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Bioenergy Review – Mapping Work

Resource efficiency science programme
Science report: SC070001/SR2

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Steve Killeen

Head of Science

Executive summary

Introduction

This report was produced to complement the Environment Agency Bioenergy Review (Bates *et al.*, 2008) and is designed to show the land requirements and potential environmental impacts of the UK's developing bioenergy sector to 2010 through a range of GIS (geographic information system)-based maps.

The report considers feedstock supplies from forestry, biomass crops like Miscanthus and short rotation coppice (SRC), arable crops for the production of biofuels, and agricultural and suitable urban wastes for anaerobic digestion. The feedstocks are used in a wide range of plants distributed across the country. The plants produce biodiesel and bioethanol for transport fuels, use biomass to produce power, heat or both (CHP), and employ anaerobic digestion for the production of biogas.

The maps show catchments around each energy plant, the radius of which is proportional to the feedstock required to meet the energy output of the plant and the production density (tonnes per unit land area) of the feedstock. Thus plants in very intensive wheat or sugar beet growing areas have relatively small circles, signifying high feedstock output in the catchment. In contrast, relatively modestly sized plants needing, for example, oilseed rape for biodiesel production, may have very large catchments in areas where few crops are grown. Such plants may use other oil sources for feedstock.

The Maps

A suite of maps show the location of existing biofuel and biomass and waste plants with site identified by size and feedstock type. The liquid biofuel feedstocks include Recycled Vegetable Oil (RVO), imported oils, oilseed rape (OSR), sugar beet and unspecified materials. The slow progress made with wheat-based ethanol plants is indicated by the lack of any such mapped plants (using a database of February 2008 information). The biomass and waste plants include major anaerobic digestion (AD) plants but not those run by utility companies and principal-fuel biomass plants, some of which burn agricultural wastes. Co-firing major power plants are shown on a separate map on the basis of their installed generating capacity.

Maps of feedstock distribution show production of material in tonnes per 10 square kilometres for wheat, sugar beet, OSR, Miscanthus, SRC, card, paper, kitchen and garden waste, poultry litter and livestock slurries. Forestry production is presented separately for conifer and broadleaf woodland in tonnes per 20 square kilometres. Because of the very low land area currently occupied by Miscanthus and SRC, additional maps of potential future production per 10 square kilometres are presented on the basis that 10 per cent of agricultural land is used for each of the crops. This is a high land occupancy and would imply significant changes in the balance of land use should such plantings be achieved.

The set-aside area in 2004 is also mapped. Since 2004, industrial cropping for biofuel and energy crops has continued (notably OSR), but the mandatory set-aside requirement has now been reduced to zero. The introduction of the decoupled Single (farm) Payment System has allowed greater flexibility of cropping. This has seen much of the set-aside cropping simply continue without set-aside payment but on what is now ordinary farmed land. As a result the feedstock production maps show single national production area without the need to consider set-aside as a separate feature.

There are two main map sets. Eight maps show the supply zones for:

Maps 13 and 14

Biodiesel production from OSR in 2010 assuming 5, 10 and 25 per cent of the plant's feedstock is produced locally, and the plant is operating at either full capacity (Map 13) or half capacity (Map 14).

A comparison of these two maps shows how impracticably large some of the catchment areas become when plants operate at full capacity or look to source more than 25 per cent of their potential output from domestically sourced material. The lower national area of the OSR crop, and therefore its wider distribution, contribute to this problem. Greater demand and higher prices could increase the crop area and reduce catchment sizes. This analysis suggests this sector may rely quite heavily on imports.

Map 15

Bioethanol production from wheat in 2010 assuming 5, 10 and 25 per cent of the plant's feedstock is produced locally, and the plant is operating at full capacity.

Wheat is higher yielding and far more widely grown than OSR. As a result the catchment areas for wheat for ethanol are much smaller than those for OSR used for biodiesel. The differences in fuel use for national and international transport of feedstocks will need to be factored into the carbon and sustainability reporting for biofuels from domestic wheat and OSR (required for the Renewable Transport Fuels Obligation), and for imported feedstocks or processed fuels.

Map 16

Bioethanol from sugar beet at the Wissington factory showing a supply zone assuming 100 per cent of the crop grown is used for ethanol, and the actual factory supply zone.

In practice, it is very unlikely that 100 per cent of the crop is used to produce ethanol. With a relatively flexible plant British Sugar will be able to vary the throughput of material depending on the relative price of ethanol and sugar and production at its other plants. The use of carbon dioxide from the fermentation processes to enrich the atmosphere in tomato production greenhouses is a one-off environmental contribution for this particular site. The map also shows the area of beet in the West Midlands that was left after the closure of the Allscott sugar factory.

Maps 17 and 18

Biomass for co-firing and dedicated biomass plants assuming 5, 10 and 25 per cent of the co-firing feedstock and 100 per cent of the dedicated plant feedstocks are provided within local catchments producing SRC and Miscanthus at either 5 per cent (Map 17) or 20 per cent (Map 18) above present levels.

The spread of co-firing sites and dedicated biomass plants produce catchments that overlap and cover much of the land area of England and Wales. Given the extent of the overlapping catchments, increased intensity of use (that is, >25 per cent of co-firing feedstock) will imply increased production within the catchments shown. The maps show the majority of biomass is made up of existing plantations, woodland and forest, the areas of biomass crops (such as Miscanthus and SRC) still being very small. The very low areas of SRC and Miscanthus currently grown produce maps at 5 per cent and 20 per cent above present levels that are almost identical. This 15 per cent increase of a small area remains a small area when displayed on a national basis as in this report. This highlights one of the problems that occurs with nascent technologies when changes are reported as percentages - the national impact of seemingly large changes can be quite small.

Map 19

Dedicated straw combustion assuming the plant takes all the straw adjacent to the plant until 100 per cent of its requirement is met.

Like wheat grain for ethanol, the high density of growers mean straw for combustion needs a relatively small area to produce a plant's fuel requirements, assuming all the straw from wheat crops adjacent to the plant are used. In practice, reliability and continuity of supply mean straw has to be sourced from a wider area than shown, with large specialist suppliers ensuring straw is baled and stacked to minimise disruption to farmers, and stored in weather resistant stacks to avoid bales being too damp when delivered to the plant.

Map 20

Anaerobic digestion plants assuming 100 per cent of feedstock is sourced locally.
The very high moisture content of many AD feedstocks puts an economic limit to their catchment size determined by transport costs.

Although the maps show catchments as circles, in common with all the other catchments those in Map 20 are unlikely to be circular in reality. Material source distribution, road networks and plant location all affect the shape of the actual catchment. This in turn affects the way the plants will interact with the environmental parameters shown in the second series of seven pairs of maps. For each parameter two maps are used to show separately the catchments for bioenergy facilities (biomass, co-firing and AD plants) and biofuel facilities (bioethanol and diesel). When considering the impact of bioenergy it is important to remember that in this study it is the production techniques used to produce the feedstock crops that are being considered, not the impact of the plants themselves.

Maps 21 and 22

Nitrate vulnerable zones (NVZs)
Arguably biomass crops like forest, woodland, and minimal input crops like Miscanthus and SRC should contribute to reduced loadings in NVZs. Cropping with arable crops used for biofuel production could also contribute to lower loadings in NVZs provided the crops are specifically managed with lower nitrogen regimes for biofuel, rather than disposed of into the biofuel market after being grown with conventional management and fertiliser use.

Maps 23 and 24

Water stressed areas
There is some scope for exacerbation of water stress with biomass crops like short rotation willow coppice and Miscanthus if grown in existing areas of water stress; both crops can have higher water demands than conventional arable crops. In contrast, existing woodland and arable crops for biofuels or biomass straw reflect the status-quo, although the quest for higher yields in any crop automatically implies higher water use.

Maps 25 and 26

Water catchment nitrate levels
As with NVZs, the production of biomass and biofuel feedstocks present opportunities for reducing crop and environmental nitrogen loadings.

Maps 27 and 28

Water catchment ammonium levels

Most water catchment ammonium is generated by activities not directly related to crop production, often based in the urban rather than rural environment. This lack of correlation with cropping activity means biofuel and biomass production will have little impact on ammonium levels. The use of biomass crops for sewage effluent disposal may cause some local variation from this if applied with inadequate care.

Maps 29 and 30

Water catchment biological oxygen demand (BOD) levels

As with ammonium, most water BOD is now generated by non-agricultural activities, also often linked with urban activity. With data like ammonia and BOD loadings, careful adherence to codes of practice is essential when applying sludges and effluents to biomass crops.

Maps 31 and 32

Water catchment phosphate levels

The relatively low use of phosphate on biomass crops and the major contribution from the urban environment will make river catchments in the biomass and biofuel feedstock production areas relatively insensitive to changes in bioenergy cropping

Maps 33 and 34

Soil carbon content

The maps show high soil carbon in uncultivated uplands and areas of lowland organic soils like the Fens and the Somerset levels. Biofuel cropping will be confined to existing arable areas and have little net impact on soil carbon. Increases in biomass cropping can be grouped into two categories: longer term sequestering crops like woodland and forest, and shorter term carbon ‘recycling’ crops like Miscanthus or SRC releasing captured carbon dioxide one, two or three years after harvest when burned. Unlike wood these crops do not offer the longer term opportunity to sequester saw wood timber carbon into buildings, furniture and structural components. All perennial biomass crops have in-ground components that sequester more carbon than arable and temporary grasslands.

Conclusions

The significant feature shown by the bioenergy and biofuel maps is the difference in their amalgamated impact areas. Projections for 25 per cent of biomass coming from local sources will produce an aggregate supply zone that covers most of England and Wales; that is, biomass growers will be widespread across most of the country. So although the biomass will be widespread it will cover a relatively small area in comparison with grassland and the principal cereals. Most of the country will not be dedicated to biomass. In contrast, the current location of most biofuel plants means their main domestic catchment areas will be in the North of England.

The location of the principal bioenergy plants is shown in the three maps below:

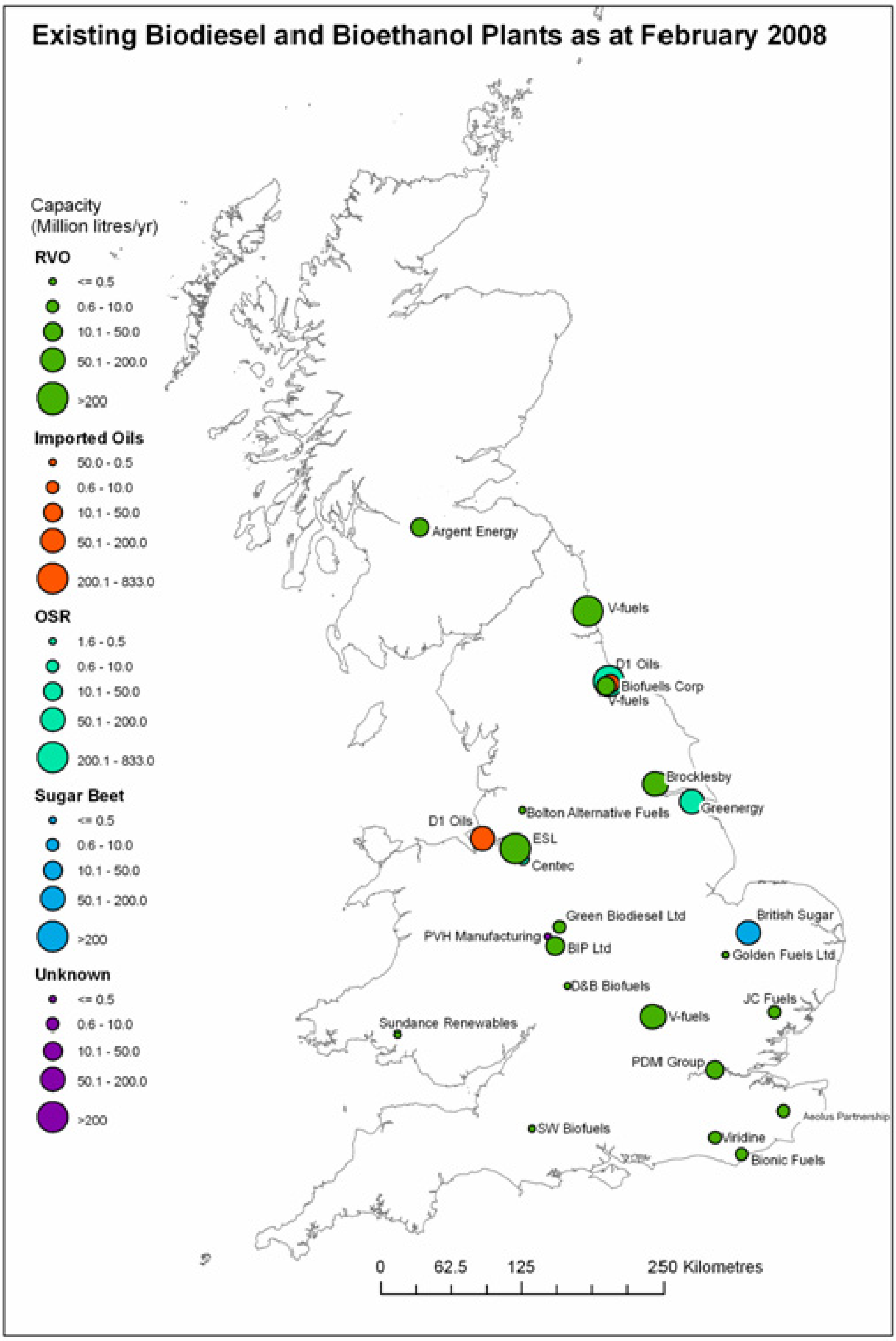


Figure a Location of existing biodiesel and bioethanol facilities in England and Wales as of February 2008. Plants are labelled as to the major feedstock used at the plant, other feedstocks may be used. Some of these plants are no longer operational.

