon which food production depends.
- Growth in yields has therefore slowed recently and is forecast to be lower than historical increases (e.g. FAO modelling suggests global cereal yields will grow by 0.8% per year between 2010 and 2050) (Figure B2.a). This reflects scope for further improvement given productivity gaps across regions. For example, the global average cereal yield is 3.6 tonnes/ha, with the Americas averaging over 5 tonnes/ha and Africa averaging 1.3 tonnes/ha (Figure B2.b).

## Box 2: FAO Agriculture Outlook 2030/2050 – key assumptions

- The FAO suggests that the largest contribution to increases in agricultural output will most likely come from existing agricultural land. This has to be achieved through sustainable intensification which makes more effective use of land and water resources (e.g. improving irrigation efficiency, maintaining ecosystem functions, enhancing carbon storage). In addition, innovative farming practices such as conservation agriculture, agro-forestry, and integrated crop-livestock systems hold the promise of expanding production efficiently.

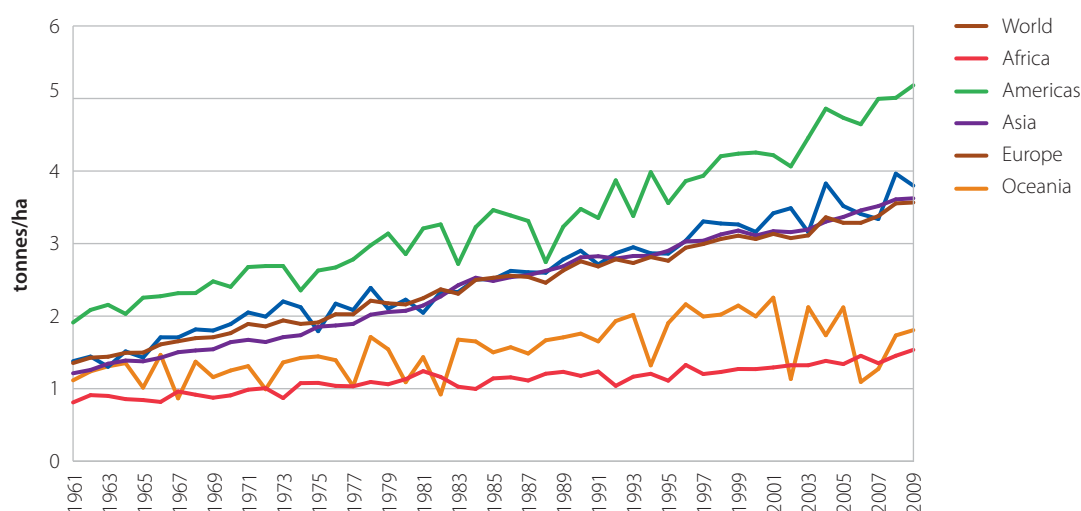
Figure B2.a: Historic and projected yield improvements for cereal crops



Source: FAOSTAT (2011); FAO (2006), World agriculture: towards 2030/2050; Bruinsma, J. (2009). The resource outlook to 2050: by how much do land, water and crop yields need to increase by 2050?; FAO (2011), The State of the World's Land and Water Resources for Food and Agriculture; managing systems at risk.

## Box 2: FAO Agriculture Outlook 2030/2050 – key assumptions

Figure B2.b: Regional variation in yields for cereal crops



Source: FAOSTAT (2011).

### Tension between food production and bioenergy

After several decades of low and stable food prices, the price of many agricultural commodities has spiked twice in the last few years. Food prices began to rise sharply in 2006, peaking in 2008. Although they then fell in 2009, they remained higher than pre-2006 levels and in early 2011, food prices rose even higher than the 2008 peak (Figure 3).

Recent food price spikes have had a disproportionate effect on developing countries:

- Poorer households in these countries typically spend up to three quarters of their income on food and so are most vulnerable to price rises<sup>10</sup>.
- Individuals in developing countries also typically consume less processed food and thus are more vulnerable to fluctuations in basic commodity prices.
- World Bank estimates suggest that an additional 44 million people may have fallen into extreme poverty in low- and middle-income countries due to the rise in food prices since June 2010<sup>11</sup>.
- High food prices may also exacerbate social tensions, causing political unrest. During the 2008 food price peak, there were protests in 61 countries and violence in 23 relating to food price inflation and volatility<sup>12</sup>. More recently, a study has linked the Arab Spring (2011) in part to very high levels of food inflation<sup>13</sup>.

<sup>10</sup> FAO, IFAD, IMF/OECD, UNCTAD, WFP, World Bank, the WTO, IFPRI and the UN HLTF (2011).

<sup>11</sup> World Bank (February 2011). Food Price Watch.

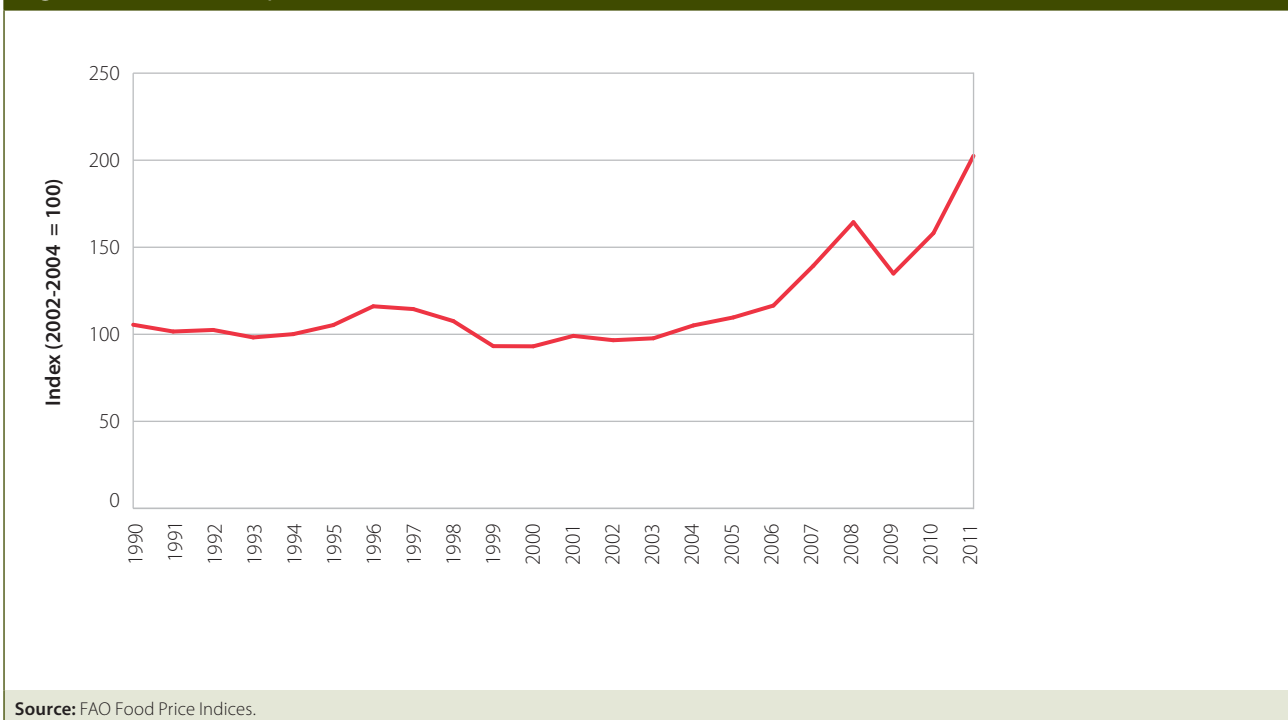
<sup>12</sup> Oxfam (2011); Growing a better future: food justice in a resource-constrained world.

<sup>13</sup> Lagi, M., (2011), The Food Crises and Political Instability in North Africa and the Middle East. arXiv:1108.2455.

Even now, at a relatively low level of bioenergy use, there is evidence to suggest a relationship between increasing use of land for growing conventional liquid biofuels feedstocks and food price inflation and volatility. The two crises have occurred due to the coincidence of a number of factors. Thus while it is difficult to isolate the impact of any one variable, the rising use of corn-based ethanol has been identified by international agencies such as the FAO and World Bank as one of the key drivers of the doubling in price of major grains and oilseeds between 2006 and 2008 (Box 3).

Given a scarce supply of land and growing demand for food (and in the absence of sufficient safeguards in place to ensure sustainable land use), there is likely to be growing competition between food production and bioenergy crops. Therefore, in our scenarios we focus on using land for energy crops that will not compete with required food production (as forecast by the FAO).

**Figure 3: Annual food prices from FAO Real Food Price Indices**



### Box 3: The role of biofuels in recent price spikes

In the global agricultural market, a number of demand and supply factors have influenced the price spikes seen in 2007/2008 and at the beginning of 2011.

#### Demand factors:

- **Growing population and income:** as global population has increased, it has become increasingly difficult for food production to keep pace. At the same time, incomes have increased, especially in the emerging economies of India and China. Demand for food – and particularly a more protein-rich diet – has therefore been growing.
- **Biofuel expansion:** as the biofuel industry has grown, largely as a result of government policies in Europe and the United States and recent high oil prices, it has increased the demand for key grains such as wheat and maize.

Normally, an inadequate supply in the face of rising demand would be cushioned by grain stocks, keeping price inflation low. However, stocks had already been depleted by several years of high demand and this meant greater volatility of prices in the face of several key:

- **Weather-related:** In the run up to the first food price spike, there were weak harvests in 2006 and 2007 with poor wheat production in US, Canada, Russia, Ukraine and the EU. Weather was even more of a factor in the second spike: a combination of drought in Australia, fairly low yields in Canada, fire then drought in Russia and several downwards revisions of US crop forecasts in late 2010 and early 2011 all contributed to short supply.
- **Governments' policy responses:** export restrictions exacerbated the already vulnerable markets, and so increased volatility. For example, in the first food spike, Russia, Ukraine, Kazakhstan and Argentina all put in place export restrictions on wheat.
- **High oil prices** have simultaneously affected supply – because the input costs of agriculture, such as fertilisers and transport, are higher – and demand – by raising the demand for biofuels as an alternative energy source, and so raising the demand for grain.
- High prices were compounded further by a **weak dollar** (agricultural commodities are generally denominated in US dollars), as well as **financial speculation** in agricultural commodities leading to greater price-volatility.

There was, therefore, no single cause of the two recent food spikes. Rather, they were the result of a complicated and interrelated set of factors, but including an impact from biofuels expansion.

Several studies have attempted to quantify the contribution biofuels consumption made to the food price spikes. The range of results is large, and reflects the difficulty of identifying the impact of any particular factor with any precision:

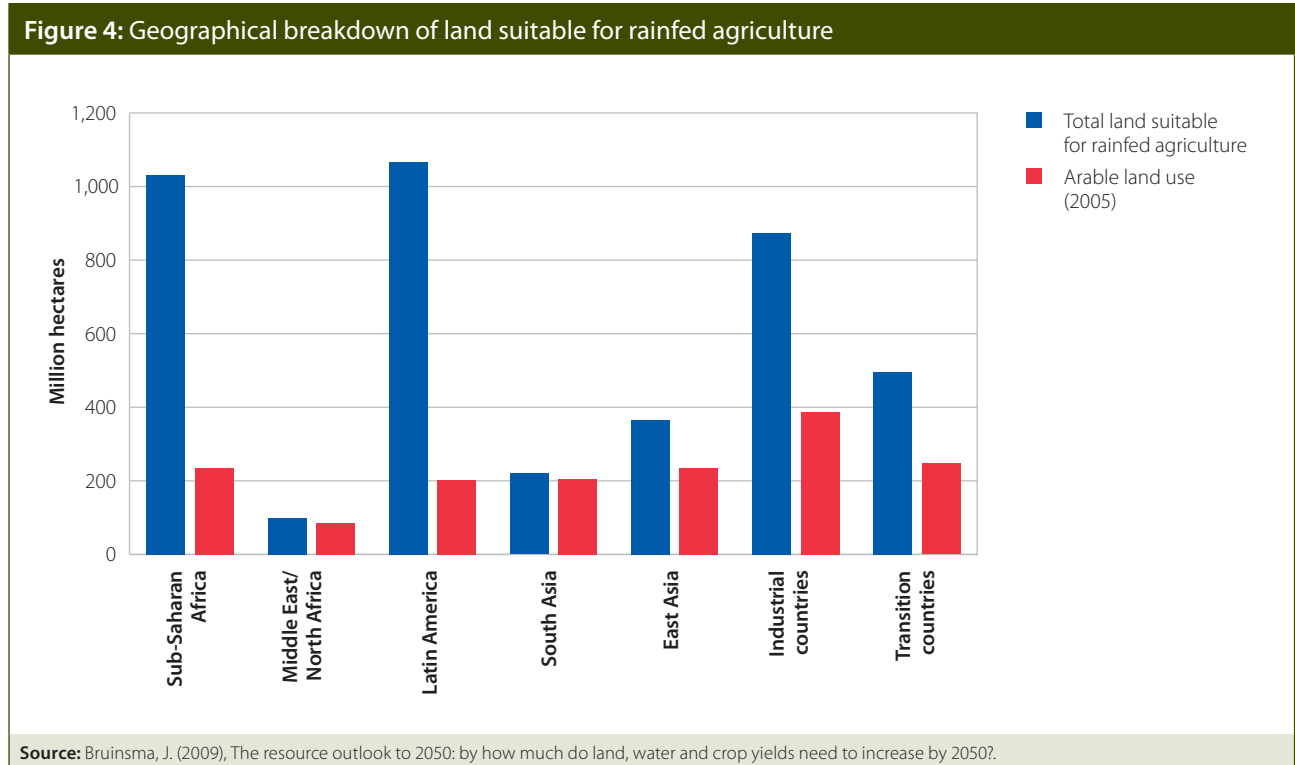
- The World Bank initially attributed 70-75% of the 2007/08 food price rise to biofuels (although later concluding this was too high)<sup>(i)</sup>.
- The International Monetary Fund (IMF) attributed 70% of the increase in maize prices and 40% of the increase in soybean prices to increased demand for biofuels<sup>(ii)</sup>.
- The International Centre for Trade and Sustainable Development (ICTSD)<sup>(iii)</sup> has suggested that if biofuel production had been frozen at 2004 levels, in 2009 maize would have cost 21% less, wheat 9% less and soybeans 5% less.

Other studies have avoided a quantitative approach. Instead, they limit their scope to explaining the range of factors, and discussing which are important. Some, including Defra<sup>(iv)</sup>, argue that the role of biofuels has been exaggerated, but in general, biofuel expansion is the most consistently cited of the key factors. Given this evidence, a range of multilateral organisations<sup>(v)</sup> have argued that biofuels ambition should be lowered to protect food security.

**Notes:** (i) Mitchell, D. (2008), A Note on Rising Food Prices. World Bank Policy Research Working Paper No. 4682. (ii) Lipsky, J. (2008), Commodity Prices and Global Inflation. New York: Council on Foreign Relations. (iii) Babcock, B. (2011), The Impact of US Biofuel Policies on Agricultural Price Levels and Volatility. (iv) Pfuderer, S. and del Castillo, M. (2008), The Impact of Biofuels on Commodity Prices. Economics Group, Defra. (v) Price Volatility in Food and Agricultural Markets: Policy Responses. Policy Report (2010) including contributions by FAO, IFAD, IMF/OECD, UNCTAD, WFP, the World Bank, the WTO, IFPRI and the UN HLT.

## Land suitable for dedicated energy crops

The FAO and the International Institute for Applied Systems Analysis (IIASA)<sup>14</sup> estimate that there is currently 4,200 Mha of land which is to some degree suitable for rainfed crop production. This estimate includes land which is currently used for growing crops (approximately 1,550 Mha). Under FAO assumptions a further 72 Mha will be required for food crops to 2050 (as described above). This suggests, therefore, that there is around 2,600 Mha that could in theory be used for crop production, the majority of which is in the developing world (Figure 4).



14 Fischer, G., van Velthuisen, H., Shah, M. and Nachtergaele, F. (2002), Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and results. IIASA.

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However, much of this land is neither accessible nor desirable for agricultural use:

- Around 1,060 Mha should be excluded to reflect other uses: an estimated 800 Mha is forest, 200 Mha protected land and 60 Mha human settlements<sup>15</sup>;
- Some of this land has a high biodiversity value, even though it does not have a nature protection designation.
- The approach does not incorporate projections of future climate change, which may have detrimental impact upon productivity due to changes in rainfall patterns, temperature and soil quality;
- In the ten years since the analysis was undertaken, it is likely that land use change has occurred and that some of the land may no longer be suitable/available for cultivation.

Our approach to land use scenarios is consistent with the Government's Foresight Report,<sup>16</sup> which concludes that we should plan for very limited expansion of agricultural land in the future but that there is a role for the restoration of degraded land.

In estimating the amount of abandoned agricultural land in the world, we draw on a number of studies<sup>17</sup>, suggesting a range of 320 to 580 Mha of low-productivity land that is no longer used for agricultural production (Box 4). There are potential constraints to accessing/cultivating the land identified by these studies (e.g. uncertain levels of productivity that can be achieved on such lands, the inputs required to restore them). We reflect these constraints in our scenarios.

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<sup>15</sup> Bruinsma, J. (2009), *The resource outlook to 2050: by how much do land, water and crop yields need to increase by 2050?*

<sup>16</sup> Foresight (2011), *The Future of Food and Farming*, The Government Office for Science, London.

<sup>17</sup> Cai, X., Zhang, X. and Wang, D. (2011), Land availability for biofuels production, *Environmental Science and Technology*, 45, 334-339; Campbell, J. E., D. B. Lobell, R. C. Genova, and C. B. Field (2008). The global potential of bioenergy on abandoned agriculture lands, *Environmental Science and Technology*, 42(15), 5791-5794; Hoogwijk, M. et al., (2005). Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios. *Biomass and Bioenergy*, 225-257.

#### Box 4: Definitions of unused land and estimates of abandoned agricultural land

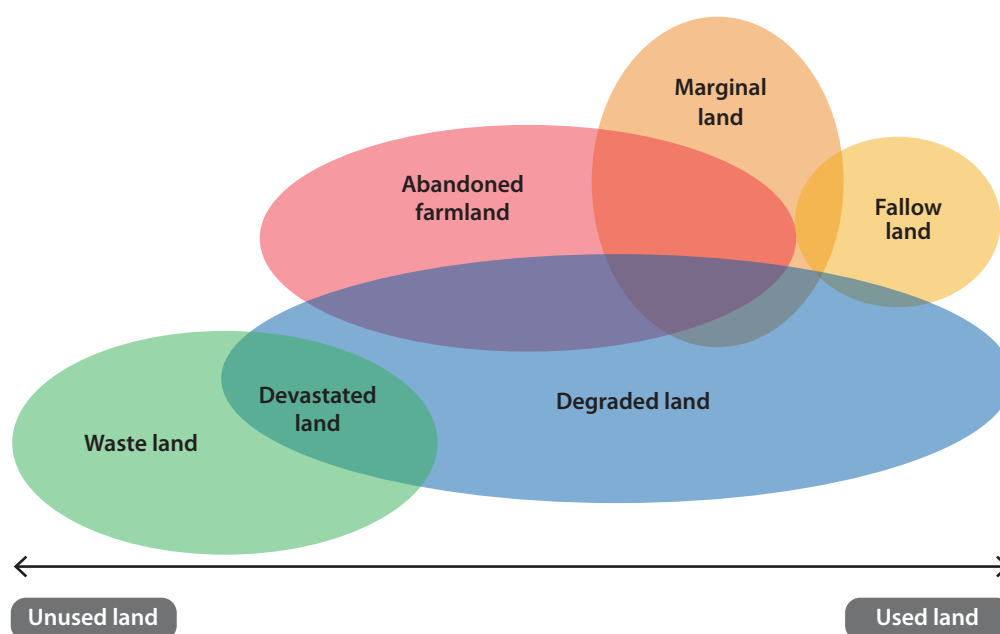
Recognising the potential for direct competition for prime agricultural land from both bioenergy and food production, we explore the potential for dedicated energy crops to be cultivated on land that is either not required, or not suitable for arable crop production.

There are a number of terms that are used to describe the land that is not suitable for agricultural production, including:

- Abandoned agricultural land: land that was previously used for agriculture or pasture but that has been abandoned and not converted to forest or urban areas. The reason for the abandonment could be economic, political (e.g. set-aside), environmental or climatic.
- Degraded land: long-term decline in ecosystem function and productivity, caused by man-made or natural triggers.
- Idle land: all types of unused land, i.e. abandoned agricultural land, degraded land, devastated land and waste land, as well as areas of undisturbed wildlife.
- Marginal land: areas where cost-effective production is not possible, under given conditions (e.g. soil productivity), cultivation techniques, agriculture policies, as well as macro-economic and legal conditions.
- Waste land: areas that cannot be cultivated under any conditions, e.g. salt flats, active dunes, deserts, ice caps, and mountains.

There is a degree of overlap between such terms (see Figure B4) and as such it is difficult to establish a reliable estimate of how much of each type of land, and its associated productivity, might be available.

**Figure B4:** Diagram of overlap between categories of land not used for food production



Source: Adapted from Wiegmann, K., *et al.*, (2008).

#### Box 4: Definitions of unused land and estimates of abandoned agricultural land

We have drawn on the following estimates of the amount of abandoned or marginal land that might be suitable for bioenergy cultivation.

- Campbell, et al. (2008) assess the productivity of land which has been abandoned in the last 300 years, showing that between 386 and 472 Mha might be suitable for bioenergy production
- Cai, et al. (2011) show that there is 302 Mha of mixed-crop and natural vegetation land with marginal productivity, including abandoned, wasted, or idle agricultural land.
- Hoogwijk et al. (2005), using estimates from the IMAGE model, state that there is between 430 and 580 Mha of 'low-productivity rest land'.

Whilst imperfect, we have used these estimates as the basis of our dedicated energy crop scenarios, assuming that there could be up to 400 Mha of abandoned agricultural land available for bioenergy cultivation, once food needs have been satisfied, in 2050. However, we do not assume that accessing this land will be easy or have neutral environmental or social impacts:

- Land that is described as 'marginal', 'abandoned' or 'idle' may not truly be such; many lands are used by local subsistence farmers for livestock rearing and other purposes. A lack of well-established property rights in many developing countries where such land may be available is likely to lead to conflict and land tenure issues. For example in India, the government identified 33 Mha of so-called 'marginal' land but a lack of participation by the rural poor in the deployment of jatropha plantations in the region has already led to unrest.
- Yields of energy crops grown on this land may be lower than average as soil quality is likely to be lower, as well as requiring high levels of inputs (e.g. irrigation and nitrogen fertilizer).
- Restoring some abandoned lands may be impossible given the level of degradation or drought (e.g. in Eastern Australia).
- Marginal land typically has no infrastructure, is widely dispersed and can be in countries of conflict or political instability.

Our Constrained Land Use scenario assumes that only a small proportion of the estimated abandoned agricultural land is used for bioenergy, whereas the Extended Land Use and Further Land Conversion scenarios rely on the majority being used for bioenergy or additional food production in 2050.

**Sources:** Wiegmann, K., (2008), Joint International Workshop on High Nature Value Criteria and Potential for Sustainable Use of Degraded Lands, Paris, June 30-July 1, 2008: Degraded Land and Sustainable Bioenergy Feedstock Production – Issue Paper. Öko-Institut; Campbell, J. E., D. B. Lobell, R. C. Genova, and C. B. Field (2008), The global potential of bioenergy on abandoned agriculture lands, *Environmental Science and Technology*, 42(15), 5791-5794; Cai, X., Zhang, X. and Wang, D. (2011), Land availability for biofuels production, 45, 334-339; Hoogwijk, M., Faaij, A., and Eickhout, B. (2005), Potential of biomass energy out to 2100 for four IPCC SRES land-use scenarios. *Biomass and Bioenergy*, 25, 225-257.

There is a wide range of potential yields for energy crops, depending on the land type, with lower yields expected on abandoned agricultural land and higher yields on current agricultural land.

- We assume that in the longer term bioenergy feedstocks are a mix of perennial energy crops such as fast-growing trees (e.g. willow or poplar) and grasses (e.g. miscanthus or switchgrass). These crops are likely to be suited to land of low productivity, have relatively low lifecycle emissions, and can be converted for use across the range of sectors.
- Current literature suggests an average global yield of around 10 tonnes dry matter per hectare (t/ha) for such crops, with yields of around 5 t/ha expected for low quality land and up to 15 t/ha on good quality agricultural land<sup>18</sup>.

<sup>18</sup> Slade, et al., (2011).

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- We reflect the range of 5 to 15 t/ha in our scenarios – using 5 t/ha in our Constrained Land Use and Extended Land Use scenarios and a mix of 5 and 15 t/ha in the Further Land Conversion scenarios. However, we recognise that there is a high degree of uncertainty over how yields of energy crops will develop over time. For example, there is potential for advanced breeding to improve yields of energy crops at a greater rate than established crops, given the lower level of research and development in this area to date.
  - Yields will be highly variable depending on the crop and soil type, which will also depend on the local climate. We do not attempt to provide a precise regional breakdown of the land area or crops grown.

Though we assume that, in the long run, energy crops will predominantly be perennial trees and grasses, this does not preclude a transitional role for food and fodder feedstocks. We envisage these may make an important contribution in the near to medium term, subject to concerns about lifecycle emissions and food security being addressed. There may also be a continuing role for food and fodder crops in regions where these are the most appropriate and high-yielding energy crops (e.g. sugar cane in Brazil). We have allowed for this in our Further Land Conversion scenarios where 30 Mha of land is planted with sugar cane for bioethanol in 2050.

More generally, any longer-term role for food and fodder feedstocks (e.g. into the 2030s and beyond) would have to be predicated on evidence that:

- these feedstocks can be grown on abandoned agricultural land,
- cultivation has lifecycle emissions comparable to those from other energy crops,
- conversion routes to appropriate uses are available and viable.

### **Scenario descriptions, key assumptions and energy potential**

We now set out four scenarios for future global supply of bioenergy from dedicated energy crops in 2050. In doing this, we are not attempting to predict the future. Instead, our aim is to provide a broad range of alternative assumptions about demand for food, agricultural productivity growth and land availability, and to explore sustainability constraints relating to food supply, biodiversity, water stress and social issues. Our scenarios then illustrate a range of possible futures for bioenergy contributions to meeting carbon budgets.