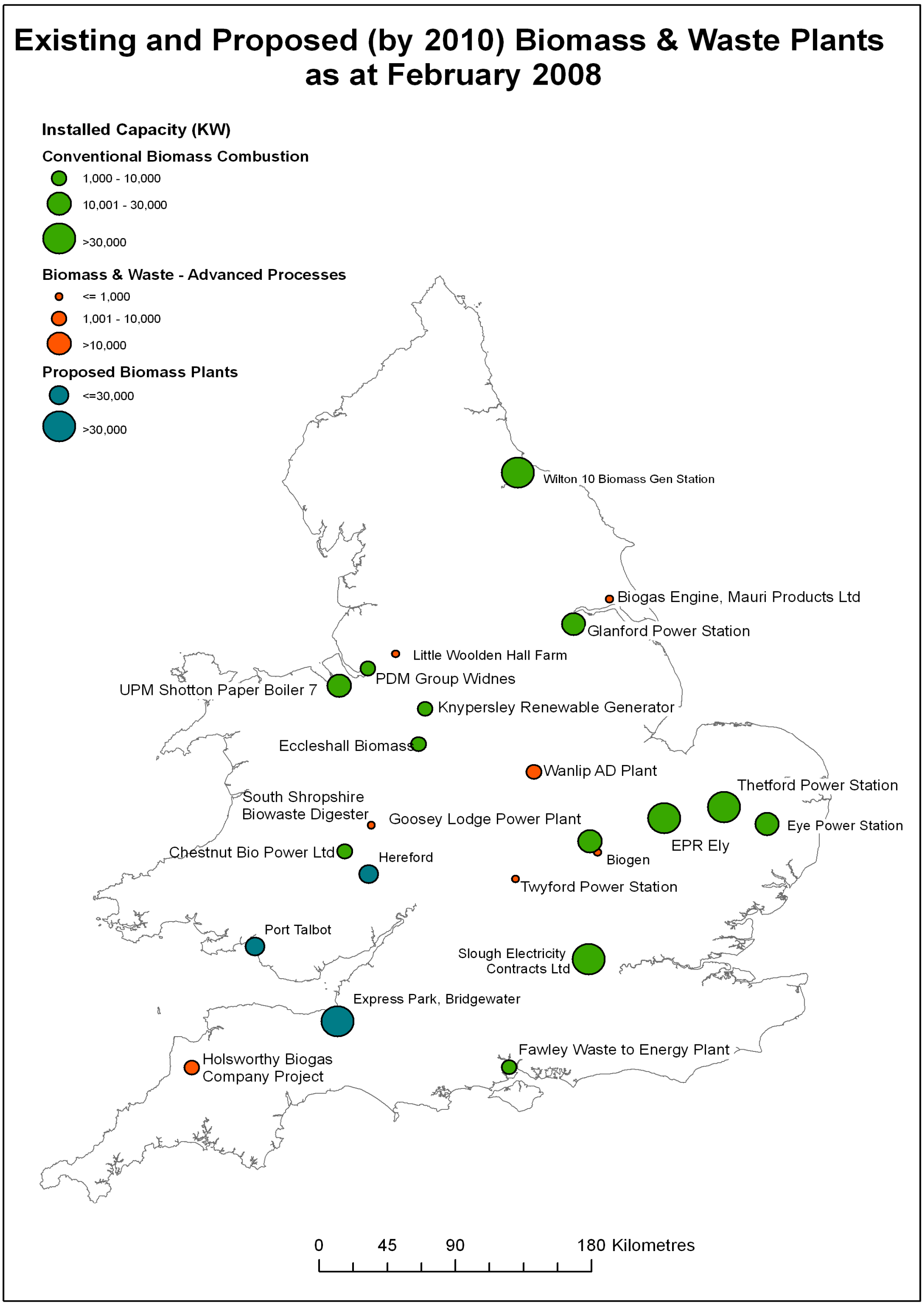


Figure b Location of existing biomass and waste plants in England and Wales as of February 2008. 'Advanced processes' refers to anaerobic digestion, gasification or pyrolysis facilities.

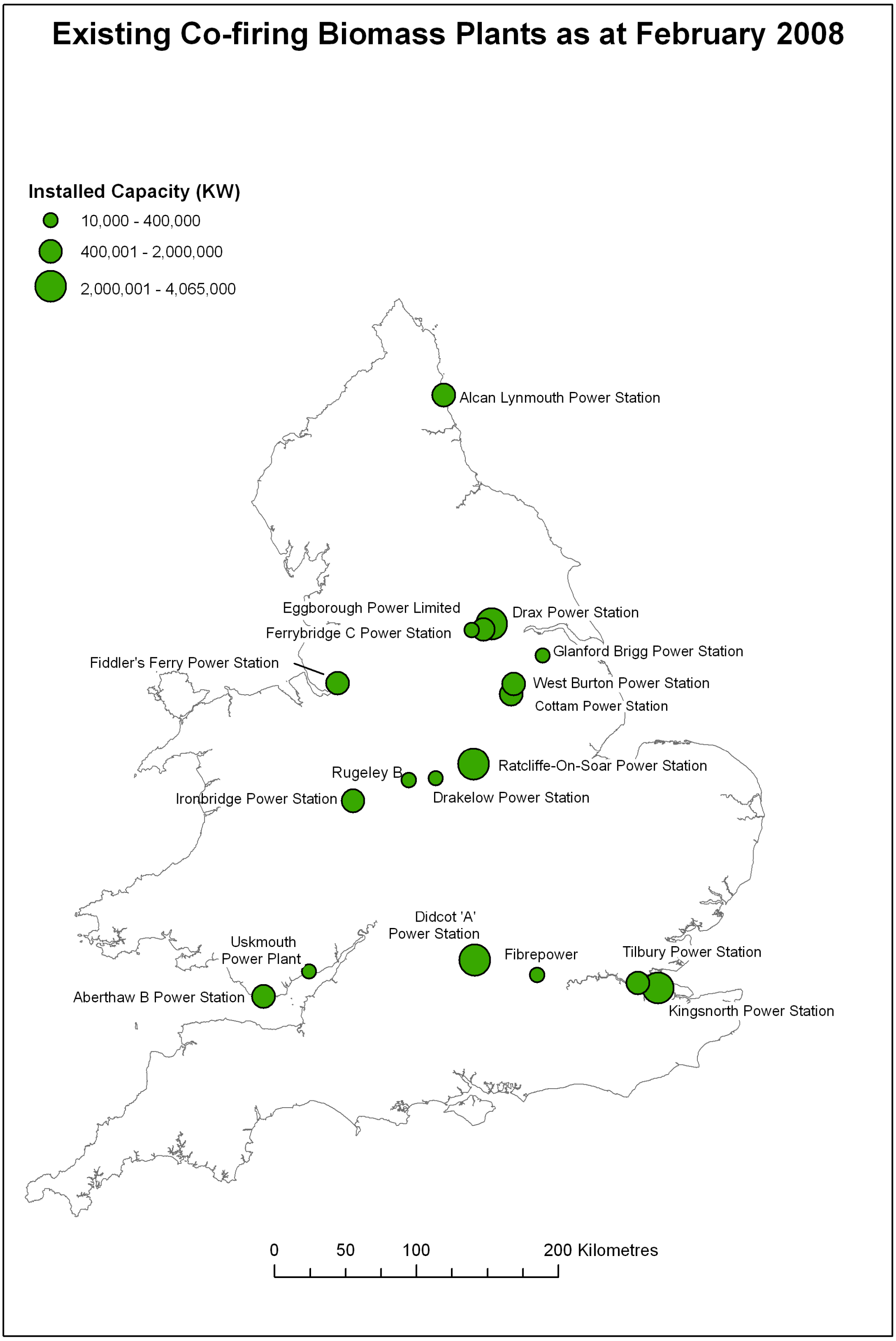


Figure c Location of co-firing power stations in the UK as of February 2008.

Although the maps in the report show bioenergy crops have some scope to contribute to greenhouse gas (GHG) savings whilst reducing the environmental loading of nitrogen, care will be needed to make sure these potential savings are achieved. One of the major strengths of domestically produced biomass and biofuel feedstocks is that they can be monitored and accredited to standards that meet the fullest rigour of acceptable carbon trading standards and obligation certification. This appears to be lacking in much of the data reported to date[1].

The maps in this report show how varied the demand for land will be for different bioenergy supply scenarios. The situation up to and around 2010 is covered by this present collection of maps, but we live in times of rapidly changing energy and food prices. The maps give *an indication* of the scale and location of near future demand for bioenergy crops and how those areas interact with factors of environmental concern.

The maps show:

- How widespread the demand for sources of bioenergy could become in a very short time period, and how the effects lie across some areas where there are already pressures on the environment, although there are some notable exceptions.
- That in the near future, although this demand will be widespread it will make up a small percentage of land use in the affected areas.

To date, progress towards Government targets for renewable energy use has fallen short of many targets, and progress with bioenergy cropping falls into this category. It remains to be seen whether levels of land use change mapped in this report will be a reality by 2010.

[1] Renewable Fuels Agency monthly reports which will require revision to cope with the omission of pre-blended biofuel imports.

Contents

1 Methods

1.1 Potential wood fuel resource mapping

In the UK, the growth rate of forest trees is expressed on the basis of stem volume production per hectare per year. This rate, expressed in cubic metres, is known as general yield class (Edwards and Christie, 1981) In order to estimate the potential amount of available wood fuel biomass for a range of common tree species by yield class, a representative range of conifer and broadleaf species were derived from the Forestry Commission yield models (Edwards and Christie, 1981) and processed through the BSORT biomass model (Matthews and Duckworth, 2005) to produce estimates of potential biomass, in oven dry tonnes (odt), over full rotations of the selected forest stands. Outputs were broken down into relevant tree components, specifically:

- Roots
- Stumps
- Sawlogs
- Roundwood
- Stem tips
- Branches
- Foliage

The estimated wood fuel production for different species, yield classes and management regimes was then plotted against yield class to investigate whether a simple relationship could be established. Three characteristic equations describing the relationship between potential biomass production and yield class were derived for the major species groups of:

- Broadleaf stands
- Larches and Douglas fir stands
- Other conifer stands

The equations are of the simple linear form:

Biomass = *a* + *b* Yield Class

The parameters for these equations are listed in Table 1.

Table 1 Parameters of equations relating biomass to yield class

	a	***b***
Broadleaf Stands	1.151	0.287
Larches and Douglas Fir	0.323	0.124
Other Conifers	0.095	0.126

In order to map the yield potential of existing forests, predictions of forest biomass potentially available for different regions of Britain were made using a combination of forest inventory data, expert system yield class estimates and associated biomass equations.

The National Inventory of Woodland Trees survey (NIWT) (Smith and Gilbert, 2003), was carried out between 1994 and 2000. The estimates of woodland cover provided by the NIWT survey were grouped into five categories with similar productive potentials:

- Pines and larches
- Spruces, Douglas Fir and other conifers
- Mixed conifer woodland
- Broadleaves
- Mixed broadleaf woodland

Expert system yield class estimates

The Ecological Site Classification (ESC) is a software-based decision support tool, developed as an expert system (Pyatt and Ray, 2001). The ESC software was used to obtain yield class potentials that were aggregated up to achieve a resolution of 20km x 20km and aligned to the Ordnance Survey grid.

ESC predictions of yield class potential were generated for species groups compatible with those used for analysis of the NIWT data. These estimates were interpreted using local knowledge and previous spatial analyses of yield class (Matthews *et al*., 1996; Matthews and Methley, 1996; Tyler *et al*., 1996; Waring, 2000) to derive robust predictions of yield class for existing forest areas.

Combining inventory, yield class and biomass estimates

The groupings of species for estimation of yield class and for estimation of biomass potential were slightly different. In order to integrate the two sets of predictions, NIWT area data was distinguished using a consistent species classification of:

- Pines
- Larches
- Douglas Fir
- Spruces and other conifers
- Mixed conifers
- Broadleaves
- Mixed broadleaves

The potential biomass production from existing forests in each 20km grid square was estimated by:

- Estimating the yield class for each species group identified above based on the adjusted ESC predictions.
- Deriving an estimate of potential biomass production for each species group in oven dry tonnes per hectare per year using the equations derived from BSORT outputs to convert yield class to biomass production.
- Multiplying the estimate of potential biomass production for each species group by the area for the species in the 20km square, obtained from NIWT.
- Summing the biomass estimates for each species group to obtain the total biomass potential for broadleaves and conifers in the 20km square.

The final estimates of potential production from existing forest areas are shown as maps in Figure 10. It should be emphasised that these results assume that all woodlands in Britain are available for bringing into full sustainable yield production. If all existing forests were actively managed for timber production and material not suited for use by existing markets (for example, construction and board manufacturers) was recovered, 1.9 million odt of wood from coniferous forest and 2.3 million odt of wood from broadleaved forest could be harvested for use as fuel each year giving a total realistic forestry biomass resource of 4.2 million odt per year. This figure ignores environmental constraints such as long-term site sustainability and physical and economic constraints such as cost of harvesting and extracting this material from the forest.

1.2 Tillage crop production mapping

Cropping data from the 2004 agricultural census (DEFRA, 2004) were used to obtain an estimate of the area of each crop of interest (wheat, oilseed rape, sugar beet) within 10km x 10km grid cells in the UK according to the proportion of arable land in the cell using ADAS Land Cover data. Cells were assigned to a government office region (GOR), and average regional yields for each crop of interest used to calculate a total yield in tonnes per 10km cell by multiplying the appropriate average yield by the hectarage of the crop. Average yields per region in the 2006 harvest for wheat and oilseed rape are shown in Table 2, and a national average yield of sugar beet was taken as 54 t/ha.

Cropping predictions for 2010 were taken from the Business as Usual III project that was carried out for Defra (Department for Environment, Food and Rural Affairs) (ADAS *et al.*, 2007).

Straw yield was determined from grain yield. Straw weight is approximately 82 per cent of that of grain weight. Given that the amount of straw left below the cutter bar at 15cm is approximately 22.5 per cent (77.5 per cent cut), and losses due to lodging, weed contamination and unharvested areas is approximately 15 per cent, an average wheat grain yield of 7.71 tonnes per hectare gives an equivalent straw yield of 4.16 tonnes per hectare.

Table 2 Average yield (t/ha) for wheat and OSR for different regions of the UK

Yield (t/ha)	North East	North West	Yorkshire & Humber	E. Midlands	W. Midlands	Eastern	South East & London	South West	Wales	Scotland
Wheat	8.5	6.2	8.2	8.3	7.3	8.3	8	7.4	6.4	8.5
OSR	3.2	3.6	3.7	3.2	3.5	3.6	3.2	3.3	3.3	3.6

1.3 Biomass crop resource mapping

1.3.1 Miscanthus

A simple predictive model of Miscanthus (*Miscanthus x giganteus*) yield was developed by ADAS, supported by yield assessment and crop physiological data from field sites (Price *et al*., 2004). The model was applied in a GIS framework using weather data on 5km x 5km grid squares, allowing potential yield to be mapped across England and Wales. The average model estimates of above ground dry matter yields at harvest for Miscanthus on arable land in England and Wales, given water limitation, are in the range 6.9-24.1 t/ha/yr. Average predicted yields per 5km cell were multiplied by the area of agricultural land within the cell, calculated from 2004 agricultural census data. This figure was then scaled according to the expected percentage of agricultural land that would be used for Miscanthus production, which for this map (Figure 11), was estimated at 10 per cent of agricultural land.

Estimates of total production (odt) at a 10km x10km grid cell resolution from existing plantings of Miscanthus were made using a combination of data on the areas of energy crops by region provided by Natural England, and existing energy crop locations planted under the 2000-2006 Energy Crops Scheme (Defra, 2007a). An estimate of one per cent of agricultural land in each cell being used for Miscanthus plantings was made (Figure 5), as this approximated the regional area estimates when summed by region. To date, national areas planted and production are relatively modest.

1.3.2 Short rotation coppice

The map of potential yield for SRC was produced by Forest Research (1999), and was based on yield estimates obtained at a network of 49 field experiments established across the UK. The yield model used to transform site specific yield estimates for five willow varieties into a national map takes into account annual rainfall, seasonal rainfall, growing degree days, frost days, soil pH and soil texture, all based on 5km x 5km grid cells. Average yield estimates for the five willow varieties grown for two three-year cutting cycles in each 5km x 5km grid square were calculated. A constraint was added to the model which classified sites at altitudes greater than 300m above sea level as 'unsuitable'.

Estimates of production (odt) at a 10km x 10km grid cell resolution from existing plantings of SRC were made using a combination of data on the areas of energy crops by region provided by Natural England, and existing energy crop locations planted under the 2000-2006 Energy Crops Scheme (Defra, 2007a). An estimate of one per cent of agricultural land in each cell being used for SRC plantings was assumed, as this approximated the regional area estimates when summed by region.

1.4 Waste production mapping

1.4.1 Domestic waste production

Published figures of average per capita domestic waste production per GOR were used to estimate the quantities of various types of domestic waste per 5km grid cell by multiplying the appropriate figure by the population within the cell obtained from the 2001 census. Annual domestic waste arisings per capita were taken to be as follows:

- Cardboard paper and packaging 32.3kg.
- Non-packaging paper 62.6kg.
- Garden waste 99.5kg.
- Putrescible kitchen waste 90.3kg.

1.4.2 Animal wastes

The poultry litter and pig/cattle slurry arisings were estimated using the ADAS Manure Management Database (MMDB). The MMDB uses a suite of algorithms integrating manure management practices, high resolution agricultural census data and land use to provide monthly arising estimates. These monthly estimates were aggregated to produce an annual volume potentially available for digestion, which consists of the manure excreted during the period in which the livestock are housed. Quantities of excreta produced by dairy cattle per annum during the housing period ranges from 1.3t for calves to 11.6t for dairy cows, based on a housing period of between 25 per cent and 66 per cent of the year depending on the type of animal. Pig excreta quantities per annum range from 0.45t for weaners to 4.0t for sows and their litters, based on a housing period of 90-100 per cent of the year. Poultry produce between 16.5t and 41.0t of excreta per 1,000 birds per annum, based on a housing period of 76-97 per cent of the year.

1.5 Scenario mapping

Using the maps of existing feedstocks and the scenarios for utilisation and supply in 2010 from AEA (Bates *et al.,* 2008), the geographical extent of the required supply zone for each plant was calculated and maps of supply zones produced for each type of plant. Supply zones were created first by converting the tonnage of feedstock required into common units of output – so GJ for biomass plants and million litres for biodiesel and bioethanol plants. Zones around plants that competed for the same feedstock were grown simultaneously by small incremental distances (100-1,000m), depending on the type of feedstock and the requirements of the plant, until enough feedstock had been sourced to satisfy the capacity of all the plants in the simulation.

When an individual plant reached its feedstock requirement from the land in its supply zone, the supply zone stopped growing. The simulations also allowed for competition between plants by merging supply zones if they overlapped and recalculating the required supply areas using the sum of the competing plants' capacities. Resulting supply zones for plants were overlaid onto maps of NVZ boundaries, water availability and areas of current water quality issues (Figures 21 -34). Specific scenario assumptions for each type of plant are detailed below.

1.5.1 Biodiesel plants

Biodiesel plants that used oilseed rape as feedstock were included in the simulation. Two scenarios were considered: existing biodiesel facilities run at half capacity and existing facilities run at full capacity (in Figures 21 -34 for the sake of simplicity only the full capacity data is presented). Within each of these two scenarios, three further scenarios were considered based on sourcing 5 per cent, 10 per cent and 25 per cent of their capacity from domestic OSR. As OSR is a valuable commodity crop with both food and other industrial uses, a distance decay factor was incorporated into the simulation whereby 100 per cent of available OSR was used if within 20km of a biodiesel plant, 80 per cent was used if between 20km and 40km from a biodiesel plant, and 60 per cent was used if greater than 40km from a biodiesel plant. Decay factors can never give a real estimate of true market offtake of crops by processing plants. Their use is to add some realism by extending the catchment beyond the extreme scenario of 100per cent usage. To convert tonnes of OSR to million litres, an estimate of 470 litres of oil from 1 tonne of OSR (at 9 per cent moisture content) was used (Mortimer and Elsayed, 2006).

The AEA scenarios suggest that under different policy options, different proportions of the plants planned will be built. In our scenario maps we have assumed all will be built, because whilst we agree with AEA's logic, it is difficult and politically sensitive to say which will go ahead, especially with the current uncertainties in the biofuels markets. In the absence of any information on the feedstock for a plant, such as the Ineos plant on Grangemouth, we assumed that a mixture of OSR and imported oils would be used.

Utilisation of oilseed rape oil for any purpose is dependent upon the ability to crush the oilseeds to liberate the oil. Spare crush capacity in the UK is limited so it is assumed that biodiesel plants would introduce their own crushers, and there are plans for crushers at both Grangemouth and Teeside.

1.5.2 Bioethanol plant

A single bioethanol plant is operational at present (Wissington), with sugar beet as its feedstock. The simulation was therefore run for this plant in isolation, assuming a theoretical 100 per cent availability of sugar beet for the facility (that is, no distance decay factor) and 100 per cent of the sourced feedstock was domestic (Figure 16). Wissington requires 700,000 tonnes of sugar beet to meet its capacity for bioethanol production, and the buffer area represents the area in which this tonnage of sugar beet is available if all beet in the area were used. However, as discussed later in Sections 3.2.1 and 4.2, any sugar beet grown in the Wissington area could potentially be used for bioethanol production and since Wissington has an approximate catchment radius of 50km, this has also been indicated on the map.

Bioethanol plants that are due to open before 2010 and that will all use wheat as their feedstock were considered together in scenarios based on sourcing 5 per cent, 10 per cent and 25 per cent of their capacity. To convert tonnes of wheat to million litres of ethanol, a figure of 370 litres from 1 tonne of wheat at 15 per cent moisture content was used (Smith *et al.*, 2006). A distance decay factor similar to the one for OSR was incorporated into the simulations.

1.5.3 Biomass and co-firing plants

A combined feedstock source was assumed for all biomass and co-firing plants that used a UK-grown feedstock, and comprised the existing area of broadleaf and coniferous forestry, wheat straw, Miscanthus and SRC. The estimated yield in tonnes of each of these feedstocks per grid cell was first converted to their energy content in GJ before being summed to obtain a combined feedstock energy content per grid cell. Conversion factors for each of the feedstock types were taken to be as follows:

- Wood pellets – 18 GJ/odt
- Miscanthus – 13 GJ/t (fw)
- SRC – 18GJ/odt
- Straw – 19GJ/odt

Tonnage of straw was calculated from the area of wheat harvested and from an estimated yield of baled straw of 4.16 odt per hectare.

Two scenarios were considered for the Miscanthus and SRC components of the available feedstock. In the first there was 5 per cent more than the existing areas, and in the second, 20 per cent more. Within each of these two scenarios, three further scenarios were considered based on facilities sourcing 5 per cent, 10 per cent and 25 per cent of their biomass capacity from domestic feedstock. The percentage of the installed capacity of the co-firing plants that was sourced from biomass was estimated at 5 per cent for all but Ferrybridge and Fiddler's Ferry power stations, which use biomass for 10 per cent of their feedstock requirement (IPA Energy Consulting and Mitsui Babcock, 2006).

The feedstock for dedicated biomass plants was assumed to be derived from 100 per cent domestic sources.

A distance decay factor was added into both co-firing and dedicated biomass simulations, so that 100 per cent of available feedstock was used if within 40km of a plant, 80 per cent if between 40 and 80km and 60 per cent if over 80km from the plant. These decay factors were based on Energy Crop Scheme limits but with a slight extension to the area to account for any supply difficulties and extra catchment spread that may arise.

Electrical conversion efficiency was taken as 36 per cent for co-firing plants (Department for Business Enterprise and Regulatory Reform (BERR), 2008), and 34 per cent for dedicated biomass plants. Biomass CHP plants were assumed to have an electrical conversion efficiency of 30 per cent. We have based the feedstock requirement on electrical conversion efficiency only as heat is essentially a by-product of the power generation. A full plant assessment also includes the utilisation of heat and an overall efficiency of CHP of around 80-90 per cent.

We note however that there is significant variation in the efficiency of combustion depending upon the technology utilised, so these figures are indicative only. Co-firing of biomass with coal, for example, may have an electrical conversion efficiency of between 35 and 45per cent and biomass CHP an electrical conversion efficiency of 30-34 per cent (IEA, 2007).

1.5.4 Anaerobic digestion

The supply zone scenarios for anaerobic digestion facilities (Figure 20) were based on the utilisation of slurry, kitchen waste or green waste feedstocks. The biogas yield from each of these feedstocks was calculated from their fresh weight – slurry has a biogas yield of approximately 19m^3 per tonne, and municipal solid waste a biogas yield of approximately 110m^3 per tonne. The amount of methane generated from the biogas was taken to be 60 per cent, which, when multiplied by the calorific value of methane (38.7MJ/ m^3), gives the energy content of the feedstock. An electrical conversion efficiency of 30 per cent was assumed, which was used to estimate the GJ of feedstock required by the plant. The three feedstock types were summed to produce the energy availability to AD by mapped cell. Only one scenario was considered for AD facilities, in which all feedstocks were 100 per cent domestic and 100 per cent of what was available was used (no distance decay).

We have based the feedstock requirement on electrical conversion efficiency only. Again, heat is considered to be a by-product of the engine. The 30 per cent electrical conversion efficiency has been used as an average figure – efficiency varies between different engines. Overall, when the utilisation of heat is taken into account, the efficiency of CHP can be around 85-90 per cent.

2 Results and observations

2.1 Existing bioenergy facilities

2.1.1 Biofuels facilities

The introduction of the Renewable Transport Fuels Obligation (RTFO) together with concerns over the security of supply and price of fossil fuels has lead to development of the biofuels industry in the UK. The RTFO stipulates that by 2010, five per cent (by volume) of all transport fuels sold in the UK should be derived from a renewable component. The recent Gallagher Review (Renewable Fuels Agency (RFA), 2008a) suggests this target should be reached by 2013/14 rather than 2010 to allow a more measured environmental impact to be achieved. Incorporation of biofuels that meet production assurance standards into fossil based petrol or diesel allows compliance with these obligations.

Biodiesel is produced by transesterification of oils, and can be produced from vegetable oils (either virgin or used oils), or from tallow (animal fats). Bioethanol is produced by fermentation of sugars to alcohol, and can be produced from cereal crops such as wheat where the starch must first be broken down to sugars, or from sugar beet.

As part of the BERR RESTATS programme, a survey of bioethanol and biodiesel producers in the UK was carried out by AEA in February 2007. These figures give the best indication of the shape and size of the industry both currently and planned, and were used in the production of the map in Figure 1. How many of these will be operating in 2010 is uncertain. The dynamic and constantly changing nature of policy, legislation and economics of both feedstock and finished product makes predictions on the future players in this industry difficult and potentially politically sensitive. Indeed, D1 Oils, which has refineries in both Bromborough and Middlesbrough, have announced since we started this report that it will cease refinery operations, blaming the 'splash and dash' policy of the US for difficult trading circumstances (Macalister, 2008).

The UK biodiesel industry is based on a number of feedstocks and over a range of scales. The distribution of the feedstock is a key determinant of location for these plants, which are often located in areas that minimise collection and haulage costs. In the case of the production of biodiesel from RVO (recycled vegetable oil), it is clear that the distribution of plants is closely linked to centres of population where sufficient feedstock can be obtained within a small area. Similarly, production of biodiesel from tallow will be located close to rendering facilities such as that seen at the PDM group biodiesel facility in Silvertown. Where biodiesel is made from imported oils, such as in the case of Greenergy in Immingham, either as part or as its sole feedstock, these plants are generally located around deep-sea ports so that sufficient feedstock can be imported and haulage is minimised. Location of larger plants at a deep sea ports allows considerable flexibility in terms of oil supply, and the supply can be switched depending upon what oil is economically competitive. AEA estimated that in 2006, the total production of biodiesel by large scale producers was 250 million litres, 36 million litres from medium scale producers, and 0.6 million litres from small scale producers[1]. In general, small and medium scale producers are located near centres of population and

[1] In the first month of reporting (April - May 2008) the Renewable Fuels Agency report a production of 74.8 million litres of biodiesel and 12.2 million litres of bioethanol including 3.3 million litres from UK beet.

often use RVO as a feedstock. There may be many more producers of biodiesel at the small scale than mentioned in this report and in Bates *et al.* (2008) since small scale producers producing less than 2,500 litres per annum do not need to be registered with HMRC. The number, scale and feedstocks used by smaller scale producers in the UK at present is therefore unclear.

To date, British Sugar at Wissington, Norfolk, is the only UK-based producer of bioethanol and utilise sugar beet. In this case, the production of bioethanol is not the main focus of the company's operation and has arisen through reforms of the European and global sugar markets whereby excess sugar above a quota could not be traded on world sugar markets. The Wissington facility is already one of British Sugar's most advanced facilities, and with sufficient sugar beet grown in the East Anglia region this facility allows the profitable production of bioethanol from excess beet.

The remaining bioethanol facilities in the UK plan to use wheat as their primary feedstock. Many plants are planned to be near deep water port locations where feedstock or ethanol can be imported if economics dictate that UK wheat is unfavourably priced. Two exceptions to this are Roquette at Corby and GreenSpirit Fuels at Henstridge in Somerset. In both cases, these planned facilities build upon an existing grain utilisation infrastructure: the Roquette facility will be close to the company's Corby starch plant, and the GreenSpirit Fuels facility is located at a grain storage facility for its parent company, Wessex Grain. In 2006, there was no production of bioethanol in the UK. The British Sugar facility at Wissington opened in late 2007, and is currently targeting a production of 55,000 tonnes of bioethanol from approximately 700,000 tonnes of sugar beet.

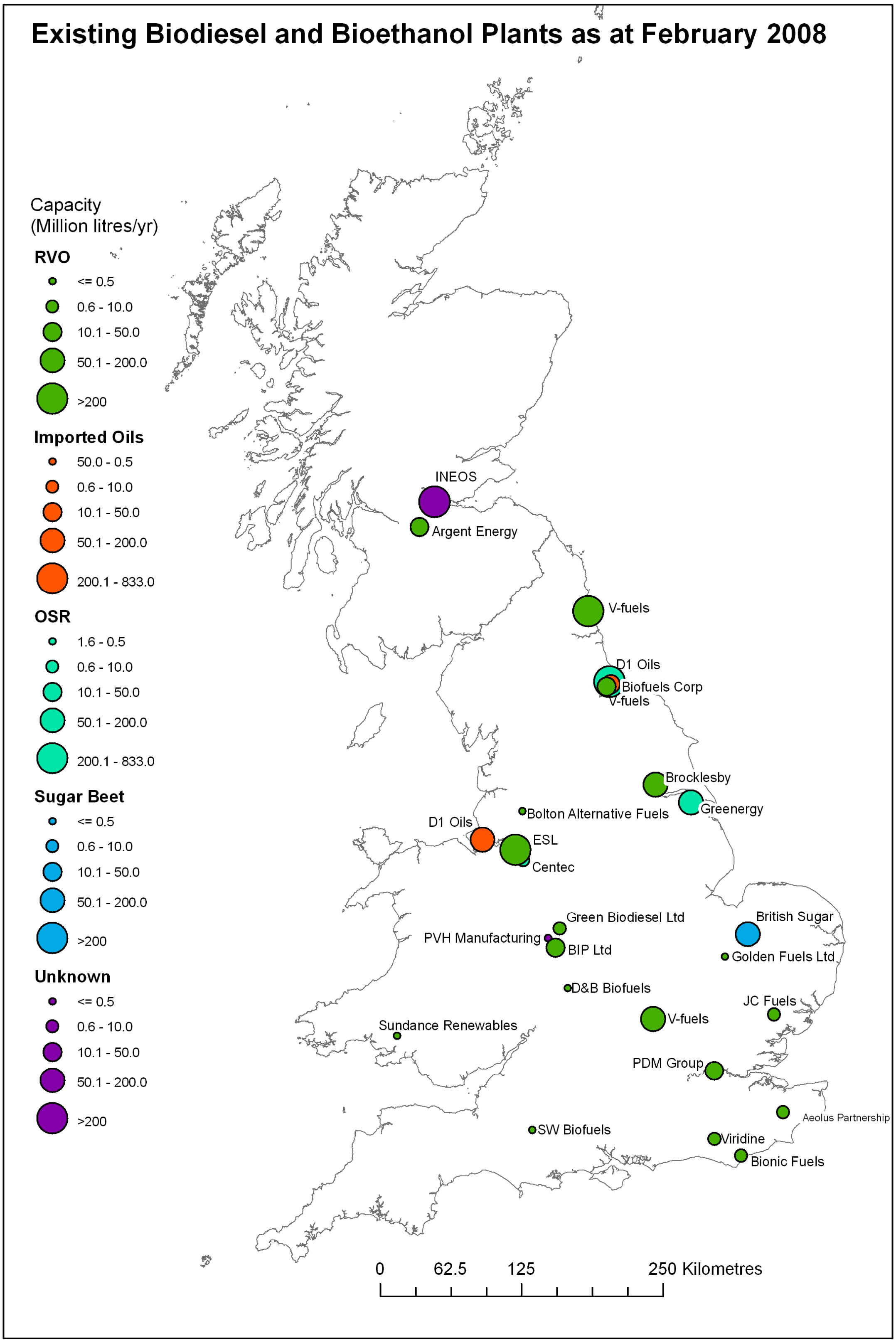


Figure 1 Location of existing biodiesel and bioethanol facilities in England and Wales as of February 2008. Plants are labelled as to the major feedstock used at the plant, though other feedstocks may be used as well.