We do not assume major breakthroughs in technology or behaviour change. While these are possible, we do not consider them an appropriate basis for current planning, as they are highly uncertain.

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The range of land covered in our scenarios is 100-700 Mha, with a range for yield of 5-15 tonnes dry matter/ha, giving rise to bioenergy shares of primary energy demand in 2050 ranging from 1-18% (Table 1):

- **Constrained Land Use.** In this scenario only a small proportion of abandoned agricultural land, with an assumed low level of productivity, is used for growth of dedicated energy crops. This scenario is designed to reflect a world where much of the abandoned agricultural land has prohibitively low productivity and/or where there are tight social and environmental constraints, and/or where land conversion would result in significant carbon release.
- **Extended Land Use.** This scenario relaxes productivity and sustainability constraints, allowing greater use of abandoned agricultural land for growth of energy crops, but still very limited use of current agricultural land and previously uncultivated land.
- **Further Land Conversion.** We include two land conversion scenarios which are either highly uncertain (e.g. as regards agricultural productivity growth or behaviour change) or require ethical judgments to be made (e.g. around biodiversity loss), and which should therefore be used only as sensitivities and not as a basis for planning. These scenarios give the same bioenergy production but for different reasons:
  - **Agricultural Land Conversion.** This includes growth of energy crops on some land where food crops are currently grown. It therefore assumes either agricultural productivity improvements going beyond that envisaged by the FAO or diet change (i.e. a reduction in livestock consumption).
  - **Natural Habitat Conversion.** This has the same level of bioenergy supply as in the Agricultural Land Conversion scenario, but under a different assumption that energy crops are grown on previously uncultivated land, which is likely to result in the conversion of a range of natural habitats. However, this scenario could involve high land use change emissions.

**Table 1: Description of key assumptions under each global 'dedicated' energy crop resource scenario**

	Constrained Land Use (CLU)	Extended Land Use (ELU)	Further Land Conversion – Agricultural Land Conversion (FLC – ALC)	Further Land Conversion – Natural Habitat Conversion (FLC – NHC)
<b>Total land use in 2050</b>	100 Mha of land – around 20% of estimated global abandoned agricultural land.	400 Mha of land – majority of estimated global abandoned agricultural land	700 Mha: includes growth of energy crops on 400 Mha of abandoned agricultural land, together with around 300 Mha of land currently used for food crops.	700 Mha: includes growth of energy crops on 400 Mha of abandoned agricultural land, together with previously uncultivated land, which is assumed to be unprotected grassland and woodland.
<b>Food production</b>	FAO projection: 70% increase in production with a net land expansion of 72 Mha.	FAO projection: 70% increase in production with a net land expansion of 72 Mha.	Agricultural productivity improvement goes beyond that assumed by the FAO (e.g. increases of 100% to 2050 rather than 65% in the FAO analysis); or it could be achieved through change to a less carbon-intense diet (e.g. around a 15% reduction in livestock consumption).	FAO projection: 70% increase in production with a net land expansion of 72 Mha.  Land expansion may occur on areas currently used as pasture/grazing land and therefore may imply increased grazing intensity of remaining land and/or indirect land use change.

**Table 1: Description of key assumptions under each global 'dedicated' energy crop resource scenario**

	Constrained Land Use (CLU)	Extended Land Use (ELU)	Further Land Conversion – Agricultural Land Conversion (FLC – ALC)	Further Land Conversion – Natural Habitat Conversion (FLC – NHC)
<b>Environmental and social constraints</b>	<p>Assumes that much of the land identified as 'abandoned agricultural land' is unsuitable for cultivation due to environmental constraints (i.e. water stress and/or biodiversity value). We also constrain the land supply due to concerns that it serves a purpose to the local community.</p> <p>It is possible that this scenario represents a world where energy crop production is concentrated in Europe and North America, where concerns over water-stress and equity issues pose less of a threat to the sustainable deployment of bioenergy.</p>	<p>Relaxes constraints identified in the Constrained Land Use scenario. Implies an optimistic land supply as there are considerable barriers to overcoming social and environmental constraints on abandoned agricultural land, e.g. conflict arising from the displacement of indigenous peoples.</p>	<p>Highly uncertain scenario, relying on technological breakthroughs in crop breeding (e.g. genetic modification) and/or behaviour change to release land otherwise required for food production, as well as the challenges associated with cultivating the majority of abandoned agricultural land (as per the ELU scenario).</p>	<p>Likely to have significant environmental impact in terms of biodiversity loss and loss of soil carbon, as well as the challenges associated with cultivating the majority of abandoned agricultural land (as per the ELU scenario).</p>
<b>Energy crop yield</b>	<p>It assumes a crop yield at the low end of the range, 5 t/ha, reflecting the fact that abandoned agricultural land has relatively low productivity.</p>	<p>It assumes a crop yield at the low end of the range, 5 t/ha, reflecting the fact that abandoned agricultural land has relatively low productivity.</p>	<p>Yields in this scenario are assumed to be 5 t/ha for abandoned agricultural land, and 15 t/ha for current agricultural land.</p>	<p>Yields in this scenario are assumed to be 5 t/ha for abandoned agricultural land, and 15 t/ha for previously uncultivated land.</p>
<b>Planting rate</b>	<p>5 Mha of energy crops are planted each year from 2015 to 2020, falling to around 2 Mha/yr thereafter.</p>	<p>5 Mha of energy crops are planted each year from 2015 to 2020, rising to around 12 Mha/yr thereafter.</p>	<p>5 Mha of energy crops are planted each year from 2015 to 2020, rising to around 20 Mha/yr thereafter.</p>	<p>5 Mha of energy crops are planted each year from 2015 to 2020, rising to around 20 Mha/yr thereafter.</p>
<b>Energy potential</b>	2,600 TWh	10,600 TWh	34,300 TWh	34,300 TWh

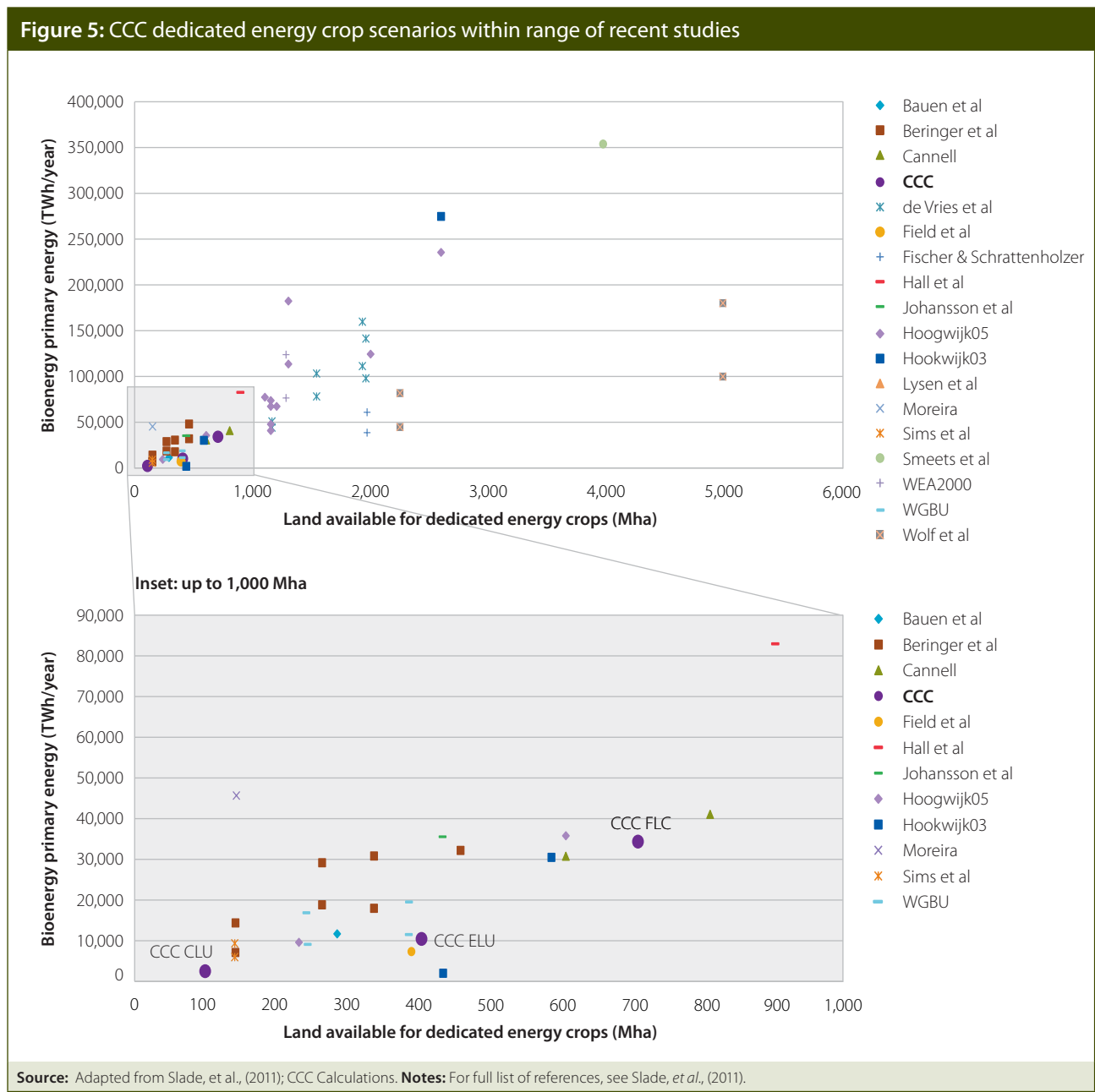
Source: CCC analysis.

We use the outputs from the four scenarios as inputs to our assessment of where scarce bioenergy should best be used.

These scenarios are towards the low end of the literature on energy crops (Figure 5), which provides confidence that we have been conservative in our attempt to address the risks and uncertainties surrounding such estimates.

Estimates from the literature with similar energy potential to the CCC scenarios are characterised by assumptions that there is high demand for food and only a small amount of land available for energy crops, and do not rely on breakthrough technologies or significant behaviour change.

Scenarios with higher bioenergy shares may become appropriate where there is clear evidence of a breakthrough on productivity improvement of novel bioenergy technologies, or significant behaviour change. Otherwise they involve a high sustainability risk.



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## 2. Global assessment of bioenergy from forestry, agricultural residues, and waste

Analysis of global resource potential from forestry and agricultural residues, as well as domestic potential from wastes in the period to 2050, is largely drawn from analysis commissioned by the Department of Energy and Climate Change and undertaken by AEA, Oxford Economics and Forest Research<sup>19</sup> (referred to below as AEA (2011)). In addition, we used a report by E4Tech<sup>20</sup> commissioned by the Department for Transport (referred to below as E4Tech (2011)). These assessments attempt to construct a sustainable picture of future supply that is constrained by market, logistical and environmental factors.

### Forestry and forest residues

Forestry biomass encompasses:

- Forest sector by-products including both primary residues from thinning and logging (e.g. treetops, limbs, slash and small round wood), and secondary residues such as sawdust and bark from wood processing.
- Dead wood from natural disturbances, such as fires and insect outbreaks (e.g. at present Canada's forests are threatened by an outbreak of mountain pine beetle, which has affected 16 Mha of forest, resulting in a large quantity of dead timber)<sup>21</sup>.
- Biomass growth in natural/semi-natural forests that is not required for industrial round wood production to meet projected demand for timber/traditional biomass.

There is also a potential for dedicated plantations for forest biomass (e.g. short and long-rotation forestry). These have been included above in our estimates for global dedicated energy crops, given the need for additional land requirements.

In examining the availability of woody biomass from forestry we focus on the first category (by-products and residues), which may represent a more sustainable picture of supply. Additional forest biomass is potentially available, for example, from increased forest management (clear felling and/or thinning of virgin forests) provided forests are well-managed to repay carbon stocks and maintain other environmental objectives (e.g. biodiversity and soil preservation). Changes in demand for timber may also provide additional resource. For example, the wood pellet sector currently developing in the south-eastern United States is utilising forest resource previously extracted for the regional timber sector, which has experienced structural decline.

We also distinguish between short- and long-term supply. In the short term, there is a growing market for wood pellets processed from forest and forest product residues to meet EU renewable energy targets:

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<sup>19</sup> AEA (2011), UK and Global Bioenergy Resource – Final report, prepared for DECC.

<sup>20</sup> E4tech (2011, forthcoming), Modes Project 1, in preparation for Dft.

<sup>21</sup> Wood Pellet Association of Canada, AEBIOM European Bioenergy Conference Brussels, Belgium, June 30, 2011.

- In 2010, 16 million tonnes of wood pellets were consumed worldwide for heat and energy purposes, of which 13 million tonnes were consumed within the EU. Demand has been met mainly through European production plus imports arising from residues from neglected forests and unused co-products (e.g. sawmill residues) in North America (primarily Canada and south-eastern United States).
- Analysis by Forest Research suggests a global potential of 200 million oven-dried tonnes, or 1,000 TWh on an energy input basis, available from forestry and forest residues in 2020. This focuses on forest sector by-products, or residues arising from current forest management operations and wood industry processes, rather than from clear felling or thinning of virgin forests not managed for timber and/or on dedicated plantations. The extent of sustainable forest biomass resource is thus dependent on timber harvested for wood and other uses (e.g. pulp and paper) (Box 5). The bulk of the forest resource is likely to come from North America, Europe and Russia.