2.1.2 Biomass plants

A wide range of biomass materials are generated both in the UK and abroad, and may be used for energy and heat generation, in either combustion, anaerobic digestion (AD), or advanced thermochemical processing. These plants may use virgin biomass materials such as forestry, SRC, Miscanthus, or use 'wastes' such as slurries, waste wood, organic municipal solid waste (MSW). Wastes are often available at low cost, free or the user can charge a gate fee (and thus provide a valuable income stream to the plant operator). Utilisation of some waste streams (such as treated waste wood) in combustion requires the facility to be Waste Incineration Directive (WID) compliant.

Biomass is bulky and of low density, so is uneconomical to transport large distances. Therefore, as shown in Figure 2, large scale plants utilising specific biomass materials will be located in areas where that feedstock is available in sufficient quantities. This is because biomass plants are often limited to one feedstock, and because combustion processes have been optimised to that feedstock, other feedstocks cannot be easily accepted. This feedstock-specific demand has lead to the utilisation of wheat straws for combustion in East Anglia (the UK's prime arable crop growing region), the utilisation of poultry litter at Eye and Thetford in areas of high poultry production, and the utilisation of waste paper sludge for combustion at Shotton where there is a paper recycling plant. Similarly, AD will be located where there is a large organic waste resource, either through MSW collection such as the Wanlip AD plant, in smaller scale operations on-farm where livestock slurries may be utilised, or use both livestock slurries and organic wastes as in the case of the Biogen plant near Bedford and the Holsworthy plant in Devon, known as centralised AD.

AEA figures report that electricity production from dedicated biomass combustion accounted for 61,707MWh in 2006 with an installed capacity of 165,719kW (Bates *et al,* 2009). The vast majority of this was through larger scale projects such as EPR Ely (straw), Wilton 10 (waste wood, wood and SRC), Slough Heat and Power (wood and non-recyclable paper) EPR Glanford and Fawley waste to energy plant (meat and bone meal). EPR Thetford and Eye (poultry litter) and Longma Thorn in Hereford using vegetable oil making up the remainder. AEA survey figures report a total installed capacity for AD of 6,301kW and total output of 12,032MWh in 2006 (Bates *et al.* 2009).

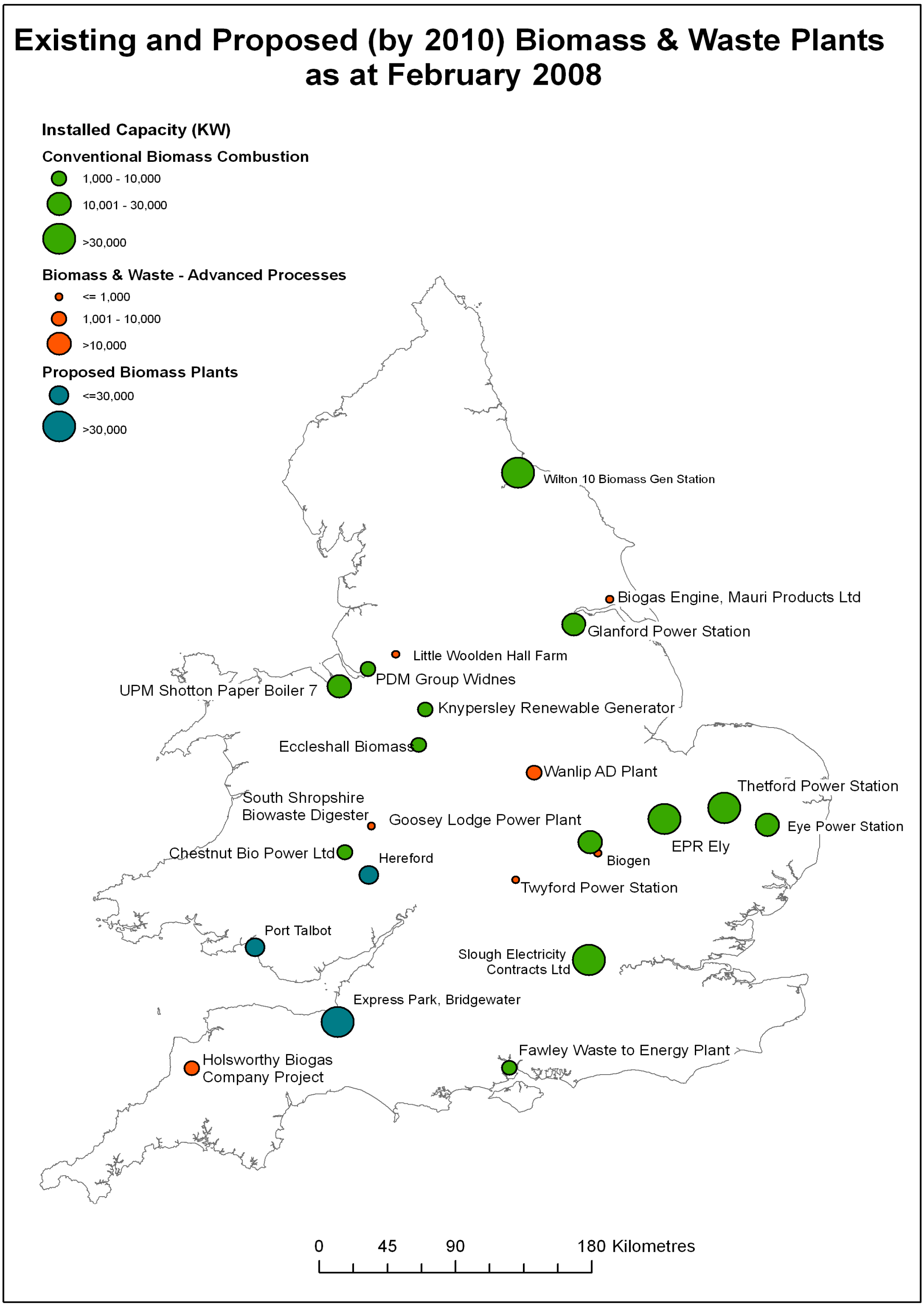


Figure 2 Location of existing and proposed (by 2010) biomass and waste plants in England and Wales as of February 2008. 'Advanced processes' refers to anaerobic digestion, gasification or pyrolysis facilities.

2.1.3 Co-firing plants

The utilisation of biomass in fossil fuel power plants can help mitigate the detrimental effects of burning fossil fuels on the environment. Under the Renewables Obligation, power generators co-firing biomass with fossil fuels are issued with tradable Renewable Obligation Certificates for each megawatt hour of electricity generated using biomass fuel. The value of these certificates in January 2008 was £49.95 (E-ROC, 2008). Although the proportion of biomass used in co-firing systems is small (around five per cent on an energy basis), the total market is large. Around 1.4 million tonnes of biomass was used by co-firing power stations in 2005 (Biomass Energy Centre, 2008c) and Drax power station has recently announced plans for three 300MW biomass-fuelled plants. Each would require 1.3 million tonnes of biomass per annum from 2014 when the first plant is planned to come on stream.

A wide range of feedstocks can be used in co-firing projects. Feedstock is often imported and includes co-products from the palm oil and olive oil industries, agricultural residues (straw, sunflower seed husks) and wood products (sawdust, pellets and chips). Co-firers are required to source a proportion of biomass from energy crops (Miscanthus and short rotation coppice). During 2009/10 this proportion has been set at 25 per cent, rising to 50 per cent in 2010/11 and 75 per cent from 2011 to 2016.

Co-firing is encouraged at existing fossil fuel power plants, so it is hardly surprising that the distribution of co-firing plants mirrors that of existing power stations as shown in Figure 3. However, in terms of the feedstock used for co-firing, it is clear that given the distribution of co-firing plants in the UK, which is mainly limited to inland areas, there must be substantial costs (both economically and environmentally) involved to achieve these targets. In order to limit the emissions from haulage of energy crops, the Energy Crops Scheme suggests 'distance to end user' limits between sites of production and combustion.

The recently announced round two of the bio-energy infrastructure scheme provides grant support to help assist groups associated with new bioenergy projects. It also supports capital plants for schemes covering a range of fuels including straws, biofuel grasses, forestry products and a wide range of coppiced timber species. This support helps broaden the potential supply base.

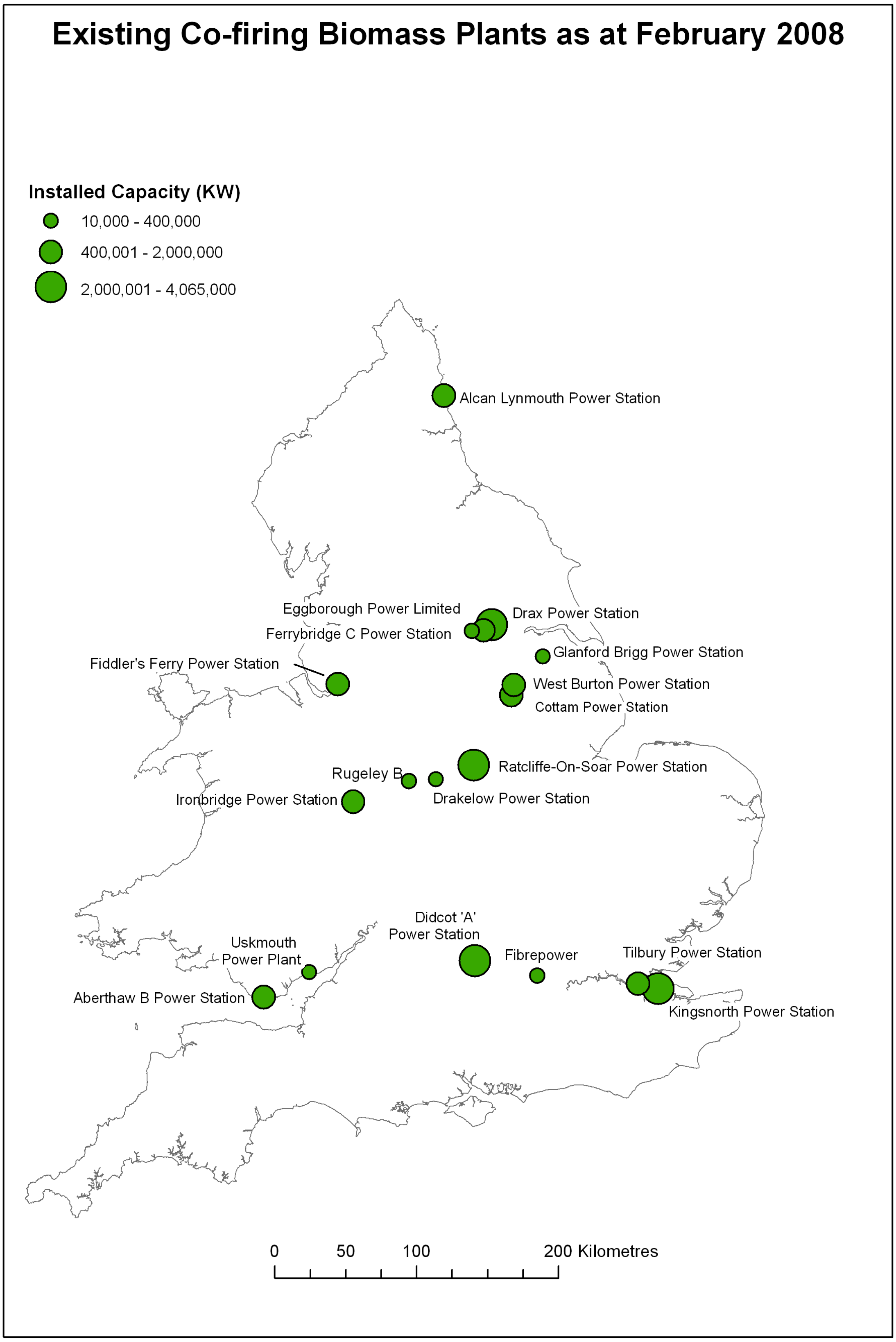


Figure 3 Location of co-firing power stations in the UK as of February 2008.

2.2 Biomass resource

2.2.1 Available crop resource

The UK has some 18.6 million hectares of agricultural land, 4.35 million hectares of which was used for cropping in 2007 (Defra, 2007b and Defra 2007d). The total area of crops in 2007 was estimated at 4.35 million hectares; cereals accounted for 2.9 million hectares (66 per cent), other arable crops such as oilseed rape and sugar beet accounted for 1.2 million hectares (27 per cent), with potatoes and horticulture accounting for some 309,000 hectares (7 per cent) between them (Defra, 2007d).

The predominant crop growing regions in the UK are located in central and eastern England, extending up the east coast up to Aberdeen, and across England to the Welsh border as shown in Figure 4. Some of the most fertile areas and areas of highest crop productivity are in the East of England around the Fens. This pattern of cropping has resulted through a combination of factors, most notably topography, length of growing season and fertility of the land combined with transport infrastructure and accessibility of the land to heavy machinery – the eastern side of the UK, particularly around East Anglia, has a long growing season, is generally dry (which aids crop harvesting) and has flattish to gently undulating land that aids machinery use and transport. Infrastructure has developed to support storage, transport, processing and export of the crops.

Crop location has determined the shape and location of much of the processing industry – for example, maltings have been established in areas of high malting barley production. Cereals are grown in rotations with non-cereal crops to prevent the build up of pests and diseases and maintain yields. In a typical rotation, wheat may be followed by another crop of wheat, and then this sequence is broken by the incorporation of a ‘break’ crop such as oilseed rape, peas or beans, potatoes or sugar beet. The break crop is then followed by another two crops of wheat, then another crop of oilseed rape and so on. Sugar beet or potatoes can substitute for oilseed rape if the ground is suitable and the margins are competitive against oilseed rape.

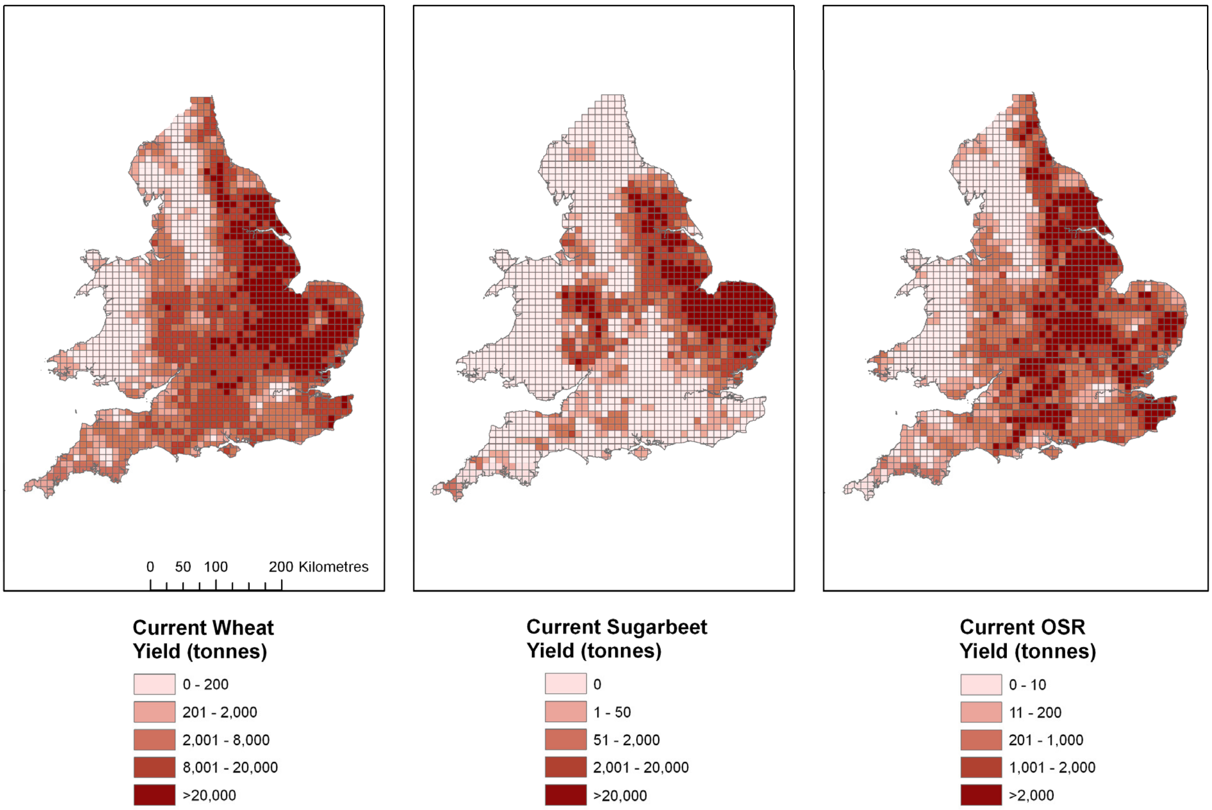


Figure 4 Distribution and yield of wheat, sugar beet and oilseed rape in England and Wales. Each square represents 10km^2; total hectares of each crop in each square has been multiplied by the average regional yield of that crop to give total productivity of the crop in each square. Data is based on the 2004 Agricultural Census.