In the long term, there is uncertainty over the continued sustainability of supply as countries make increasing use of domestic forestry residues. There is a risk that the potential scale of demand for forest biomass (e.g. for power generation) may displace use in other sectors and/or lead to unsustainable sourcing. We reflect these concerns by assuming that the tradable share of global forestry resource is reduced over time.

#### Box 5: Estimates of bioenergy from forestry and forest residues and potential sustainability constraints

The Forest Research estimates are derived using the Forestry Commission Carbine modelling analysis of national forest inventories plus FAO timber statistics using the following approach:

- Historic trends in forest management and afforestation/deforestation are applied forward.
- Demand for timber for wood, paper and pulp is projected forward and residuals are assumed to be available for bioenergy (e.g. forest residues including small round wood and branch wood, co-products including saw log off cuts, including slab wood). Competition between uses of these residuals by the pulp, paper, panel board sector and bioenergy sector are not taken into account.
- Constraints are applied over time given increased demand for wood in construction by Asia, Latin America and Europe.
- Other key constraints include recoverability of resource, transportability, competing use of industry facing few alternatives,

In practice there are a number of concerns arising from harvesting forest products for bioenergy, particularly given the size of potential demand by the EU to meet 2020 renewables targets. These include:

- Over-extraction: Robust criteria and enforcement is needed to ensure forests are sustainably managed for bioenergy (e.g. sufficient residues are retained onsite for biodiversity/soil preservation purposes). At present it is not clear whether Government criteria adequately ensure the sustainability of supply (see Technical Paper 1 – Lifecycle emissions).
- Carbon accounting: Forests must be well managed to pay off carbon debt (typically accounted for within a 20-year time period).
- Competition leading to displacement: Increased demand for forestry residues for bioenergy may displace the supply of timber in other sectors, leading to the potential for unsustainable sourcing and associated direct and indirect LUC impacts.

Sources: AEA (2011) UK and Global Bioenergy Resource – Final report.

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## Agricultural residues

Agricultural residues are currently traded for use as animal feed, as a fuel for co-firing and as a feedstock for other products. Examples include olive oil residues, palm kernel expeller and sunflower pellets. Data from Ofgem shows that around 5% of biomass used for UK electricity generation under the Renewables Obligation in 2010/11 came from imported agricultural residues (mainly olive residues from Spain).

A key constraint to the wider use of agricultural residues for energy will be competition from existing uses. In particular, incorporation of straw back into the soil is an important form of nutrient recycling and aids soil stability:

- In the UK straw is often harvested, used as animal bedding and then the farmyard manures returned to the field as a fertiliser.
- Recent analysis published by the World Bank assumes that 40% of total produced residues can be used for biofuel production for most crops – the exceptions would be rice straw and sugarcane bagasse where 100% of the residues can be removed<sup>22</sup>.
- If ash from the combustion of straw for bioenergy purposes can be returned to the soil this can help return minerals to the soil but cannot contribute organic matter or help soil structure.

Estimates of the global resource:

- The IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (2011) concluded the technical potential from dry agricultural residues (e.g. cereal straw from harvesting, rice husks from rice milling) could amount to between 5,000 and 20,000 TWh by 2050<sup>23</sup>.
- Using international data to identify residues that can be aggregated and traded, AEA (2011) assume agricultural residues could offer around 10,000 TWh (technical potential) in 2030. The main constraints in terms of potential availability to the UK are in-country use (meaning volumes placed on international markets will only be a fraction of that consumed globally) and competition from other markets. Of the 10,000 TWh that may be available globally by 2030, AEA (2011) estimate that ~900 TWh (range ~300-1,500 TWh) could become available on international markets.

The AEA estimates are within the IPCC range and we have used these in our analysis.

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<sup>22</sup> World Bank (2011), Second-generation Biofuels: Economics and Policies.

<sup>23</sup> The higher end of this range may include some residues that are unlikely to be traded internationally.

## Wastes

It is unlikely that ‘wastes’ will ever be traded on a significant scale for bioenergy purposes due to the nature of the feedstocks (often wet and difficult to handle) and the costs of transporting them over long distances. The IPCC reviewed the literature on global availability and arrived at a range of 1,500–14,000 TWh for organic wastes (e.g. from households and restaurants, discarded wood products including paper, construction and demolition wood) in 2050. We have assumed that this resource is used locally and not traded. We do not, therefore, include wastes in our global bioenergy scenarios, but assume that UK-produced wastes are available for UK use (see Section 3).

## Summary of global bioenergy resource

Total global primary energy supply is projected to be in the region of 187,000–256,000 TWh (675–925 EJ)<sup>24</sup> in 2050. Our scenarios equate to between 4,200–37,000 TWh (15 and 135 EJ) of bioenergy resource in 2050, with dedicated energy crops contributing 2,600 to 34,300 TWh and forestry and forest residues and agricultural residues adding around 1,500 to 3,300 TWh (Table 2). These scenarios suggest that bioenergy supply could contribute between 2 and 20% to global primary energy demand in 2050<sup>25</sup>.

	2020			2030			2050		
	CLU	ALU	FLC	CLU	ALU	FLC	CLU	ALU	FLC
<b>Energy crops</b>	790	790	3,170	1,410	4,050	13,560	2,640	10,560	34,330
<b>Forestry</b>	970	1,070	1,310	1,100	1,480	1,510	1,150	1,530	1,560
<b>Agricultural residues</b>	250	570	840	300	920	1,540	300	920	1760
<b>Total</b>	2,000	2,440	5,330	2,810	6,450	16,600	4,090	13,020	37,650

**Source:** CCC analysis; AEA (2011); E4tech (2011, forthcoming).  
**Notes:** Totals may not sum due to rounding. The total for energy crops in this table does not account for the 30 Mha planted with sugar cane, which is included in the final breakdown of feedstocks.

These estimates are within the low to lower-mid range as presented by Slade, et al., (2011) and at the low end of the range recently suggested by the IPCC<sup>26</sup>. This is in part due to our assessment of global resource focussing on feedstocks which are likely to be traded on the international market and therefore excluding resource which could be used locally in each country (i.e. straw and biodegradable waste). This also reflects the cautious approach in our land use scenarios, which we believe is appropriate given sustainability concerns.

24 IEA (2010), Reference and Blue Map Scenarios. 1 EJ = 277 TWh.

25 Primary energy accounted for on the ‘physical energy content’ method, as used by DECC, the International Energy Agency and Eurostat. This method counts the heating value of combustible fuels (bioenergy, fossil fuels), the heat produced by nuclear and geothermal facilities (which is then used, at an assumed 38% efficiency, to generate electricity) and the electricity output of non-thermal renewable generation such as wind and hydro. Primary energy required to meet demand varies depending on the technologies used; this method tends to under-represent the contribution of non-thermal renewable (e.g. wind) and of heat pumps, for which the electricity input is counted and where primary energy can therefore be 3–4 times lower than heat output.

26 IPCC (2011), SRREN: 22,000–53,000 TWh/yr, with 74,000–83,000 TWh/yr as upper levels.

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However, there are considerable uncertainties surrounding the economic potential of these feedstocks, particularly given that we are already making significant assumptions regarding what needs to be achieved in order to harness this resource (especially in our Further Land Conversion scenario). For example, the German Advisory Council on Global Change<sup>27</sup> assumes that economic potential is 50% of technical sustainable potential.

Key constraints to energy crop development are likely to include:

- Rates of land conversion implied are considerably higher than historic trends<sup>28</sup> (except in the Constrained Land Use scenario).
- It may not be economically viable to use low-grade land.
- Some of the abandoned agricultural land is so degraded that no crop growth is possible e.g. because of soil salinisation.
- Inputs required may be considerable: to achieve even modest levels of bioenergy deployment, projected demand for nitrogen fertiliser in 2030 could increase by 4-23% (which would also have implications for lifecycle emissions) and require a doubling of irrigation water requirements<sup>29</sup>.
- Climate change may negatively impact land availability and crop productivity.
- Global land use monitoring and enforcement framework is not sufficiently sophisticated to deliver these outcomes sustainably.

Further research is required to clarify these issues.

For our estimates of non-energy crop feedstocks, particularly for domestic resource, key constraints to developing biomass supply include a lack of infrastructure, storage and transport facilities, and the dispersed nature of the feedstocks.

Use of these feedstocks for bioenergy is also likely to compete with many other existing uses, including the traditional use of biomass for woodfuel, the spreading of organic fertiliser (e.g. manures) to agricultural land, use of wood fibre and other biomass materials in the construction industry, use of wood for the paper, pulp, and panel board manufacture industries, and use of straw for animal bedding. Alternative potential uses, for example, for biochar production (Box 6) or for new building materials, could be introduced over time and compete with bioenergy use.

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27 German Advisory Council on Global Change (WGBU), 2010. Earthscan.

28 Between 1961/63 and 1997/99, about 5.5Mha of new permanent crops were developed annually. In our scenarios, we assume between 2 and 20 Mha per year.

29 Under a 240Mha land use scenario, as calculated by Beringer (2010).

### Box 6: Biochar

A potential alternative use for biomass is for production of biochar, a solid charcoal produced via pyrolysis, or the partial combustion of biomass (e.g. crops, straws or wastes) in limited oxygen. Biochar can be applied to agricultural soils with the potential benefits of a permanent increase in soil carbon, stabilisation of soil structure, suppression of other GHGs (e.g. N<sub>2</sub>O emissions arising from fertiliser use) and enhanced fertiliser-use efficiency. These effects have yet to be widely demonstrated, although recent trials in the UK have indicated modest benefits.

At present UK research is focussing on the impact of biochar on soils, the effect on yields in commercial farms, as well as the potential benefits of applying biochar to contaminated soils. Further work is also required to develop more efficient technologies for producing biochar.

Given competing demands for biomass, lower value fuels (e.g. wastes and residues arising from other biotechnological conversion processes) may be best suited as feedstocks for pyrolysis. Biochar may thus play a niche role in the UK, that could expand over time if agronomic values (e.g. improved yields and fertiliser efficiencies) and potential carbon abatement benefit (particularly given the challenges to reducing CH<sub>4</sub> and N<sub>2</sub>O emissions arising from agricultural activities) can be demonstrated.

Biochar may also play an important role in developing countries given the greater availability of biomass and potential for greater positive impacts on soils and yields.

**Source:** Shackley, S., (2011). The feasibility and costs of biochar deployment in the UK. *Carbon Management* 2(3), 335-356; Personal communication with UK Biochar Research Centre (November 2011).

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## 3. UK bioenergy supply scenarios

We derive UK bioenergy scenarios, which we input into our modelling of appropriate bioenergy use, from global scenarios for tradable bioenergy feedstocks (e.g. energy crops, forest biomass and agricultural residues) along with estimates of UK domestic production of non-tradable feedstocks (e.g. wastes). We assume that the UK can receive a pro-rata share of globally tradable feedstocks on the basis of primary energy demand in 2050, of which a portion can be supplied by domestic resource. Further bioenergy supply is also available to the UK from non-tradable domestic waste feedstocks.

### UK share of tradable feedstocks

In order to establish the amount of bioenergy the UK might use, it is necessary to consider how much of the global resource might be accessed by the UK.

In the short to medium term, it is likely that the EU will be a key consumer of the world's bioenergy supply. This is reflected in the current trade in forestry residues for energy where of the 16 million tonnes of wood pellets traded in 2010 for bioenergy, the EU consumed 13 Mt (i.e. 80%) and the UK was around 6% of the global total (1 Mt)<sup>30</sup>.

By 2050 however, the global demand for biomass is expected to increase substantially and all countries are likely to compete for resource. Of the various methodologies for allocating global supply of tradable bioenergy (e.g. equal per capita, pro-rata GDP share), a bioenergy share reflecting the UK's share of total energy consumption best proxies the likely outcome under a market-based allocation of bioenergy. This applies under assumptions that the UK energy system has a broadly similar structure to the global economy.

We consider the resulting share as a proxy of what we might be able to use rather than an entitlement. In reality, the UK share may actually be lower. This is due to its relatively low share of energy-intensive industry in GDP, and the high value of biomass in energy intensive industry, as well as its relatively low share of domestic bioenergy production in higher penetration scenarios, suggesting relatively high costs of transporting bioenergy feedstocks and products.

We estimate the share on the basis of projected UK primary energy demand – based on modelling presented in Chapter 4 of the main Bioenergy Review report and Technical Paper 3 – compared to the IEA Blue Map scenario estimate of total world primary energy demand<sup>31</sup>. This gives a UK share of 1.2% in 2050 (i.e. 2,270 TWh divided by 186,856 TWh).