Wheat accounts for approximately 70 per cent of the UK cereal area and is the most important crop for UK agriculture. In 2007, wheat was estimated to cover 1,816,000 hectares and at an average grain yield of 7.2 tonnes per ha^2, resulting in a total UK production of 13.14 million tonnes of grain (Defra, 2007d).

Wheat can be grown on a range of soil types with reasonable water holding capacity, but the main areas of wheat production are down the eastern side of the UK, from Humberside to East Anglia.

Wheat grain is predominantly used for four main purposes and the end use of wheat determines what type of wheat is grown. Broadly, high protein hard wheats are grown for flour milling whilst soft wheats are preferred for feed, starch and alcohol markets. In 2005, approximately one third of the wheat crop was grown for milling markets, one third for livestock feed, and the remaining third for seed, starch and distilling markets. Milling wheats generally yield less than feed varieties, and spring varieties yield less than winter sown varieties.

The yields of wheat straw are typically around 4 t/ha baled. Yield can be affected by previous cropping and if planted as a second or third crop in a rotation, diseases such as take-all can depress yield.

Sugar beet production covered some 125,000 hectares in 2007 (Defra, 2007c), and had an average yield of 60.2 tonnes per hectare (Defra, 2007b). Sugar beet production is limited to

7,000 quota holders, almost all of which are in England (Defra, 2007c). It is a bulky, heavy crop which precludes economic transport over large distances. It is not surprising therefore that the majority of sugar beet grown is around four existing processing facilities: Newark in Nottinghamshire, Wissington and Cantley in Norfolk, and Bury St. Edmunds in Suffolk. Figure 4 above also shows a concentration of sugar beet production in Shropshire surrounding the Alscott plant. However, this plant is no longer functioning and since the data used in the mapping of production were from prior to this plant's closure, it is unclear as to how much beet is still grown around this area.

As sugar beet is harvested in the autumn/winter, such crops need to be confined to light and medium soils so as to minimise damage to the soil structure and to reduce soil tares. There is a need to avoid localities with late frosts, for example northerly latitudes and high altitudes, so as to minimise bolting (when the plant produces a seed head not a root in the first year.) There is a need for adequate soil moisture either naturally or through irrigation to maintain economically viable yields. Although the crop has a deep tap-root drought susceptible soils should be avoided unless irrigation is available.

Oilseed rape (*Brassica napus*) is the most important combinable non-cereal crop in the UK and covers 681,000 hectares or 3.91 per cent of the UK agricultural area (Defra, 2007d). Oilseed rape was introduced as a crop into the UK in the 1960s and has been increasing in popularity since. It is well adapted for growth in the temperate UK climate and can grow on a variety of different soils from clays to sands as long as drainage is not impaired. It is grown throughout the UK arable area but particularly in the eastern and central regions of England. Spring varieties are less well suited to the wetter, more northerly regions than winter sown varieties and only a small area is grown. It provides an effective break crop between cereal crops, reducing disease build up and preventing the yield depression seen in continuous wheat cropping systems. Increased frequency of OSR cropping in rotations should be avoided, since yield depression results from disease build up. OSR is tolerant of saline soils and will tolerate soil pH in the range 5.5 to 8.0. Ideal conditions are a well structured, clay loam with a pH of 6.5 -7.

Oilseed rape oil can be used in foods, but also provides a valuable commodity for industrial markets such as lubricants and biodiesel production. Oilseed rape for industrial markets may be either high erucic acid oilseed rape (HEAR) or double low (00 – low in erucic acid and glucosinolates) and the type grown depends upon what market is being targeted. Either HEAR or double low can be used for biodiesel production. The yield of winter oilseed rape seed is typically around or a little over 3 t/ha (Defra, 2007c) and similarly its baled straw yield is around 3 t/ha although little is baled at present.

Straw can be either incorporated into the soil after harvest or baled and stored for alternative uses. The choice of whether the straw is baled or incorporated can depend upon the economic value of the straw and any alternative uses the farmer has such as for animal feed or combustion; often the choice of whether to bale or to incorporate may vary on a year by year basis. Nix (2003) gave figures for the amount of wheat straw used for different purposes and this is outlined in Table 3 below.

Table 3 Utilisation of straw (according to Nix, 2003).

Straw use	Percentage
Incorporated	40
Baled for own use	30
Baled for sale	7
Sold in swath	23

Recent increases in fertiliser costs have made the nutrient content of straw far more valuable. If the current price relativities are maintained this may work against significant increases in baling of crop residues for bioenergy.

Whilst the figures above relate to the amount of tillage crops grown in the UK and their yield, it is crucial to note that both OSR and wheat crops have alternative uses for food and industrial purposes so that the amount actually available for bioenergy production may be substantially less than this. The situation in the sugar market differs slightly as sugar trading reforms have restricted exports of surplus of production, which can now go towards bioethanol production. The UK usually has a wheat export surplus of around 2-3 million tonnes per year (excluding 2008), meaning that this is surplus to home requirements for food and other markets. The UK usually has an OSR surplus of between 100,000 and 200,000 tonnes of seed. Market forces will determine how much of the UK crop goes to biofuels production or for existing markets.

2.2.2 Energy crop production

There are few official statistics for the area and yield of energy crops actually currently grown in the UK. The best estimates can be derived from applications under the Energy Crop Scheme (ECS) in England although the use of these statistics must be treated with some caution. Firstly, despite the large capital investment required to establish both Miscanthus and SRC, some land owners may have chosen to plant without grant aid. Secondly, and possibly more importantly, the ECS shows only the area for which a grant has been applied for establishment of the crop and not the amount of crop which is actually grown. Both SRC and Miscanthus are particularly susceptible to unfavourable weather conditions in the first year after planting. A particularly dry spring after Miscanthus planting can lead to widespread failure to establish the crop. This was observed in several areas of Lincolnshire in 2007 (ADAS, pers. comm., 2008). In the absence of any other suitable data, the ECS can provide a starting estimate so long as its limitations are recognised.

As shown in Table 4, there is a relatively small area of Miscanthus or short rotation coppice currently grown in the UK, and the total areas are very small compared with cereal production.

As shown in Figure 5, the distribution of energy crops is tightly linked to the market pull from large power stations such as Drax, Cottam and smaller scale schemes such as the Eccleshall biomass plant in Staffordshire. Given that the energy crop scheme encourages applicants within a specified radius of a biomass user (currently the ECS stipulates establishment grants can be awarded to landowners within 15km of a small plant, and 20km of a larger plant), this pattern of clustering around markets is hardly surprising. Also given the requirement under the energy crop scheme for an end use contract to be in place (or proof of self utilisation) for the grant to be awarded, these figures reflect the best estimate for actual resource planned to be available for bioenergy use. However, given the problems associated with establishing these crops (particularly Miscanthus) these figures may overestimate the actual amounts available.

A further 1,000 hectares of SRC was established under the Forestry Commission's woodland grant scheme prior to the introduction of the ECS. Most of these plantings were for the ill-fated initial ARBRE project and may now be destined for co-firing in the large coal burners of Yorkshire and Nottinghamshire.

Table 4 Hectares currently under energy crop agreements in each region[3]

Region	Miscanthus area (total ha)	SRC area (total ha)
North East	302	0
North West	67	153
Yorkshire and Humberside	1,317	309
East Midlands	1,172	752
West Midlands	758	18
South West	891	21
Eastern England	263	0
South East	266	223
Total	5,036	1,476

[3] Areas are under live agreement for a period of five years; crops outside this five-year agreement are not recorded on the table above.

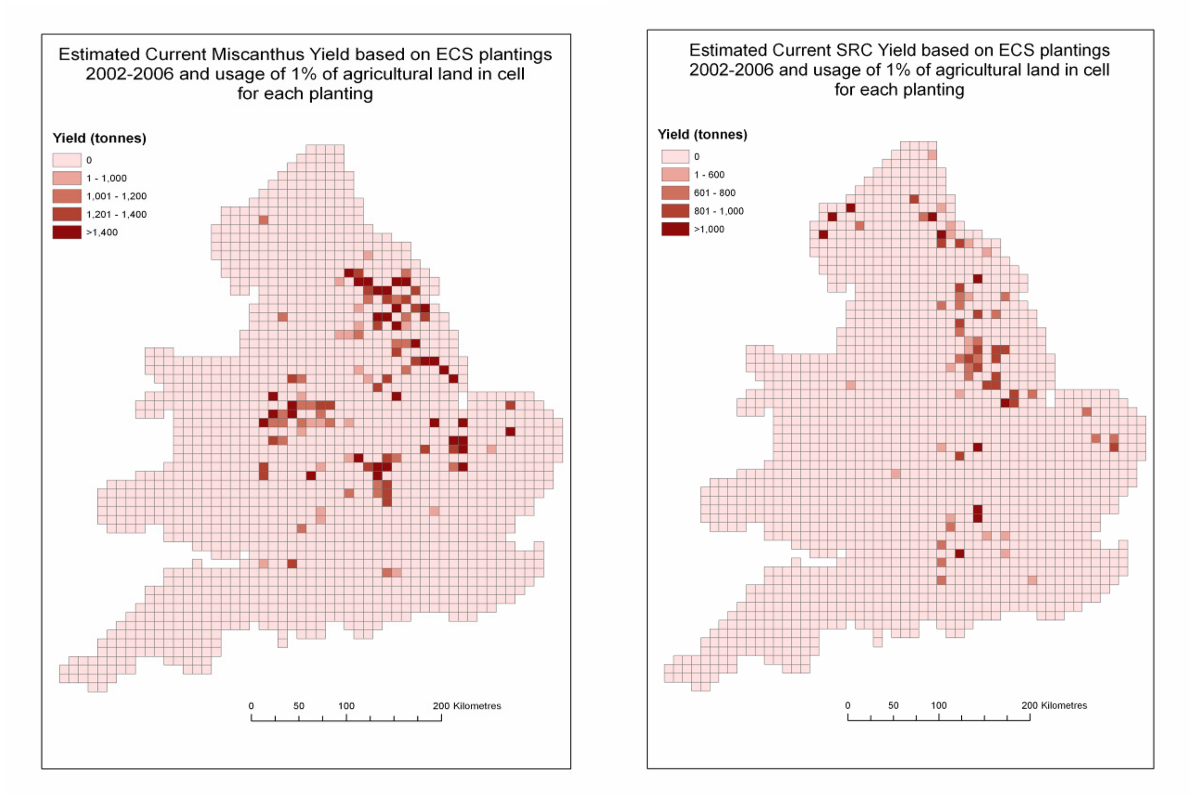


Figure 5 Existing locations of Miscanthus and short rotation coppice in England planted under the ECS. The total production of each crop has been estimated assuming that for each application 1 per cent of the agricultural land in each 10km^2 had been converted to that crop, and using the average production figures in the yield constraint maps indicated in Figure 11.

Table 5 below shows the planned plantings for Miscanthus and SRC for 2008 (Mills, 2008). To what extent these figures represent what has been planted is currently unknown, although Natural England believes that these may change significantly as not all areas may have been planted. What is clear is that there has been a significant increase in the interest in planting Miscanthus over SRC both nationally and in most regions in the past year, with particular interest in the East Midlands and South West regions. Since these figures are not confirmed, and we have no indication of the locations of the plantings within each of these regions, we have not attempted to map them as part of this study.

Table 5 Area of Miscanthus and SRC due to be planted in 2008.

Region	Miscanthus area (total ha)	SRC area (total ha)
North East	22.73	0
North West	0	86.44
Yorkshire and Humberside	417.60	95.25
East Midlands	2,824.75	168.92
West Midlands	452.22	3.12
South West	2,268.48	0
Eastern England	0	0
South East	563.63	107.13
Total	6,549.41	460.86

2.2.3 Waste production

Wastes may come from a variety of different sources and, depending on the nature of the resource, can be used in a number of different processes related to bioenergy subject to appropriate controls. Waste can be a low cost alternative to other sources of bioenergy, and is usually available at low cost, can be free, or can even bring in a gate fee for disposal. Waste production is usually expressed on a per capita basis; therefore the following maps show that production of waste materials is associated with centres of high population. Whilst these maps show the production of wastes in a particular area, it is important to note that they do not show collected and available waste resources which will depend upon the waste and the waste collection policies of local authorities and large companies, and may be significantly lower than shown here. The utilisation of wastes impacts land use, water use and may allow several policy and legislative requirements to be satisfied, for example the reduction of land filling.

Wastes can be broadly classified as:

- Recycled paper
- Municipal wastes (municipal solid waste and municipal green waste)
- Food industry wastes
- Animal by-products
- Livestock slurries

Paper and non-packaging paper may be used as a bioenergy source and the distribution of this waste is shown in Figure 6. Indeed, Shotton paper burner number seven is a prime example of one such plant in the UK which is using paper sludges for power generation, and the Fibrepower plant at Slough burns waste paper as well as forestry waste.

Municipal green waste consists of vegetable and plant material arising from parks and private and municipal parklands. Household green wastes are source-segregated and collected at kerbside or are brought for collection from household recycling centres. Grass and hedge clippings are also suitable uncontaminated materials which may be obtained by local authorities or through private collectors. This is usually cleaner, and more homogenous than kerbside collected household material. Arisings of green waste in England and Wales are shown in Figure 7.

Putrescible and kitchen waste covers a wide range of materials from a variety of sectors, including ready meal producers and their waste service providers. The waste they generate can be classified as 'meat included' (subject to animal by products regulations) or 'meat excluded' food and kitchen waste. This type of waste varies from wet sludge to dry solids, much with low meat content. At the other end of the scale there are small catering businesses, hotels and restaurants that have little infrastructure to segregate waste and are reliant on end of pipe collection from their premises. The distribution of these waste arisings throughout England and Wales is shown in Figure 7.

Animal by-products can be derived from slaughterhouses and rendering plants and the two are often co-localised. There are a number of EU and national regulations associated with materials of this type depending upon the waste category.

Slurries and manures vary according to livestock type; pig slurries have a high water to solids ratio whilst poultry wastes can be a high dry matter feedstock. Collection of wastes is dependent upon the amount of time the livestock is housed. The bulky nature of livestock wastes means that it is not economic to transport them great distances, so they are often dealt with on farm through land spreading or land filling. Legislation limiting land filling and land spreading is leading the search for alternative outlets for animal waste disposal. Livestock waste arisings throughout England and Wales are shown in Figure 8.