Although our scenarios focus on the long term, our modelling of appropriate use covers the period to 2050 and requires assumptions on the level and composition of bioenergy on the

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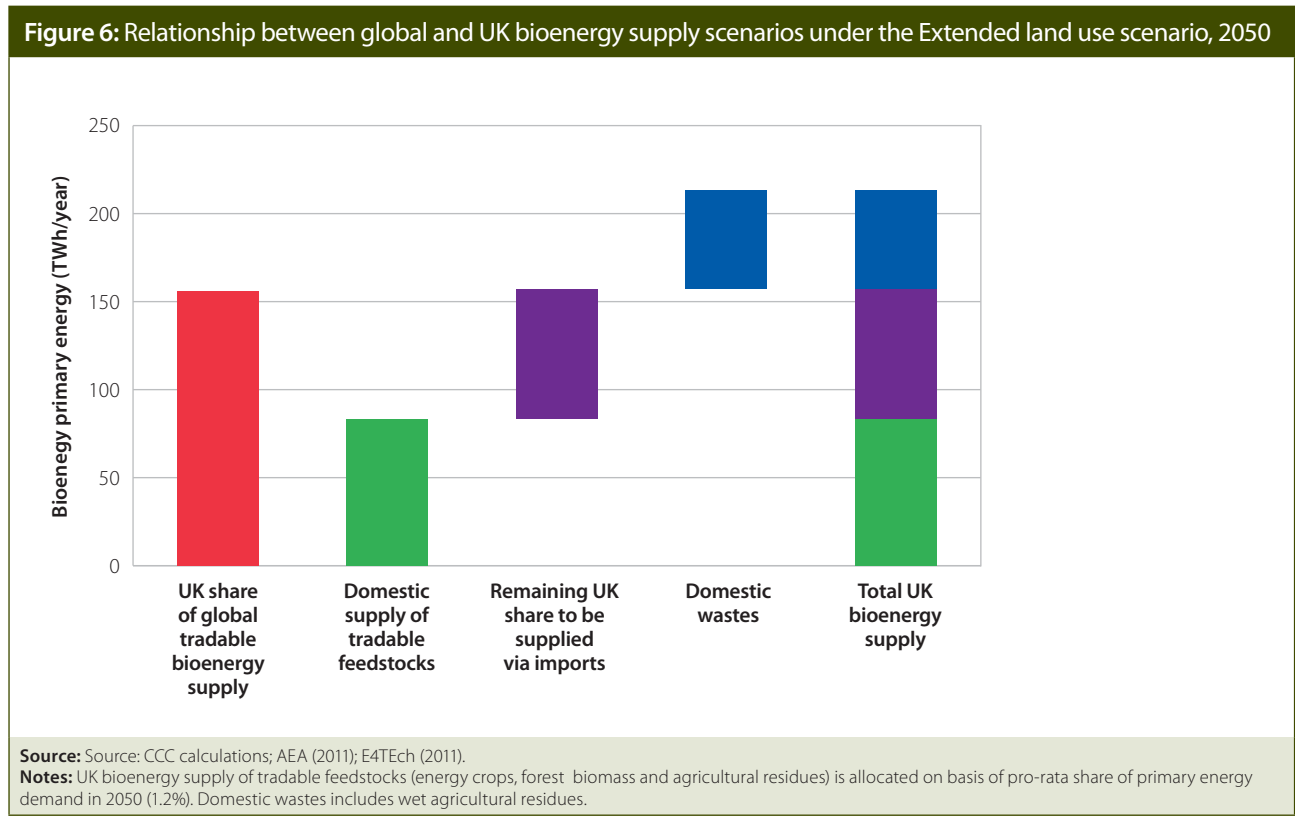
<sup>30</sup> Wood Pellet Association of Canada (2011); Poyry (2011), Pellets – Becoming a Global Commodity? Global market, players and trade to 2020.

<sup>31</sup> This method counts the heating value of combustible fuels (bioenergy, fossil fuels), the heat produced by nuclear and geothermal facilities (which is then used, at an assumed 38% efficiency, to generate electricity) and the electricity output of non-thermal renewable generation such as wind and hydro. Primary energy required to meet demand varies depending on the technologies used; this method tends to under-represent the contribution of non-thermal renewables (e.g. wind) and of heat pumps, for which the electricity input is counted and where primary energy can therefore be 3-4 times lower than heat output.

path to the levels in our 2050 scenarios. Based on the evidence that the UK may access a higher share of bioenergy in the short term (e.g. given ambition to meet 2020 EU renewable targets), we have assumed that the UK share of traded resource is around 5% in 2020, falling to 4% in 2030. We use these shares to determine upper bound of UK sustainable bioenergy resource from tradable feedstocks in our resource scenarios.

Domestic production of these tradable feedstocks may contribute to the overall total bioenergy supply (see our analysis of bottom up estimates of domestic resource below) and we assume the remainder of the UK's pro-rata share will be met by imported forest biomass, dry agricultural residues and dedicated energy crops.

We then add potential resource arising from domestic non-tradable feedstocks (e.g. wastes) to give a total bioenergy supply available to the UK (Figure 6).



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## **Bottom up estimates for tradable feedstocks: dedicated energy crops, forestry and forest residues, agricultural residues, and macro-algae production**

Although we base our overall supply assessment on the UK's share of global tradable bioenergy resource, we also consider what might be available as domestic resource in the UK. We do not envisage significant amounts of trading in forestry residues or agricultural residues in the long term as we assume that countries increasingly rely upon domestic residues for their own purposes. The development of UK supplies is therefore crucial to the UK government's bioenergy strategy, particularly given we can be more confident that domestic biomass meets environmental objectives. We also include resource estimates for macro-algae produced offshore in our FLC ("Further Land Conversion") scenario.

### **'Dedicated' energy crops**

Miscanthus, a giant grass species, and Short Rotation Coppice (SRC) willow, a woody perennial crop, have been more extensively researched and better established in the UK relative to other woody and grassy energy crops<sup>32</sup>. Both crops can grow on poorer quality land, require fewer inputs, and have been found to host higher levels of biodiversity relative to conventional crops (Box 7).

The key factors determining UK domestic supply are the land available for growing energy crops – which in turn depends on land required for the growth of food, biodiversity and water stress, together with stored soil carbon – and the productivity of this land.

### **UK land availability for bioenergy production**

There is good land use data for the UK. Of a total land area of 24.3 million hectares:

- 18.7 million hectares or 77 per cent is devoted to agricultural activities (Defra, 2010).
  - 11.5 million hectares is classified as permanent grassland and common rough grazing
  - 6 million hectares is croppable land of which 4.7 million hectares is used for arable crop production and 1.3 million hectares is temporary pasture land (often improved through application of fertilisers),
  - The remainder is left uncultivated as uncropped arable land.
- Non-agricultural land accounts for 5.6 million hectares of which 3 million is woodland, 2.4 million hectares is urban, and 0.3 million hectares is mountainous and water.

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<sup>32</sup> Research has extensively focussed on scope for miscanthus and SRC willow expansion in the UK but additional energy crops could be suitable such as camelina, hemp, other woody crops such as SRC poplar and other grasses such as reed canary grass and switchgrass (UK Biomass Energy Centre).

Numerous studies have assessed the area of land that is both suitable and potentially available for growing energy crops within the UK, with estimates ranging from 0.4 to 1.3 million hectares (e.g. Aylott (2008), EU Refuel (2007)). These studies make varying assumptions for the types of land that could become available for energy crops but acknowledge the potential tradeoffs between environmental objectives (including biodiversity, soil carbon, and pollutants) and food production. Moreover, any large-scale changes in land use could affect rural landscapes (Box 7). The categories (and potential drivers) of available land and associated impacts are summarised in Box 8.

#### Box 7: Environmental and other aspects of growing perennial energy crops (SRC willow and miscanthus) in the UK

- **Land quality:** Both miscanthus and SRC willow are suitable for planting on lower quality land (e.g. non-arable land) and thus are more likely to minimise impacts to food production relative to food and fodder crops. SRC willow, in particular, can grow on land contaminated with heavy metals. Higher yields, however, may not be attainable on lowest quality land.
- **Biodiversity:** Miscanthus and SRC willow plantations are likely to host higher biodiversity levels (e.g. flora, birds, invertebrates) relative to cereal crop fields. However most studies have been limited to early, non-commercial sites and there is a risk that biodiversity benefits may be reduced as crops are more intensively managed to improve yields.
- **Soil carbon:** More carbon is likely to be sequestered or retained in the soils of SRC willow and miscanthus plantations relative to annual crops (e.g. cereals, oilseed rape) and managed grasslands. Conversion of permanent grassland, forest and semi-natural land, however, is likely not to be beneficial from a soil carbon perspective.
- **Fertiliser:** There is limited knowledge about site-specific nutrient requirements for SRC willow and miscanthus within the UK although both have lower fertiliser requirements relative to arable crops and in some trial and commercial sites no fertiliser is currently applied. Both crops can also utilise manures, and/or sewage sludge and other wastes subject to regulatory approval.
- **Water:** Both miscanthus and SRC willow may have higher water demands than arable crops due to higher growth and transpiration rates, longer seasonal growth, and deeper rooting; both may be better suited for planting in areas with higher annual rainfall and could be utilised as a flood mitigation measure in high risk areas.
- **Landscape:** Both crops grow taller than arable crops, particularly SRC willow which can grow to 5-6 metres, and the concern is that plantations may obscure rural landscape features, obstruct views, and cause rapid changes in scenery once harvested. Rural landscape impacts may be reduced by blending plantations with other dominant landscape features (e.g. areas with high levels of forest cover).

**Sources:** Aylott, et al. (2010), Estimating the supply of biomass from short-rotation coppice in England, given social, economic and environmental constraints to land availability. *Biofuels*, 1(5), 719-727; Haughton, A.J. et al. (2009), A novel, integrated approach to assessing social, economic and environmental implications of changing rural land-use: a case study of perennial biomass crop. *Journal of Applied Ecology*, 46, 315-322; Rowe, R.L. et al. (2007), Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. *Renewable & Sustainable Energy Reviews*; RSPB (2010), A review of the environmental consequences of biomass production for UK energy consumption; Hillier, J., et al. (2009), Greenhouse gas emissions from four bioenergy crops in England and Wales: Integrating spatial estimates of yield and soil carbon balance in life cycle analyses. 1, 267-281.

### Box 8: Potential land available for energy crop production in the UK and associated impacts

The literature identifies the following categories (and potential drivers) of available land within the UK:

- Uncropped arable land, including set-aside, fallow land, field margins, and field corners: Compulsory set-aside policies under the EU Common Agricultural Policy (CAP) to reduce agricultural surpluses have resulted in an average of 0.6 million hectares of land being set aside over the past ten years (10% of arable land). This has tended to be of lower quality (e.g. Grade 3 and 4 under the UK Agricultural Classification System). Set-aside has also functioned to promote farmland biodiversity, including insects and birds. In 2008, set-aside was abolished in response to rising cereals prices and the area of uncropped arable land has since reduced to an average of 0.2 million hectares. It is currently unknown whether set-aside will be reintroduced.
- Arable and pasture land released from agricultural production:
  - Economically marginal land. A recent study for DECC (Fera and ADAS, 2011) found that economically marginal land could total around 2.9 million hectares, including 0.1 hectares of temporary grassland and 0.5 hectares of permanent pasture. This includes low-productive land that could move from arable to energy crops, assuming a higher energy price, or grassland where stocking rates have declined. Farmers have identified potential opportunities in using unsuitable or low-productivity arable land, including steep banks and awkward corners as well as highest risk land. For example, subsidies received from the EU CAP may promote arable crop production on marginal land that yields low quantities but requires additional resources (e.g. fertiliser, labour, equipment). Optimising resources for the most productive arable land could reduce overall impacts to food production and improve overhead savings while diversifying income.
  - Land released due to improvements in agricultural productivity and livestock intensification. A 2007 IIASA and Refuel study modelled that 1.1 million hectares of land could be released from arable production and pasture land in the UK due to improvements in agricultural productivity (e.g. yields in line with historic trends) and a small increase in livestock intensity (this study also assumes use of set-aside land). This disregards the potential for 'released' arable and pasture land to remain in production to increase food production for export, which may be required given increasing global population and diet change. Moreover, use of pasture land is not without tradeoffs. Increasing livestock densities could impact animal welfare, lead to increased imported feedstuffs (with potential land use impacts abroad) and increased nutrient runoff. Converting pastureland rich in soil carbon to energy crop production could also result in a large release of carbon into the atmosphere.
  - Land released due to a reduction in meat consumption. In our Fourth Carbon Budget report (December 2010) we presented evidence by Cranfield University which assessed the scope for releasing land and reducing emissions through consumption change. The study found that consumption change away from livestock products could release up to 0.3 million hectares of arable and 7 million hectares of pasture land within the UK. The analysis also found approximately 40% of UK grassland to have some arable potential (e.g. suitability for energy crop production).
- Changes to agricultural systems e.g. agro-forestry. Rather than food and fuel competing for the same land, integrating arable crop and livestock production with energy crops (e.g. trees and grasses) could enhance the sustainability of UK farming (e.g. benefits from soil carbon sequestration, improved productivity, weed control, and nutrient recycling). Further research is required to understand the potential benefits of agro-forestry and other integrated farming systems in the UK.

**Sources:** AEA (2011), UK and Global Bioenergy resource; FERA and ADAS (2011), Assessment of the availability of 'marginal' and 'idle' land for bioenergy crop production in England and Wales.

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## CCC UK energy crop scenarios

Large scale land use change to grow energy crops within the UK would have wide sustainability and rural landscape implications. Any policies to encourage domestic energy crop production should be designed to minimise such impacts (e.g. through focus on lower quality land and low-productivity land, compliance with CAP environmental objectives, siting production to minimise structural changes to rural landscapes e.g. low slopes, etc.). There is great uncertainty about future UK land use, which is influenced by numerous factors including global food supply and demand, market intervention, rural development, environmental policy as well as climate change<sup>33</sup>.