Waste wood is derived from building demolitions and thus availability is closely related to population density. There is an estimated 10 million tonnes of wood waste generated each year with around 6 million tonnes going to landfill. It has been estimated that recovering energy from 2 million tonnes of waste wood could generate 2,600GWh electricity and save 1.15 million tonnes of carbon dioxide equivalent emissions, with greater benefits available by recovering heat as well as power (Defra, 2008). Waste wood is often contaminated and a mixed waste stream, limiting its usefulness for other purposes but can be burned in Waste Incineration Directive compliant facilities.

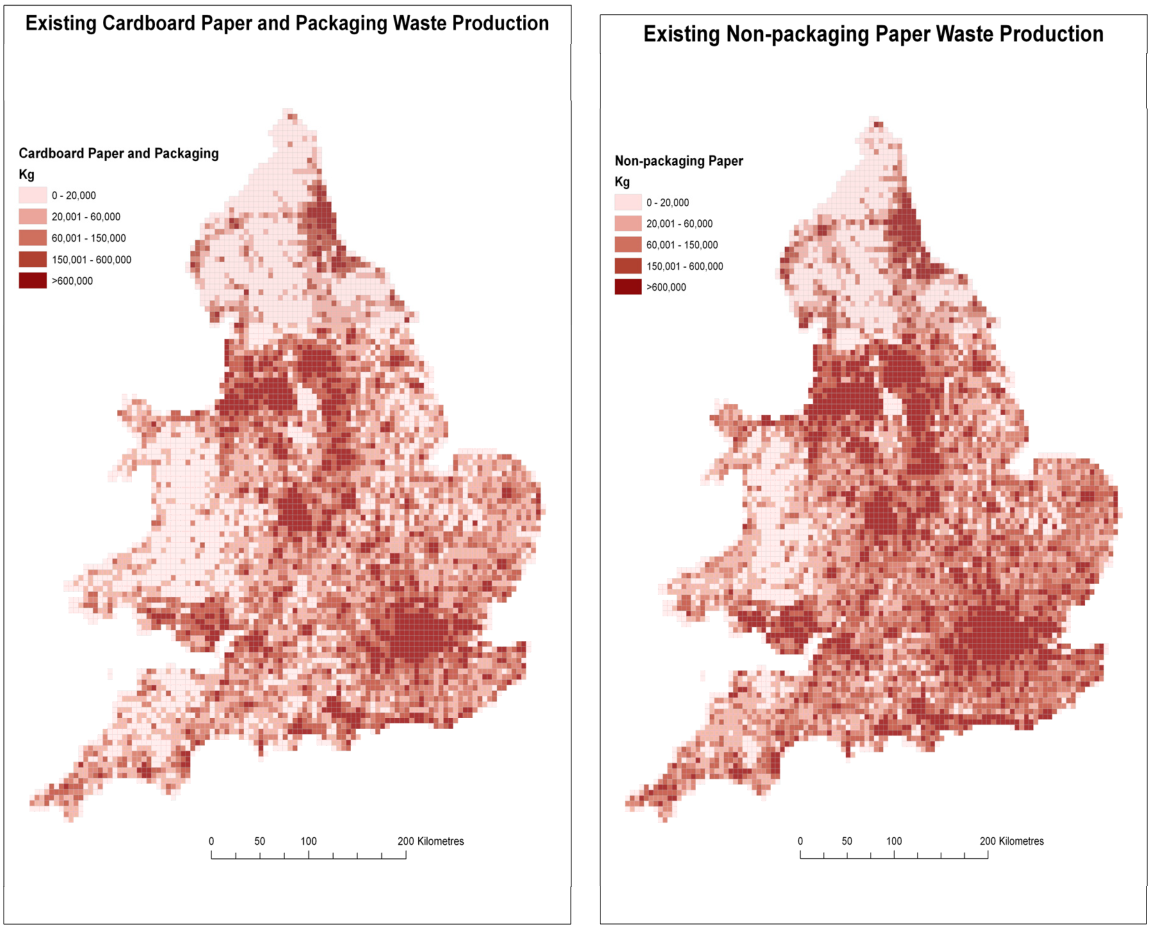


Figure 6 Existing cardboard paper and packaging waste and non-packaging paper waste in England and Wales in 2004. Data is expressed in 10km^2 grids, taking into account the population in that area together with the per capita waste production figure to give a total waste production figure for that square.

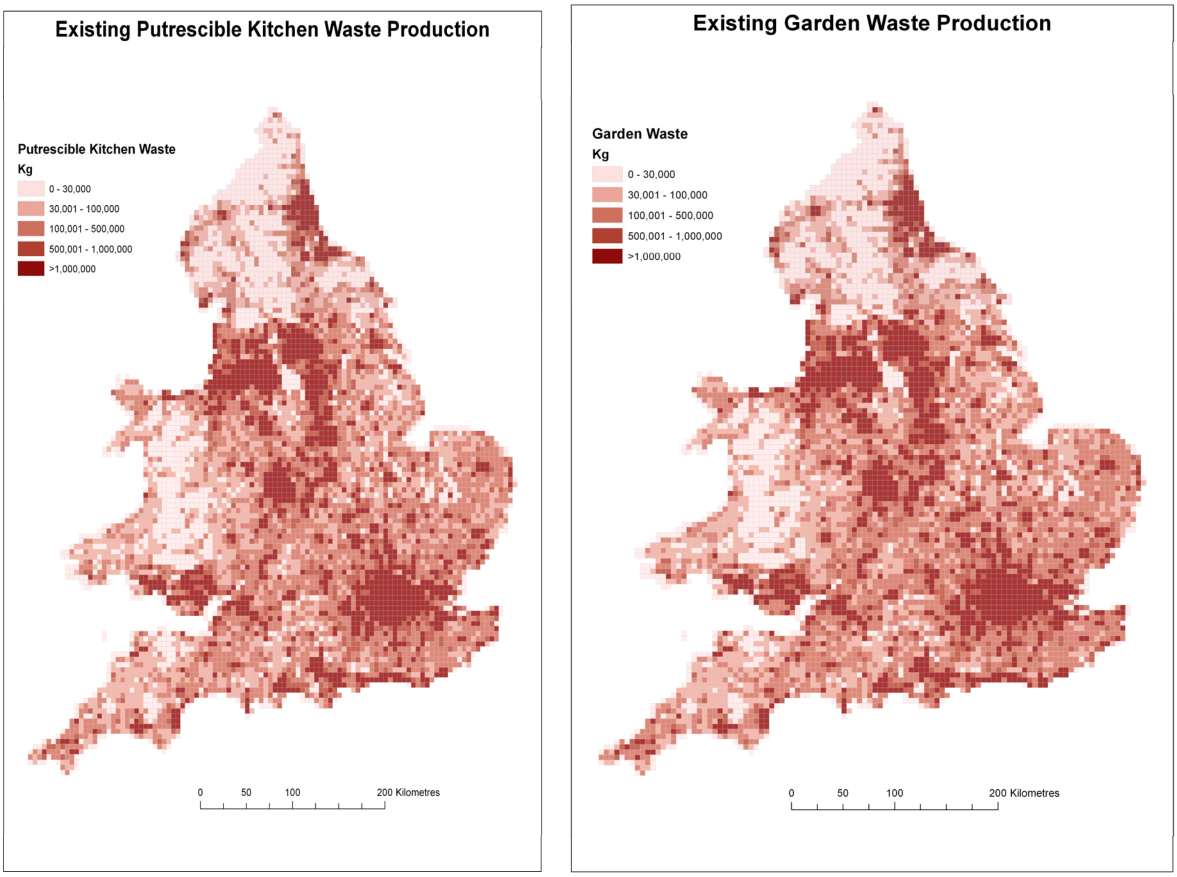
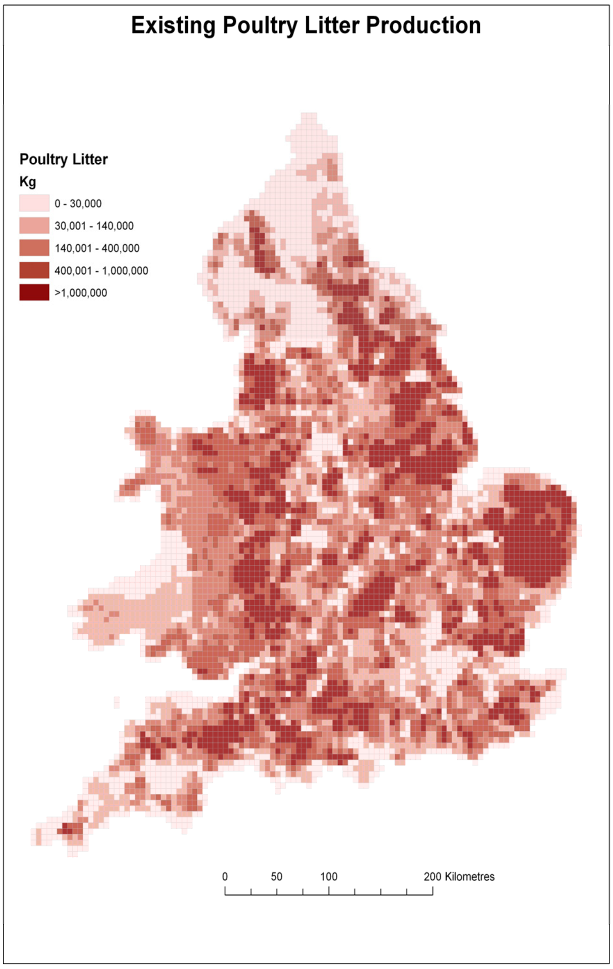


Figure 7 Existing putrescible kitchen waste production (left) and garden waste production (right) in England and Wales. Data is expressed in 10km^2 grids. The population in each square has been multiplied by the per capita waste production figure to give a total waste production figure for that square. Data is based on the 2001 Population Census.



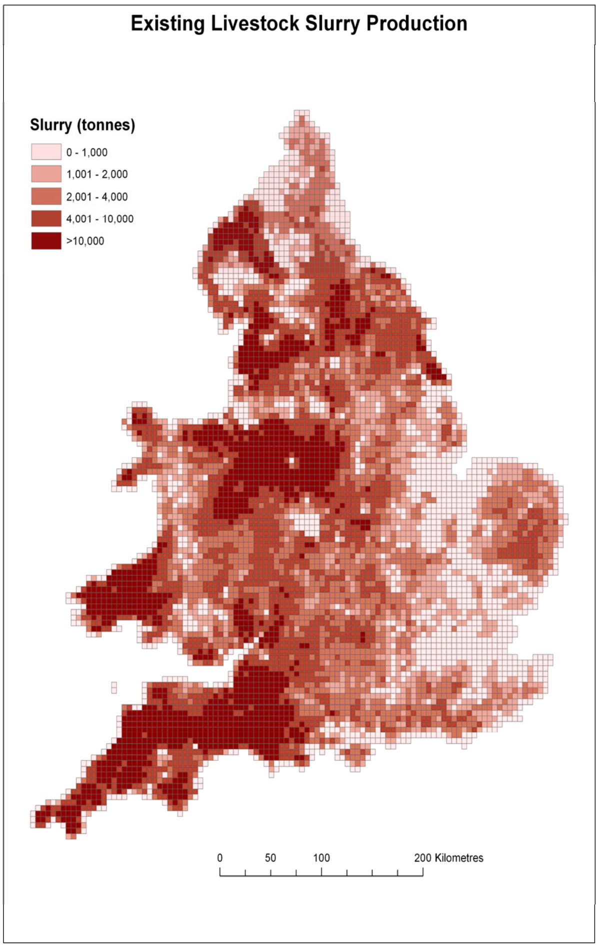


Figure 8 Existing poultry litter (left) and slurry (right) production in England and Wales. Data is expressed in 10km^2 grids. The livestock population in each area was multiplied by the per capita waste production figure to give a total waste production figure for that square.

3.2 Potential biomass resource in 2010

2.3.1 Potential arable resource

The potential arable resource in the UK in 2010 was taken from Business As Usual III estimates of the value of cropping and yields in 2010 (ADAS *et al.*, 2007).

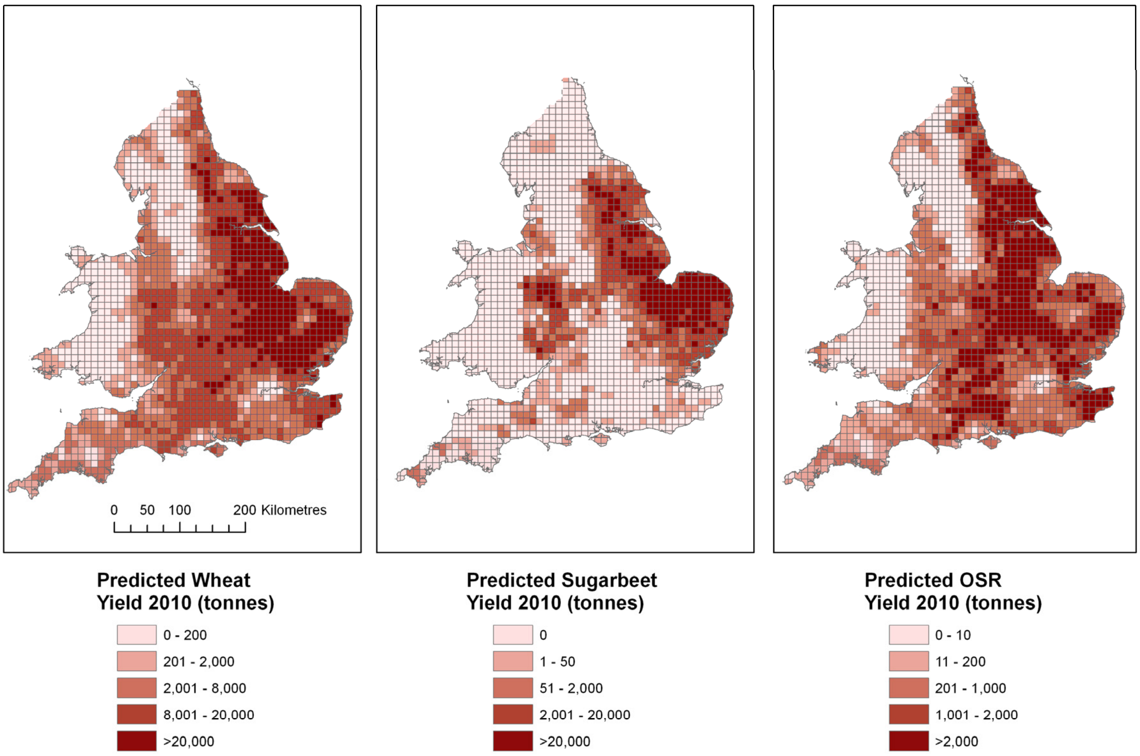


Figure 9 Estimated total yield (production) of wheat, sugar beet and OSR in England and Wales in 2010. These yields are based on areas cropped and current yields of these crops, using business as usual forecasts for cropping in the future. Data is expressed as production from 10km^2 grid squares with estimated yield for that crop multiplied by the total estimated hectarage of the crop in 2010.

The Business as Usual report suggests that in the 2010-2015 time frame there may be an increase of 12 per cent for OSR and 16 per cent for wheat grown in the UK. This was projected to arise to satisfy the requirement for biofuel production as many of the bioethanol and planned biodiesel facilities will be operational in this time frame. However, the price of wheat grain and OSR seeds have over the past year reached high levels and, given that under the SPS farmers can chose to farm whatever crop they wish, this in itself has provided incentives for increased cropping of wheat. Indeed the wheat area for the 2007/2008 season was estimated at 2.068 million hectares, an increase of 14 per cent on the previous year (HGCA, 2008).

Table 6 Changes in wheat, oilseed rape and sugar beet production in England and Wales from 2004-2020. Modelled figures from the Business as Usual project for England and Wales were combined and the percentage change in area cropped was calculated. Projected reductions compared to previous periods in area are shown by minus values.

	2004 - 2010	2010 - 2015	2015 - 2020
Wheat	-2.46	16.05	-0.21
OSR	6.20	12.26	-4.13
Sugar beet	-13.66	2.41	-2.57

There seems little capacity to increase the production of both wheat and OSR in the UK beyond the limits reached in the 2010-2015 period. The production of both crops has been highly profitable (especially with the high grain and oilseed prices in 2007/08) so in areas where these can be grown profitably they will be. The further expansion of these crops will depend upon utilisation of previously set-aside land, marginal land or tighter rotations. From an environmental point of view, the two latter situations are far from ideal since increased inputs of fertiliser, pesticides and so on would be required to maintain yields and enhance profitability as yields tend to decrease with increased cropping and disease pressure increases. It is therefore most likely that the supply of materials for bioenergy production will be diverted from existing markets and uses, and market forces will determine to what extent the feedstock in an area is utilised. For this reason, we have shown the total projected amount of wheat and oilseed rape as the potentially available resource for bioenergy production in 2010 regardless of end use.

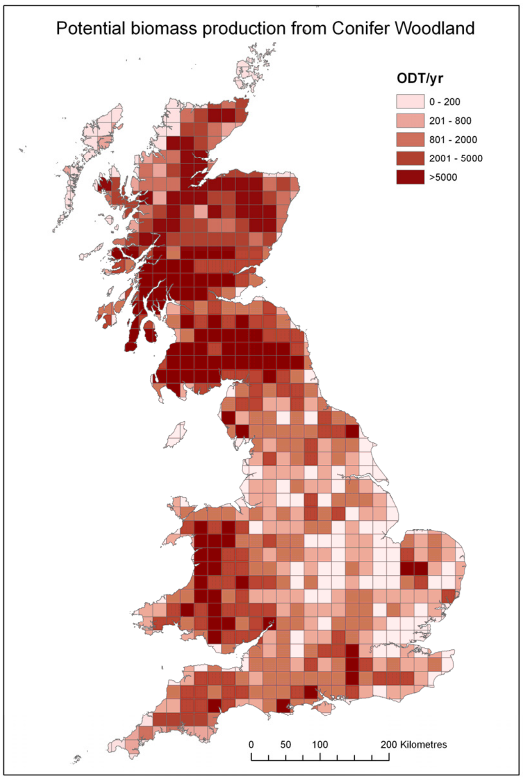
2.3.2 Potential woodland resource

Figure 10 shows the potential biomass production from both the conifer and broadleaf forest estate in England and Wales. The woodland resource is both publicly owned (22 per cent (Forestry Commission, 2007a)) and privately owned (78 per cent). Large areas of privately owned woodland have not been actively managed for a number of years. One of the reasons for this lack of management has been the low price of timber. A lack of active management can have detrimental effects on biodiversity and other aspects of woodland ecology (Forestry Commission, 2007b). To address these issues, and to tap into an under-utilised renewable, low carbon fuel source, in England the Forestry Commission produced a strategy aimed at bringing an additional two million tonnes of wood fuel to the market each year by 2020 (Forestry Commission, 2007b). This figure was calculated by estimating the currently unharvested annual increment produced by English forests and woodlands (4.2 million tonnes) and adjusting this estimate to account for those areas of woodland where harvesting would not be possible because of environmental constraints (such as designated conservation areas) and physical and social constraints (for example, lack of suitable access to woodland or lack of woodland owner engagement or desire to supply fuel to the market).

To put the 2 million tonne figure into context, the total softwood harvest in the UK in 2006 was 8.5 million green tonnes (roughly equivalent to 4.3 million odt), of which 4 million tonnes came from non-Forestry Commission/Forest Service woodland. Total hardwood harvest in the same year was 439,000 green tonnes, of which 393,000 tonnes came from non-Forestry Commission/Forest Service woodland. Any ‘new’ material coming onto the market from the existing forest resource is likely to come from privately owned woodlands, as output from the Forestry Commission estate has, in most cases, existing markets which are often serviced by long-term supply contracts.

In the period 2008-2010, the regions of the country most likely to offer significant increases in the production and use of woodfuel from forestry are South West and South East England, the East of England and North East England. These regions contain considerable forest resources and in some instances are also receiving additional support via the Forestry Commission or Regional Development Agency to help mobilise this resource. The largest concentrations of conifers in England are found in the North on the border with Scotland, typified by Kielder forest; in the middle of East Anglia is Thetford forest, composed mainly of pine species; and in the South West in Devon and Cornwall. As shown in Figure 10, conifer woodland is abundant throughout the inland areas of Wales. Broadleaf woodlands are distributed throughout England and Wales, though these are often in the form of small, unconnected woodlands. Some of the most heavily wooded areas for broadleaf species are found to the south of London in Surrey, Hampshire and Kent.

Although some material may enter the co-firing markets and also the large power generation plants such as Sembcorps' Wilton 10 power station and the plant at Lockerbie managed by E.On, it is likely that (especially in the southern regions of England) small- and medium-scale heat projects requiring a few tens or hundreds of tonnes of fuel per year will be the most common end use for this material. This is due to a combination of economics (fuel for small-scale boilers tends to fetch a better price than fuel for larger power generation projects), woodland ownership patterns (many owners of small blocks of woodland able to produce relatively small parcels of woodfuel) and logistics (woodfuel has a low energy density by volume). Government grants designed to offset some of the capital cost associated with installing wood fired boilers and CHP systems are likely to run during the period 2008-2010 (Defra, 2007e; Biomass Energy Centre, 2008b). Other grants may assist with the development of the woodfuel supply chain (Biomass Energy Centre, 2008a). As with perennial energy crops, any afforestation programme aimed at increasing the forest resource and fuel production capability will not be 'on stream' by 2010. It is unlikely that significant areas of forest residues (small branch wood, branch and stem tips) or stumps will be harvested by 2010 because of uncertainties over the effect these operations have on long-term site sustainability. The economics of these operations are also unclear in many cases.



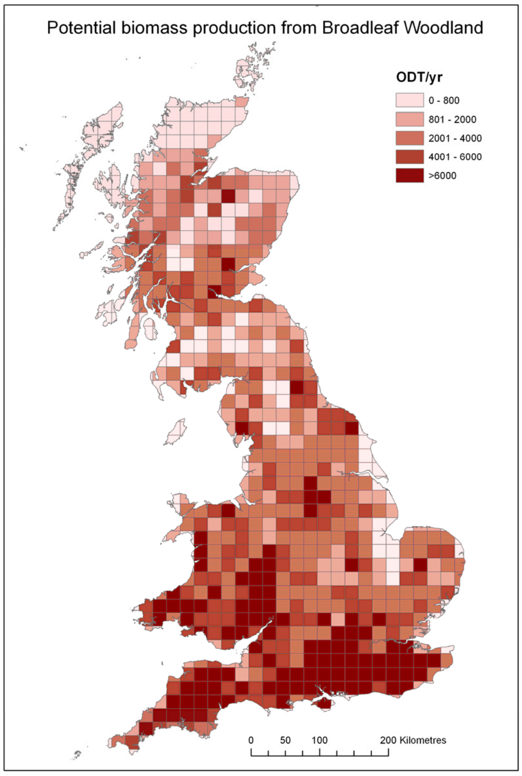


Figure 10 Potential resource of wood from conifer (left) and broadleaf (right) woodland in England and Wales. Data is expressed in 20km^2 squares and represents the average yield multiplied by the area of forestry in that area.

2.3.3 Potential energy crop resource

Both Miscanthus and SRC are relatively 'new' crops for UK farmers and landowners. The high initial establishment costs together with the long commitment period for these crops once established mean that any decision to invest in these crops needs to be based on impartial and sound advice. Both SRC and Miscanthus grow well in the UK, yet yield can vary significantly depending on soil type, rainfall, altitude and land topography. To help aid planting decisions, Defra commissioned maps that examined the potential yield of both SRC and Miscanthus in the UK taking into account factors that could affect yield (Forest Research, 1999; ADAS, 2003). Figure 11 is based on the yield constraint maps for SRC and Miscanthus and shows the potential locations and predicted associated tonnages of both energy crops assuming 10 per cent of agricultural land is utilised for production of these crops. In reality, the amount of these crops grown may be considerably less than this; at current margins, we suggest one per cent would be a more realistic figure.

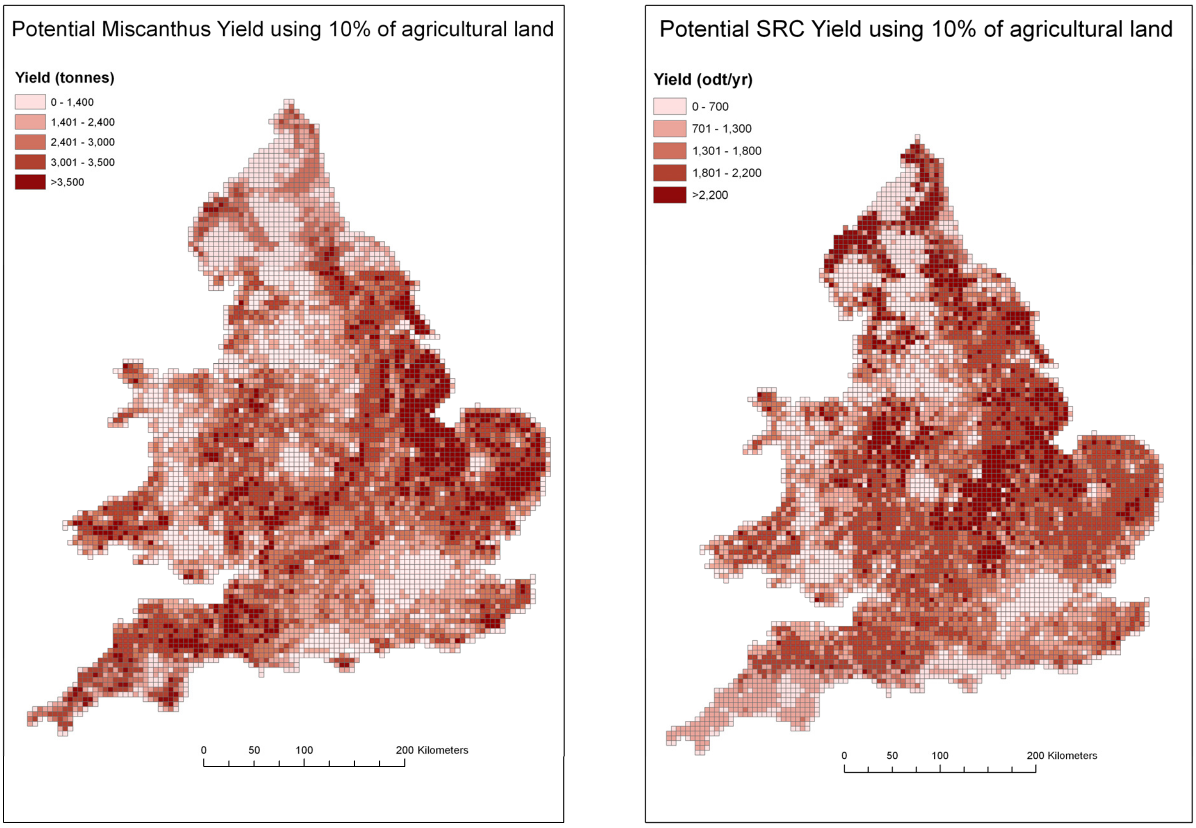


Figure 11 Potential production of Miscanthus (left) and SRC (right) assuming that 10 per cent of agricultural land is planted with the crop. Each square represents $10km^{2}$. The average predicted yield of Miscanthus and SRC in each square was multiplied by 10 per cent of the agricultural land in each area to give an estimate of potential production in tonnes for each square.

Whilst large areas of the UK are suitable for the production of energy crops as shown in the maps above, the uptake of these crops over the next 10-15 years is very uncertain. At present, uptake is minimal because even with government support in the form of planting grants, the economics are marginal. Both SRC and Miscanthus were previously eligible to be planted on set-aside land as non-food crops without compromising the Single Farm Payment. The removal of set-aside now means that SRC and Miscanthus may compete for land with cereal and oilseed crops such as wheat and OSR for which the margins are much more favourable (especially with the current high prices for both these commodities). This provides a considerable disincentive for wider uptake of energy crops in the UK. A recent study for the National Non-Food Crops Centre (NNFCC) indicated that with current support schemes, grain prices below £85-90 per tonne and low to medium yields would be needed before energy crops are even close to being competitive (Turley and Liddle, 2008). Even with increased support and returns, ADAS experience has shown that farmers are wary of moving to energy crop production for a number of reasons, including concern over committing themselves to the required long-term contracts. Environmental suitability can vary within relatively small areas, so although the maps show the main area of potential production, uptake will always be the choice of individual growers. Getting several growers to work together in groups offers a good way to build up 'critical mass' in terms of both useful tonnages of saleable material and in the assembly of a suitable capital outlay for the cropped area.

Both Miscanthus and SRC take a number of years before they can be harvested for bioenergy use. Miscanthus planted in 2008 would be harvested for the first time in 2010, although it would take a further two to three years before it reached its full yield. SRC planted in 2008 would not be harvested for bioenergy use until 2011. Therefore whilst these maps show the potential areas where Miscanthus and SRC could be grown, these represent areas of potential resource in the longer term beyond the 2010 timeframe considered in this report.

As well as supporting the establishment of willow and poplar short rotation coppice, the remit of the current energy crops scheme has been extended to include slower growing broadleaf tree species including sycamore, ash, lime and chestnut (Forestry Commission, 2007c). These species are typically grown on rotations of between 12 and 15 years. Harvested stems could be processed into logs for use in high efficiency log batch boilers or chipped to provide fuel for woodchip boilers. This type of coppice could be used on farms or estates where existing woodland is currently managed to produce woodfuel. It is unlikely that significant areas of this coppice will be established in the short-term and any new plantations will not be harvested in the time period covered by this report.

There is increasing interest in establishing native and non-native tree species using techniques developed from conventional forestry and woodland management but optimised to produce fast growing, single stemmed trees over a relatively short rotation (typically 8 to 15 years). This approach is referred to as 'Short Rotation Forestry' (SRF). Currently, there is no grant support for SRF and it is yet to be proven as economically and environmentally sustainable at the commercial scale in the UK. It is possible that small areas of this crop will be established in the short-term but any new plantations will not be harvested in the time period covered by this report.

2.3.4 Area of previously set-aside land

Set-aside was first introduced as part of a series of measures aimed at tacking the over-production of cereals within the EU under the CAP reforms of 1992. Cereal support based on production was stopped and instead, farmers and landowners could receive support based on a proportion of their land set-aside (taken out of production). Initially at least, the payment varied depending on the type (rotational or permanent) and size of the area to be set-aside. On a year-on-year basis, the area of compulsory set aside has varied since its introduction in 1993. Now however, the European Commission has decided to discontinue set-aside. With farmers receiving support for compliance with a range of environmental standards (EC Regulation 1782/2003), and liberalisation of world commodity markets, set-aside had a much diminished role in managing production and the environment.

Whilst set-aside could not be used for growing food crops, it has been used for growing industrial crops such as OSR for biodiesel, and for energy crops such as Miscanthus and SRC. Of the set-aside land cropped under the industrial crops scheme in 2007, 70 per cent was oilseed rape, 15 per cent was cereals and the remainder minor crops such as poppy and chamomile (NNFCC, 2008). The utilisation of set-aside land for industrial crops allowed farmers to use set-aside yet stay eligible for the SPS subject to a contract with the end user being in place. The amount of set-aside cropped under the industrial crop scheme in England fluctuated in recent years, from 76,000 ha in 2005, to 75,000 ha in 2006 and 90,000 ha in 2007.