There are also a number of market constraints to developing energy crops within the UK:

- **Competition with conventional crops:** Energy crops will require significant support and development of end-use markets to demonstrate attractiveness relative to conventional crops. For example, while the market for SRC willow and miscanthus has developed over the past 15 years under the Energy Crop Scheme, which subsidises 50% of costs incurred over a five-year period, poor cash flows and returns have limited market development (currently 10-15,000 hectares of willow and miscanthus have been planted within the UK).
- **Farmer resistance:** Farmers are wary of developing crops for the energy market given past experience with crop establishment and yields. SRC willow production practices in particular are markedly different from conventional crops and require specific harvesting equipment. Perennial energy crops offer less flexibility to farmers – unlike with annual crops, they are not able to quickly respond to changes in market conditions (e.g. when wheat prices increase).

Consequently we are cautious in our scenario estimates. Our approach to developing domestic energy crop bioenergy resource estimates is described below.

### Land

As in our global energy crop scenarios, we model domestic energy crop production on low-productivity or 'marginal' land and on land potentially released from agricultural production with varying levels of impact to food security and other environmental objectives. We explore scope for planting energy crops on approximately 5, 10 and 13% of arable land by 2050, with the scenarios as follows:

- **Constrained Land Use:** 0.3 million hectares of land planted with Miscanthus and SRC willow by 2050, which could be low-productivity and inaccessible arable land (higher risk land, steep banks, awkward corners), and/or or a portion of land previously set-aside under the EU Common Agricultural Policy (historically 0.6 million hectares, but declining to 0.2 million hectares in recent years). This scenario would represent approximately 5% of UK arable land.

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<sup>33</sup> Murphy, R. and Whittaker, C. (2008), Assessment of UK Biomass Resource: A Mirror Report to the US's 'Billion Ton Report', Imperial College London.

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- **Extended Land Use:** As above, but using additional low-productivity land, to plant a total of 0.6 million hectares of energy crops by 2050. This scenario would require a land area nearly equivalent to the area of land previously set aside, which could impact biodiversity relative to current levels. Conversely, if energy crops were to replace low-yielding conventional crops rather than set-aside land, biodiversity levels could be higher. This scenario would represent planting energy crops on up to 10% of arable land by 2050.
  - **Further Land Conversion:** 0.8 million hectares planted by 2050, which would likely come about through release from production of some arable land and/or some pasture land with arable potential (e.g. temporary grassland), due to improvements in agricultural productivity and/or intensification of livestock farming (which could release up to 1.1 million hectares of land). In this scenario, which would account for 13% of arable land by 2050, there is greater potential for biodiversity, animal welfare and soil carbon impacts.

We reflect evidence from empirical and case studies, which estimate that SRC willow yields could improve from an average of 9 oven-dried tonnes/ha in 2010 to 14 t/ha in 2050<sup>34</sup> and miscanthus yields from an average of 10 t/ha in 2010 to 19 t/ha in 2050<sup>35</sup>. Our Constrained and Extended Land Use domestic bioenergy scenarios reflect the lower end of the yield range (9 and 10 t/ha) whilst our Further Land Conversion scenario reflects the upper end (14 and 19 t/ha). Improvements in yield could minimise the land use impacts of energy crop production, although this may require greater inputs (e.g. increased fertiliser use and associated emissions).

### Planting rate

To achieve a maximum of 0.8 Mha by 2050, an average of 20,000 ha of energy crops would need to be planted each year from now. We assume an equal annual percentage rate increase in land cultivated with energy crops although planting rates will likely be constrained by the availability of equipment and planting material in the UK.<sup>36</sup>

Our estimates of bioenergy available from domestic energy crop production range from 3 to 13 million oven-dried tonnes in 2050, or 15 to 70 TWh on an energy input basis (Figure 7).

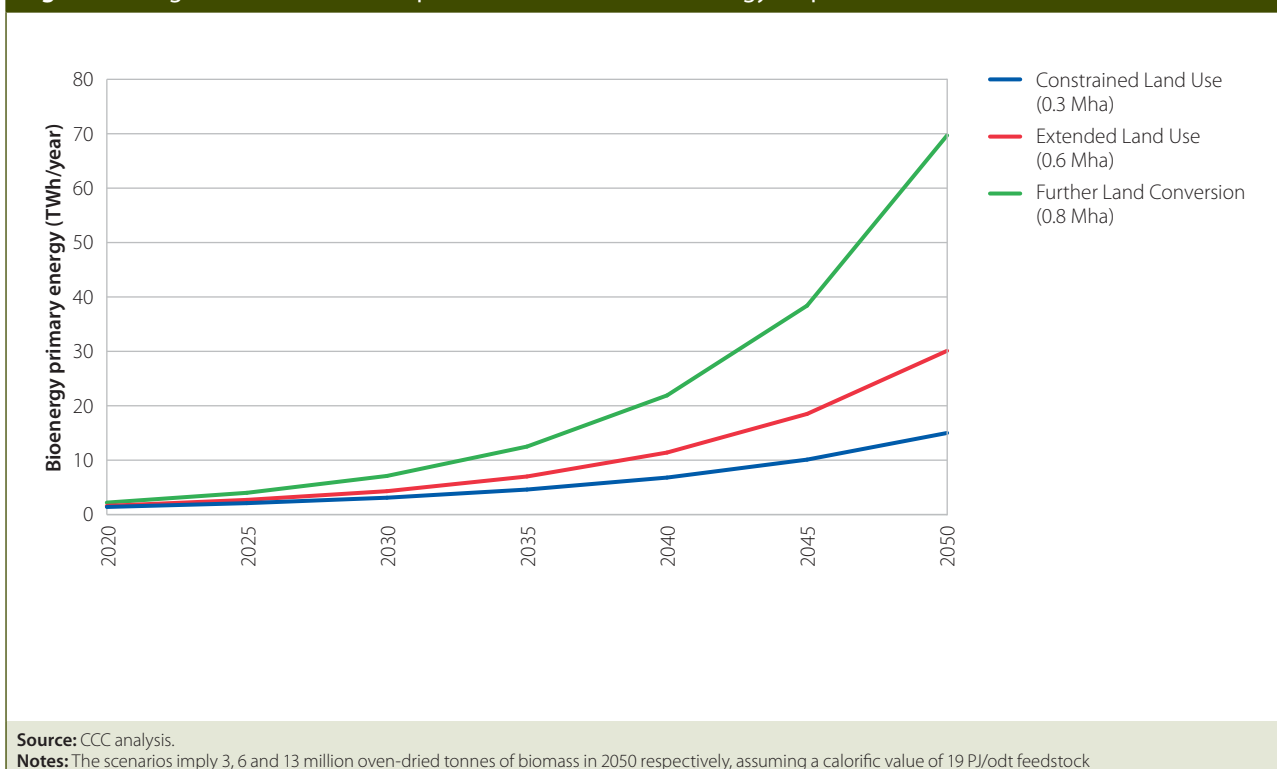
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<sup>34</sup> Aylott MJ, Casella E, Tubby I. (2008), Yield and spatial supply of bioenergy poplar and willow short-rotation coppice in the UK. *New Phytol.* 178(2), 358–370.

<sup>35</sup> Richter GM, Riche AB, Dailey AG, Gezan SA, Powelson DS (2008), Is UK biofuel supply from Miscanthus water-limited? *Soil Use Manag.* 24, 235–245.

<sup>36</sup> Unlike arable crops, which can be planted with seeds, miscanthus requires establishment of rhizomes (pieces of the root) which are collected from nurseries or multiplication fields where miscanthus has already been established.

**Figure 7: Range of estimates for UK production of dedicated energy crop feedstocks under CCC scenarios**



## Forestry and forest residues

Domestic sources of supply from forestry encompass forest residues, small round-wood (stemwood), biomass from tree surgeries in urban areas (arboricultural arisings), sawmill residues and short rotation forestry (SRF) plantations (or planting fast-growing trees in 8 to 20 year rotations).

Key market constraints to accessing forestry feedstock for bioenergy include:

- **Competing uses:** At present sawmill residues and stemwood are used by the panel board manufacture industry. Other uses include wood chips for horticulture and animal bedding. The AEA (2011) analysis allocates half of sawmill residues and a third of small round wood resource to competing industries. No competition is assumed for forest residues and arboricultural arisings.
- **Accessibility:** Harvesting and transporting forest feedstock is likely to be difficult, given its dispersed nature and low bulk density and the need for collection, drying and storage facilities. Convincing thousands of private land owners to bring their forests into management for bioenergy will also prove challenging.
- **Certification:** The costs of ensuring adoption of sustainable forest management practices are likely to be high.

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There are a number of sustainability concerns related to managing forests for bioenergy that could constrain supply. These include:

- Level of residue retention in soils for biodiversity and preservation of soil structure: The AEA (2011) analysis assumes 50% of residues are retained on site but there is a risk of over-extraction if forests are not sustainably managed.
- Land take and soil carbon emissions arising from forestry: Dedicated short-rotation forests will require additional land, most likely pasture land, which could impact livestock densities (and therefore animal welfare) and result in soil carbon displacement.
- Non-native species: While the Forestry Commission analysis in AEA (2011) assumes planting a mix of native and non-native trees in short rotations, there is a risk that faster-growing non-native species (such as eucalyptus, sycamore and southern beech) may dominate SRF given they are faster growing and more productive. Non-native species are associated with high potential water use and negative impacts on rare British bird populations<sup>37</sup>.

The Forestry Commission (AEA, 2011) has developed an approach to estimating the resource arising from forestry and forest residues, which examines potential residuals from current and planned forest management and sawmill operations, the resource from UK-wide arboricultural arisings (e.g. tree surgeries), and the potential for SRF plantations on rough grazing and permanent pasture-land. The potential resource is estimated at 5.8 million oven-dried tonnes or 37 TWh in 2050 in a medium scenario.<sup>38</sup>

The dispersed nature of UK forestry resource suggests a limited role in supplying bioenergy for large-scale power. Rather, domestic forestry and forest residues may play an important role in local heating and power solutions (e.g. districting heating networks and domestic boilers) (Box 9).

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<sup>37</sup> McKay, H. (ed.) (2011), Short Rotation Forestry: review of growth and environmental impacts. Forest Research Monograph, 2, Forest Research, Surrey, 212pp.

<sup>38</sup> AEA (2011), UK and Global Bioenergy Resource – Annex 1 report: details of analysis; our 'Extended Land Use' scenario reflects a bioenergy market price of £6/GJ and overcoming easy constraints.

### **Box 9: Regional strategies for deploying domestic bioenergy**

UK bioenergy resources can make a meaningful contribution to decarbonising large-scale power, industry, and transport (e.g. representing 60% of UK bioenergy supply in our Extended Land Use scenario). However the dispersed nature of the resource and the challenges to harvesting, storing and transporting large quantities suggest a particularly important role for domestic feedstocks in regional applications (e.g. domestic boilers, anaerobic digestion and district heating and power). An assessment of current regional strategies for deploying biomass to meet smaller scale energy needs is provided below.

#### ***Scotland***

The Scottish Government is concerned about the scale of potential demand for biomass by the power sector, competition with supply to non-energy sectors (e.g. the timber industry), and the sustainability of relying upon large amounts of imported biomass. It is thus seeking to support deployment of biomass in heat-only or combined heat and power plants and at a scale appropriate to make best use of local supply, which could be obtained from forestry operations (e.g. residues and sawmill wastes) as well as through dedicated forest plantations (the current target is for planting of 10,000-15,000 hectares/year to 2020).

#### ***Wales***

The Welsh Government is supportive of deployment of forest biomass for both larger scale converted power plants, that would require imported feedstocks, as well as for smaller scale electricity generation projects, which could utilise local biomass (e.g. sawmill co-products, which could amount to 450,000 oven-dried tonnes per year). Woodland creation programmes could supply additional bioenergy feedstocks although expansion plans are not as ambitious as those in Scotland.

There are limited plans to develop SRC willow and miscanthus markets, but Wales has indicated support for energy crops that could be attractive in marginal upland areas (e.g. sugar rich grasses currently being researched by IBERS) subject to resolutions around public resistance and impacts to sheep farming.

Wales is also evaluating biomass district heating schemes for public estates and opportunities for energy generation from waste (e.g. anaerobic digestion) for gas grid injection.

#### ***Northern Ireland***

Northern Ireland is supporting small-scale biomass development at the farm level to improve farm business efficiencies and sustainability. Support for the establishment of SRC willow, processing of forestry residues, and woodland creation has been established via grants. The Northern Ireland Department of Agriculture and Rural Development is also keen to support the processing of agricultural wastes in AD facilities.

#### ***England***

In regions of England not adjacent to large end users (e.g. large power stations) or located off the gas grid, the current interest in energy crops and forestry residues is for use in heat markets and self-supply. A resource potential of 2 million tonnes from unmanaged forests has been identified as a potential resource but the challenge is to convince landowners to bring forests into management. There also has been limited uptake of miscanthus and SRC willow in England, despite subsidies provided under the Energy Crop Scheme. The key challenge for energy crop farmers located away from large-scale end users is a lack of infrastructure. SRC willow in particular requires specific planting machinery, and smaller scale developers do not have access to harvesters. Whilst miscanthus uses similar equipment as conventional crops, it may require specialist boilers, and thus may not be readily applicable to schools and urban offices, etc.

**Sources:** Personal communication with Forestry Commission Scotland, Welsh Government, Northern Ireland Executive, Crops for Energy; The Renewables Obligation (Scotland) Order 2011 Consultation on Review of ROC Bands October 2011, accessed at <http://www.scotland.gov.uk/Publications/2011/10/27123530/4>.

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## Agricultural dry residues

The main dry agricultural residue available in the UK is straw, which has an average harvestable yield up to ~14 million tonnes per year. The main issue with straw is that the yield varies from year to year (up to 30%) according to harvest conditions, so the quantity available for bioenergy is uncertain. Wheat milling residues, seed husks and chicken litter are also potential bioenergy feedstocks.

A number of constraints (AEA, 2011) are likely to restrict the availability of dry agricultural residues for energy purposes. These include the dispersed nature of the resource, competition for feedstock (e.g. from animal bedding and feed markets) and obtaining planning permission for new plants which are often subject to local public opposition:

- Around half of available straw is used for livestock feed and bedding. In particular, some types of straw (e.g. barley straw) are used as a source of roughage in livestock feed rations<sup>39</sup> and as a result are considered high-value products. They are therefore unlikely to be diverted to energy use in the future.
- Oil seed rape (OSR) straw is difficult to harvest and is generally incorporated back into the soil. As a result, OSR straw has not been included in the estimates of straw that would be available for energy use (although it could ultimately become a useful feedstock for second generation biofuels).
- Dry agricultural residues tend to be highly dispersed and are often not located close to demand.
- The public perception of combustion plants means that it may be difficult to secure planning permission.

The total annual volume of seed husks and milling co-products is around 1.4 million tonnes, plus a small amount of bean hulls. The majority of this resource already has a market as animal feed. Competition from the fuel market could therefore result in higher feed prices, rather than a diversion of the resource for energy use. AEA (2011) therefore assumed that, while there is some future potential, there is no practical resource available in the current market.

It is estimated that around 1.1 million (dry) tonnes of chicken litter could be considered for energy use in the UK each year. A significant proportion of this resource is already used in power stations<sup>40</sup>. Transport costs limit the distance it is economic to transport poultry litter and material is typically gathered from within 40 kilometres.

In total, AEA (2011) estimate that around 6 million oven-dried tonnes of dry agricultural residues (31 TWh) could be available for bioenergy use in 2050. Taking into account the extent to which the constraints identified above may be overcome, our Extended Land Use scenario assumes 23 TWh could be used for bioenergy purposes in 2050.

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39 Copeland, J., & Turley, D. (2008) National and regional supply/demand balance for agricultural straw in Great Britain; accessed at <http://www.northwoods.org.uk/files/northwoods/StrawAvailabilityinGreatBritain.pdf>

40 Ofgem data shows that around 0.5 million tonnes of poultry litter was used in power stations in 2010/11.

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## Macroalgae

The domestic resource potential for macroalgae, or seaweed grown in coastal waters or off-shore infrastructure, is highly uncertain. Key uncertainties and constraints to developing macroalgae resource include the success of the technology, high production costs, potential interference with shipping routes (or offshore wind turbines), and the existence of rough conditions at sea.

The resource potential of macroalgae in the UK is based on an evaluation of natural standing stocks off the northwest coast of Scotland, which identified 100,000 hectares as suitable. Additional resource was identified further offshore. This evidence, based upon a 2008 study for the Crown Estate<sup>41</sup>, was presented in the DECC 2050 Pathways analysis, with resource potential ranging from 0-13 TWh in 2050. Given uncertainties, we include estimates of 3.5TWh of UK macroalgae resource by 2050 in our Further Land Conversion scenario only.

## UK domestic supply of non-tradable feedstocks

In this section we focus on the domestic supply of non-tradable feedstocks, which we identify as a range of waste sources from various activities and wet agricultural residues such as manure.

## Wastes

UK waste policy follows the 'waste hierarchy', which is a legal requirement of the revised EU Waste Framework Directive. This gives top priority to waste prevention, followed by re-use, then recycling, other types of recovery (including energy recovery), and last of all disposal (e.g. landfill) (Figure 8). This means recycling will take precedence over incineration with energy recovery even if recycling is more costly.

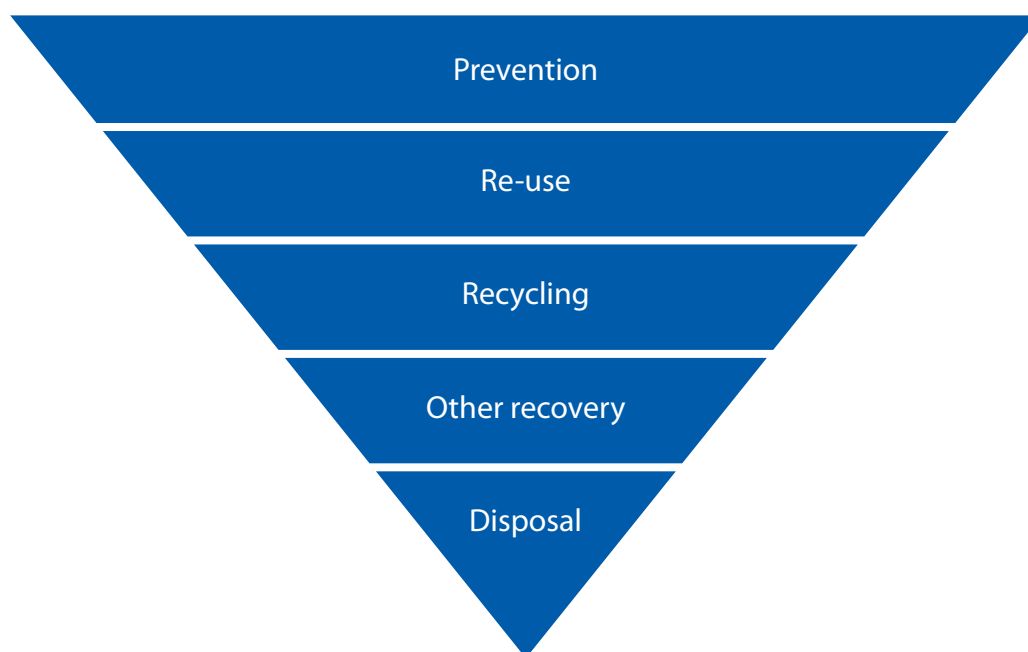
Even taking into account the relatively low position of energy from waste in the hierarchy, there is still potentially a significant UK waste resource that could be diverted for bioenergy use. We have drawn on the scenarios and assumptions set out in AEA (2011), supplemented by analysis from Defra for resource estimates to 2030. Estimates for 2050 resource potential are guided by E4Tech (2011). The following sub-sections examine the potential from:

- Waste wood
- Renewable fraction of solid waste
- Landfill gas
- Food waste
- Sewage sludge
- Used cooking oil
- Wet agricultural residues (manures)

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41 Kelly, M. And Dworjanyan, S. (2008). The potential of marine biomass for anaerobic biogas production. Report to the Crown Estate.

**Figure 8: The UK waste policy hierarchy**



Source: EU Waste Framework Directive.

## Waste Wood

The majority of waste wood arises in the industrial, construction and demolition sectors. A detailed commercial and industrial waste survey was carried out in 2009<sup>42</sup> but there is no routine survey on the composition of this waste. Estimates of the waste wood resource therefore rely on surveying a relatively small number of sites and extrapolating the results. Significant uncertainties remain.

The major constraints on using waste wood for energy are competition from other sectors and lack of re-processing capability. There is already currently a relatively high demand for waste wood, which is used in panel board manufacture, horticulture, agriculture and wood energy plants<sup>43</sup>. Other constraints include:

- Location of feedstock compared to demand
- Lack of standards for waste wood fuel
- Planning and licensing requirements
- Lack of suitable small-scale combustion plants for contaminated wood waste

<sup>42</sup> Defra Waste Statistics, available at <http://www.defra.gov.uk/statistics/environment/waste/wrfg03-indcom/>

<sup>43</sup> Horticulture and agriculture need the cleanest grades of waste wood.

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AEA (2011) assumed that around 4 million tonnes of waste wood could be available for energy use. This excludes some waste wood that is considered difficult to collect or is contaminated with other materials.

With some investment in re-processing capability, it is believed that the remaining constraints can be overcome without too much difficulty. AEA (2011) estimated 22 TWh resource potential from waste wood in 2030. We assume this remains unchanged in 2050.

### **Renewable fraction of solid waste**

In 2008, waste arisings in the UK comprised around 290 million tonnes:

- Around 32 million tonnes of household waste, around 67 million tonnes of waste from the commercial and industrial sector and almost 190 million tonnes from the mining, quarrying and construction sectors.
- Around 48% was sent to landfill and around 45% was recovered (excluding energy recovery).

The main constraint on sending solid waste for energy recovery is its relatively low position in the waste hierarchy and most is likely to be reused or recycled (in line with recycling targets). Many of the remaining constraints associated with diverting waste to energy recovery are quite hard to overcome e.g. existing long-term waste disposal contracts rendering waste inaccessible, public acceptance and planning approval issues.

Total waste arisings have been falling slowly since around 2003<sup>44</sup>, but as the number of households increases, this decline may not continue in the longer term. AEA (2011) assume that household waste arisings will grow at a rate of 0.3% per year up to 2025, with zero growth in commercial and industrial waste arisings in the future. This is largely due to an assumed continuing shift to a service-based economy (meaning industrial waste will continue to decline) and continuing waste minimisation activities.

AEA (2011) assume that the residual waste going to energy recovery rises to reach 50% in 2025, with the balance going to landfill. Defra has updated the AEA (2011) analysis with the latest data on commercial and industrial waste arisings and estimated a potential resource of around 7-9 TWh in 2020, rising to 8-10 TWh by 2030. We assume the resource potential reaches 9-11 TWh by 2050.

### **Landfill gas**

The landfill tax was introduced in 1996 and has been the main driver of reducing waste sent to landfill (which has fallen 45% since 2000/01<sup>45</sup>). The standard rate is currently set at £56 per tonne (2011/12), rising by £8 each year to reach £80 per tonne by 2014/15. In addition, there are a number of targets relating to waste management (most are statutory EU targets).

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<sup>44</sup> Defra Waste Statistics, available at <http://www.defra.gov.uk/statistics/files/20110617-waste-data-overview.pdf>

<sup>45</sup> Defra (2011), Waste Review, p69.

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The AEA (2011) analysis for landfill gas potential is aligned with the solid waste scenario described above to avoid double-counting. The 'accessible potential' landfill gas estimates are effectively estimates of technical potential and are not based on current energy generation from landfill gas. In addition, they do not take into account the difficulties in generating energy from landfill gas at low methane values. Landfill gas potential will fall in future, as waste continues to be diverted away from landfill and the gas generation potential of the waste that is sent to landfill declines due to the progressive removal of components with a high biodegradable content for AD and composting (but this is not taken into account in the AEA modelling).

Defra has updated AEA's analysis with the latest data on commercial and industrial waste arisings and estimated that the resource available for bioenergy use is 17-18 TWh in 2020, falling to 8-9 TWh by 2030. We have assumed that resource potential from landfill gas drops to 4 TWh by 2050.

### **Food waste**

Analysis by Defra based on the latest food waste data from WRAP suggests that around 10 million tonnes of food waste could be available for bioenergy use. This does not include any farm food waste (which could go to AD) due to a lack of available data.

It is assumed that around 50% of household food waste could be available through separate food waste collections and around 90% of commercial and industrial food waste. This estimate takes into account the difficulties associated with achieving separate food waste collections on a wide-scale. Defra estimate that the resource available for bioenergy use could be 4-9 TWh in 2020, rising to 6-9 TWh by 2030. We have assumed that the potential in 2050 is equal to the potential in 2030.

### **Sewage sludge**

Sewage sludge production is currently around 1.4 million tonnes dry solids, equivalent to 2.8 TWh of primary energy. Around two-thirds of sewage sludge is treated by AD at present, generating around 1 TWh of electricity. Not all sewage sludge can be accessed because it is produced in small and remote sewage treatment works.

If sewage that is currently being incinerated could be diverted to AD the accessible potential (primary energy) would rise to around 3.6 TWh. This is assumed to increase to 4.1 TWh by 2030 as the population grows. Key constraints set out in AEA (2011) include regulatory and policy constraints (for example the Water Framework Directive) and difficulties associated with the feedstock not necessarily being located close to fuel demand. AEA (2011) estimate the resource potential in 2020 could be 2.5-3.5 TWh, rising to 2.9-3.6 TWh by 2030. We have assumed the potential continues to increase modestly over time, drawing on E4Tech (2011) for a 2050 estimate of 3.5-4.0 TWh.

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## Used cooking oil

The main sources of used cooking oil (UCO) are catering, food factories and households. Households could represent the greatest resource of UCO. While there are some initiatives by local authorities to collect UCO from households, these are relatively small scale<sup>46</sup>. The resource is limited by its use in food preparation:

- Household UCO would need to be collected separately from other household waste if it is to be used for biofuel.
- The higher quality of food factory UCO means that it is suitable for some animal feed applications.

Other competing uses include export and oleo chemicals. AEA (2011) estimate the resource available for bioenergy use to be in the range 1.3-1.8 TWh in 2020, rising to 1.5-2.0 TWh by 2030. Drawing on E4Tech (2011) for a 2050 estimate, we have assumed resource potential rises to 2.5-3.0 TWh.

## Wet agricultural residues (manures)

Slurries tend to be fairly dilute and are therefore generally co-digested with other feedstocks. Only livestock slurries were considered in the AEA (2011) analysis. Farmyard manures were excluded as they were considered to be prone to problems when digesting. Livestock waste data were based on 2004 Livestock Census data and it was assumed that livestock numbers are unlikely to change significantly over time. The slurry estimates take into account current farm practices (e.g. housing of livestock).

Small farms are unlikely to be attracted to AD (unless the price of energy increases substantially), particularly those that are remote and therefore some distance from the location of energy demand. AEA (2011) assume around one-third of farms fall into this category.

AEA (2011) concluded that wet manures could provide 2-5 TWh of resource in 2020 and 2030. E4Tech (2011) estimated that this would rise to 3-6 TWh by 2050.

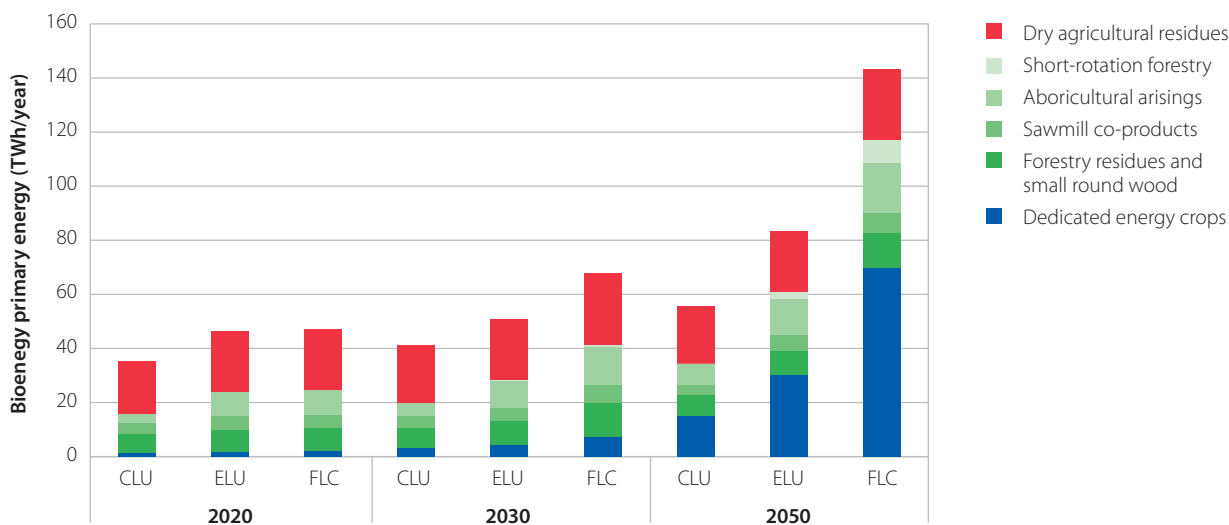
## Summary of UK domestic resource

The bottom-up estimates for tradable feedstocks suggest UK domestic resource from energy crops, forestry and agricultural residues could reach 54-143 TWh by 2050 (Figure 9). The estimates for non-tradable feedstocks (wastes) suggest resource potential could reach 50-59 TWh by 2050 (Figure 10). In total, this gives a potential of 135 TWh in the Extended Land Use scenario (within a range of 108-208 TWh) in 2050.

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<sup>46</sup> Environment Agency Waste Protocols Project, Biodiesel, available at [http://www.environment-agency.gov.uk/static/documents/Business/Financial\\_impact\\_assessment\\_for\\_biodiesel\\_.pdf](http://www.environment-agency.gov.uk/static/documents/Business/Financial_impact_assessment_for_biodiesel_.pdf)

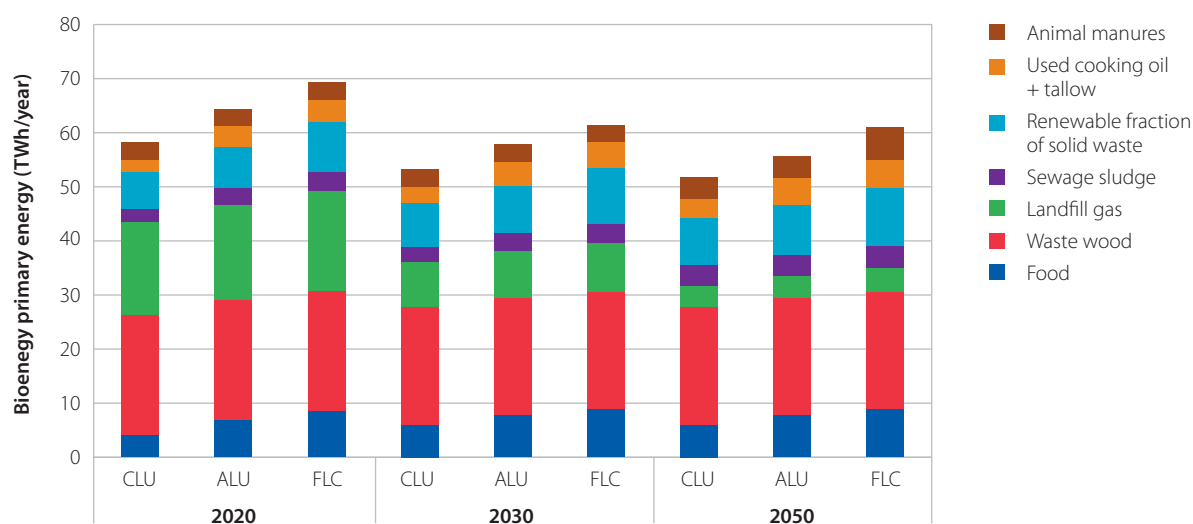
**Figure 9: Range of estimates for UK production of tradable feedstocks 2020, 2030, 2050 under CCC scenarios**



Source: CCC analysis; AEA (2011); E4tech (2011).

Notes: CLU = Constrained land use, ELU = Extended land use, FLC = Further land conversion scenario; green shading denotes different categories of forestry and forest residue feedstocks.

**Figure 10: Range of estimates for UK production of non-tradable feedstocks (waste) 2020, 2030, 2050 under CCC scenarios**



Source: AEA (2011); E4tech (2011); Defra.

Notes: CLU = Constrained land use, ELU = Extended land use, FLC = Further land conversion scenarios; Waste resource declines over time due to prevention policies.

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## 4. Summary of UK bioenergy supply scenarios and conclusions

Bringing together our estimated shares of global tradable resource with the domestic non-tradable resource gives results of 108, 213 and 504 TWh of UK bioenergy supply, or a bioenergy share representing 5, 10 and 22% of primary energy demand in 2050 (2,270 TWh<sup>47</sup>) in our Constrained Land Use, Extended Land Use and Further Land Conversion scenarios respectively.

Of total bioenergy supply, domestic production of energy crops, forestry, forest residues and agricultural residues, together with waste could play an important role in securing bioenergy supply, accounting for 100%, 65%, and 40% in our Constrained Land Use, Extended Land Use and Further Land Conversion scenarios (Figure 11).

Benchmarked against the literature, our scenarios are within the low to lower-mid range (as categorised by Slade, et al. (2011)), reflecting our cautious approach which we believe is appropriate given sustainability concerns. However, as we set out above, a bioenergy share of 22% (under our Further Land Conversion scenario) would require sustainability tradeoffs (e.g. encroaching on land required for food production or of high biodiversity value) and is not an appropriate basis for planning.

In order to limit development to sustainable levels, new regulatory arrangements would have to be introduced (e.g. limiting the types of land on which dedicated energy crops can be grown, and the extent to which these can be used to meet carbon targets). Confidence should be provided about regulatory arrangements before any new targets for the longer-term use of bioenergy are set.

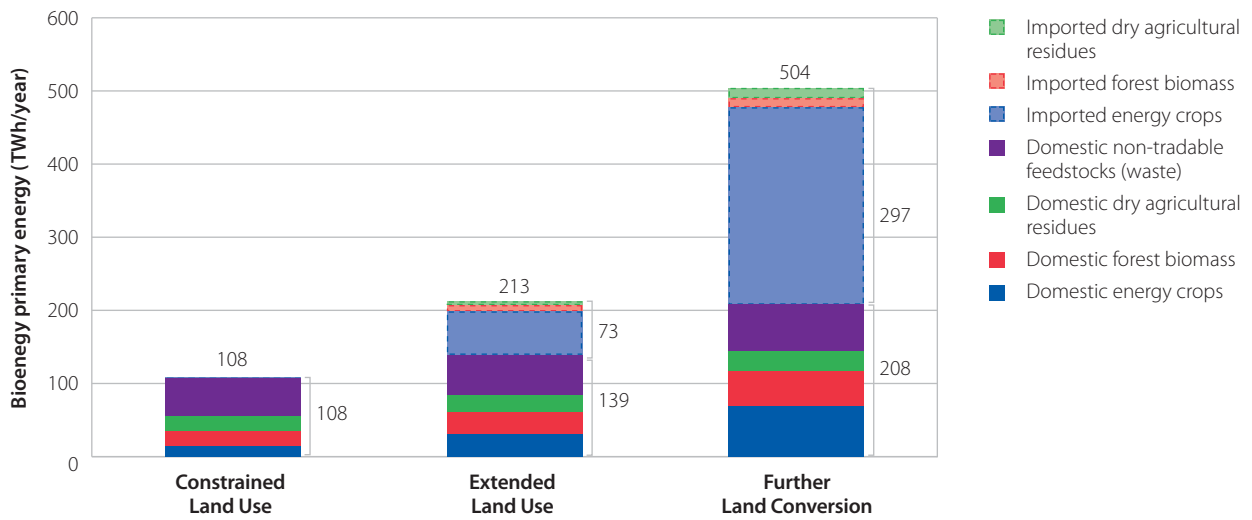
There are also considerable uncertainties surrounding the economic potential of bioenergy feedstocks, particularly given we are making significant assumptions regarding what needs to be achieved in practice in order to harness this resource, which requires further research and investment in infrastructure, storage and transport facilities.

Figure 12 presents the breakdown of our bioenergy supply scenarios between 2011 and 2050.

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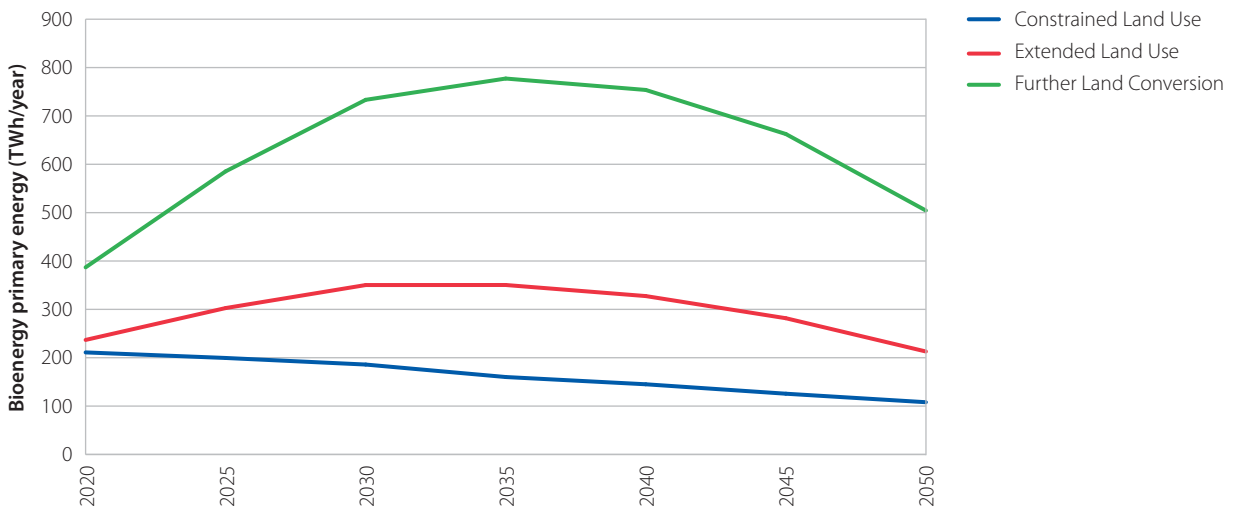
<sup>47</sup> Primary energy accounted for on the 'physical energy content' method, as used by DECC, the International Energy Agency and Eurostat. This method counts the heating value of combustible fuels (bioenergy, fossil fuels), the heat produced by nuclear and geothermal facilities (which is then used, at an assumed 38% efficiency, to generate electricity) and the electricity output of non-thermal renewable generation such as wind and hydro. Primary energy required to meet demand varies depending on the technologies used; this method tends to under-represent the contribution of non-thermal renewables (e.g. wind) and of heat pumps, for which the electricity input is counted and where primary energy can therefore be 3-4 times lower than heat output.

**Figure 11: Summary of UK bioenergy scenarios in 2050**



Source: CCC calculations; AEA (2011); E4tech (2011).

**Figure 12: UK bioenergy scenarios, 2020-2050**



Source: CCC analysis; AEA (2011); E4tech (2011).

Notes: Bioenergy resource available to the UK peaks in the 2030s and declines due to assumption that the UK share of imported feedstocks declines over time.





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