Alternatively, set-aside land could be left fallow either permanently ('permanent set-aside') or could vary from year to year ('rotational set-aside'). In 2008, compulsory set-aside was set at zero per cent to combat increasing prices of commodity crops, and it is widely believed that set-aside will soon be permanently abolished. The current decoupled payments under the SPS now allow farmers to crop land or leave it fallow as market economics dictate; the payments are environmental rather than 'coupled' to production.

ADAS estimates that a further 20-30 per cent of previously set-aside land could be brought back into production after the removal of set-aside. The most likely to come into production are those areas under rotational set-aside, where set-aside has been used as a break crop, although there is evidence that high grain prices are beginning to encourage voluntary set-aside back into production. Set-aside land varies in its suitability for cropping, and permanent set-aside has usually been on the least productive parts of a farm. Depending upon the farm, the productivity of land can vary substantially, so set-aside land on one farm may be highly suitable for cropping, whilst on another it may be less so. The highest yields of crops are associated with better land quality – farmers may choose not to utilise an area if it performs poorly unless there is sufficient financial incentive to use a land as yields may be compromised or significant inputs may be needed to increase yields.

Set-aside land can be highly beneficial from an environmental point of view and retention of set-aside land as-is can help in achieving the aims of agri-environmental schemes. Therefore, even though Figure 12 below indicates the percentage of agricultural land in each area which *could* be brought into production, to what extent the area of set-aside used for growing crops will increase is unknown and the environmental impact of using previously set-aside land depends largely on the nature of the land and its previous use. As the prices are lower for industrial crops than for food crops, we believe that with a zero per cent set-aside rate it is likely that most growers of OSR and wheat will move to normal (that is, non-market specific) contracts.

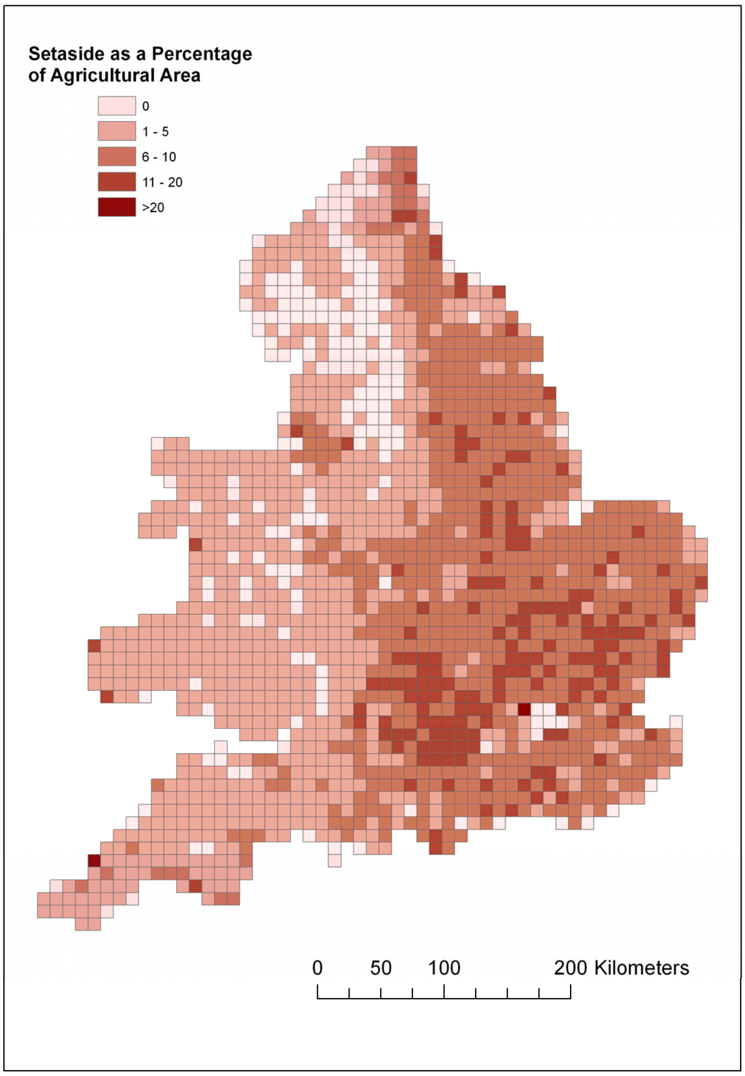


Figure 12 Area of set-aside land in 2004 as a percentage of the total agricultural land area.

2.3.5 Bioenergy scenario maps for 2010

The legislative drivers for increasing renewable energy use provide an impetus for the development of both the supply sector and production sector. To what extent these targets will be met from UK production and from UK-derived feedstocks is unclear. In a previous report by AEA (Bates *et al*., 2008), a number of scenarios were proposed for the development of this sector to 2010, and using these scenarios as a basis, we have mapped the supply areas of crops and materials around existing and planned bioenergy facilities to 2010.

In this report, demand of energy plants for feedstocks/ fuel is represented by the size of circles centred on the point of use. Demand is determined by the size of plant and by various assumptions made on plant efficiency, and by assumptions about the percentage of consumption taken from domestic sources as against imports. The ability of an area to fulfil demand is also determined by yield per hectare and the percentage of land given over to any one crop within the catchment area. It is important to realise that the maps represent demand and possible resource use not where material will actually be produced. Areas nearer to plants represent a high demand and a potential for environmental impact but it is not necessarily a reflection of what will happen in reality. Supply to a plant is affected by many factors: road links and ease of lorry access; topography for cultivation of land; existing demand and contractual arrangements with other buyers; and the demand for other more profitable crops in the area. Supply catchments are thus rarely, if ever, circular. Circles however offer the best method for representing relative demand and possible environmental impacts.

In each of the maps which follow, we have examined scenarios for 5, 10 and 25 per cent of feedstock sourced for each facility from UK production, with the supply zones for each scenario shown by a series of circles radiating from the processing plant in question. These scenarios were applied to every plant investigated with the exception of AD plants, dedicated biomass power plants, and bioethanol production at Wissington.

The areas encompassed within these circles are indicated in the tables following the maps and are based on cropping data from 2004, the most recent survey year for which spatially referenced agricultural data with UK coverage was readily available. The representation of supply catchments as circles with radii proportionate to local yields and tonnage required is of necessity a simplistic approach that gives a basic indication of demand. However there are many calls on UK cereal and oilseed production – animal feed and food manufacture, brewing and distilling and on-farm use for livestock feed (see http://www.hgca.com/cerealsmap/version7.html). Cereal and oilseed bio feedstocks for fuel have to work in the open market and their movement is dictated by the costs the buyer is prepared to pay, including transport costs. Livestock feed mills in the west of the country must be able to secure supplies in the main cereal areas to the east. Food manufacturers operate with margins that allow them to buy and transport grain to mills and flour to bakeries. So the maps presented in this report are simple indications of demand.

In reality, a much more complex economic 'map' should overlay all the potential end user maps and in theory would show how material is likely to move to its end users and how the areas of production are modified by this competition for resources. To date, the prices paid for bioenergy feedstocks have been low, as has the relative price of oil. The current realignment of values (prices) strengthens the competitive position of the energy feedstock market, but this is also producing some knock-on effects on food prices as producers secure their supplies. In such a volatile market, simple area/demand indicators give perhaps the clearest picture. Farmers are known to respond to local demand, and thus it is a reasonable assumption that feedstock will be derived from around local plants – especially in the case of biomass where the bulky nature of supply means that haulage costs over long distances can be prohibitive.

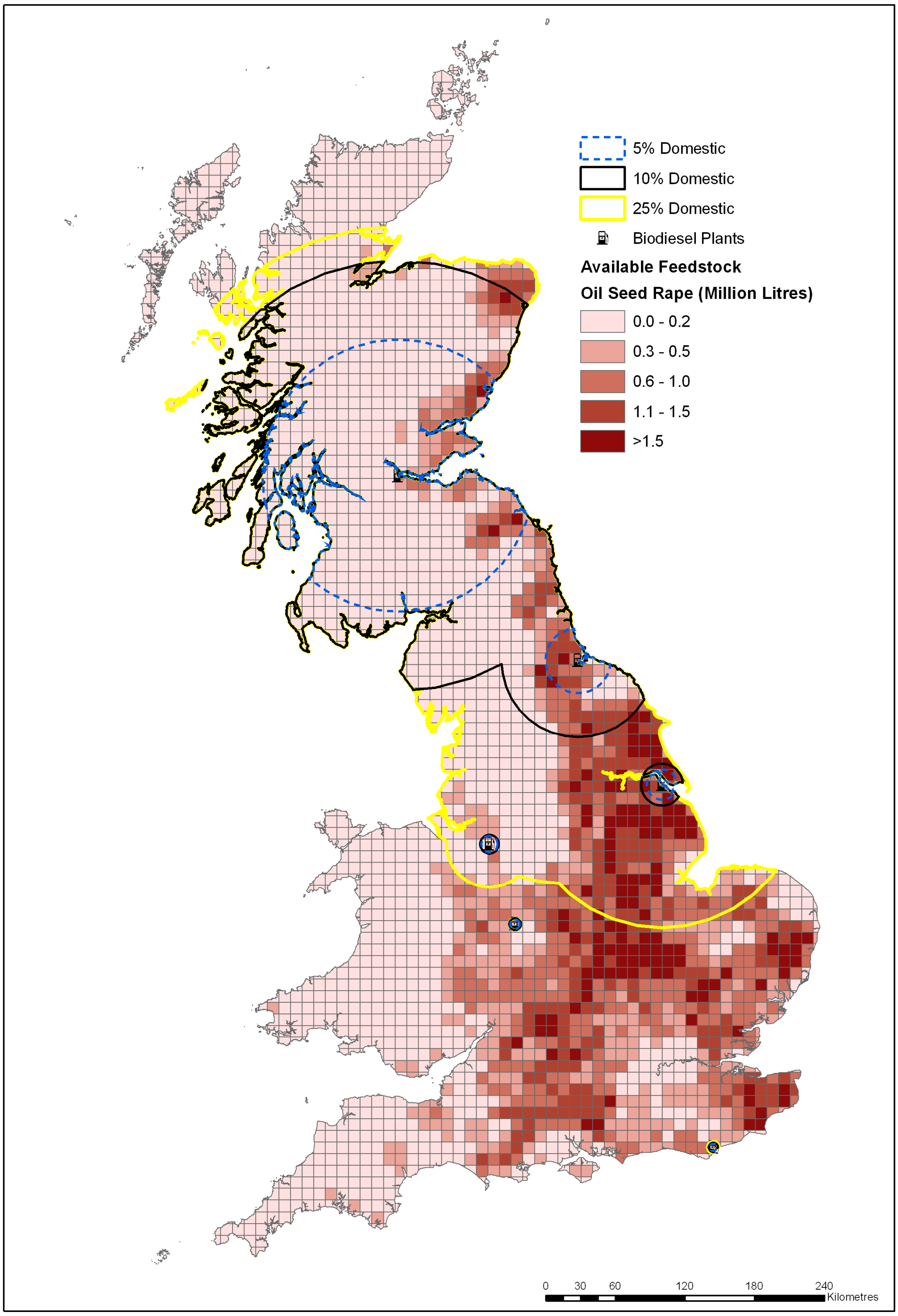


Figure 13 Supply zones of OSR for biodiesel production in 2010 given that 5 per cent, 10 per cent and 25 per cent of the total feedstock capacity for the plant is derived from locally grown OSR and plants are operating at full capacity. This figure excludes small-scale producers of OSR for biodiesel, as there are no accurate figures for the number, location or feedstock requirements of such groups.

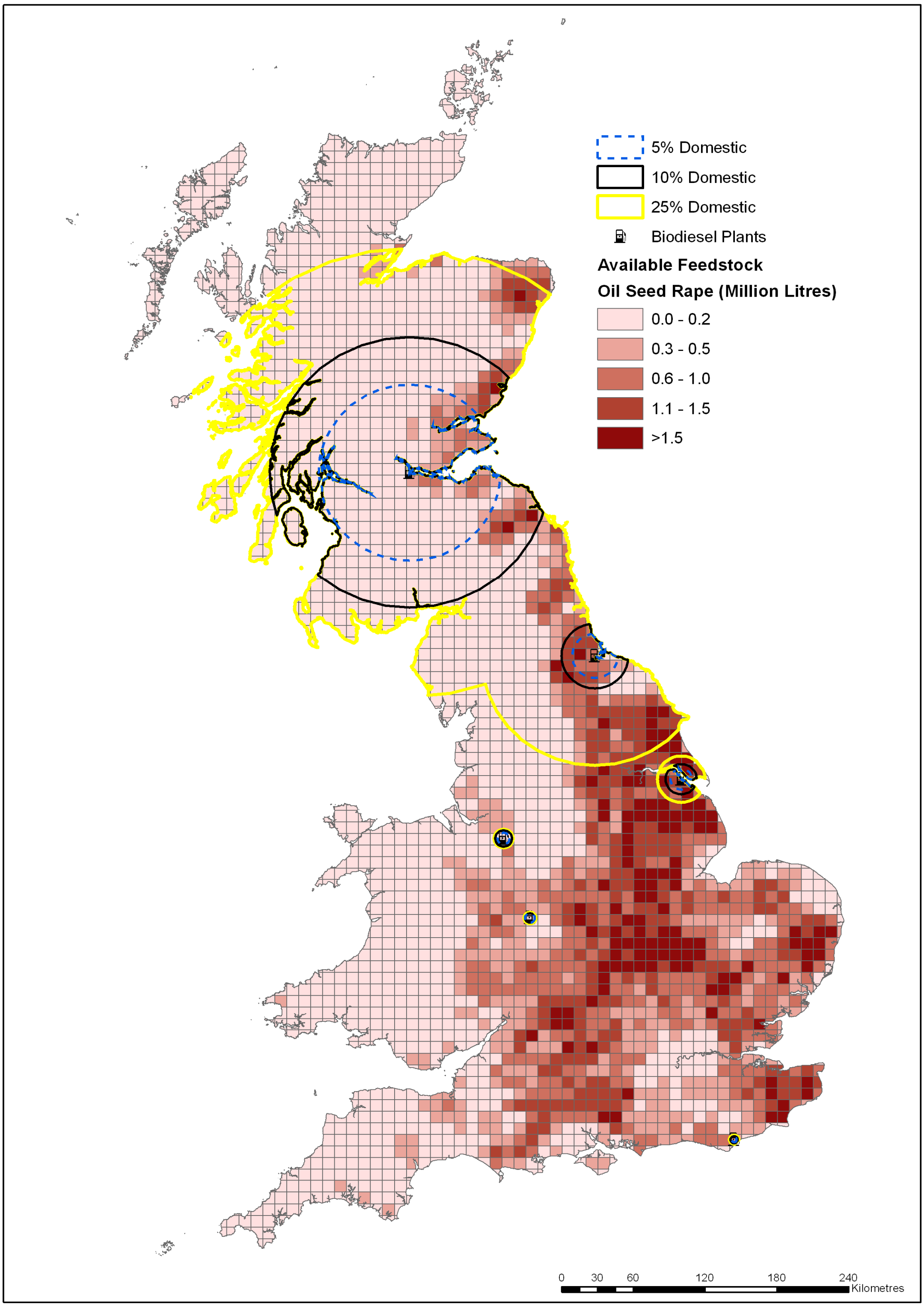


Figure 14 Supply zones of OSR for biodiesel production in 2010 given that 5 per cent, 10 per cent and 25 per cent of the total feedstock capacity for the plant is derived from locally grown OSR and plants are operating at half capacity. This figure excludes small-scale producers of OSR for biodiesel, as there are no accurate figures for the number, location or feedstock requirements of such groups.

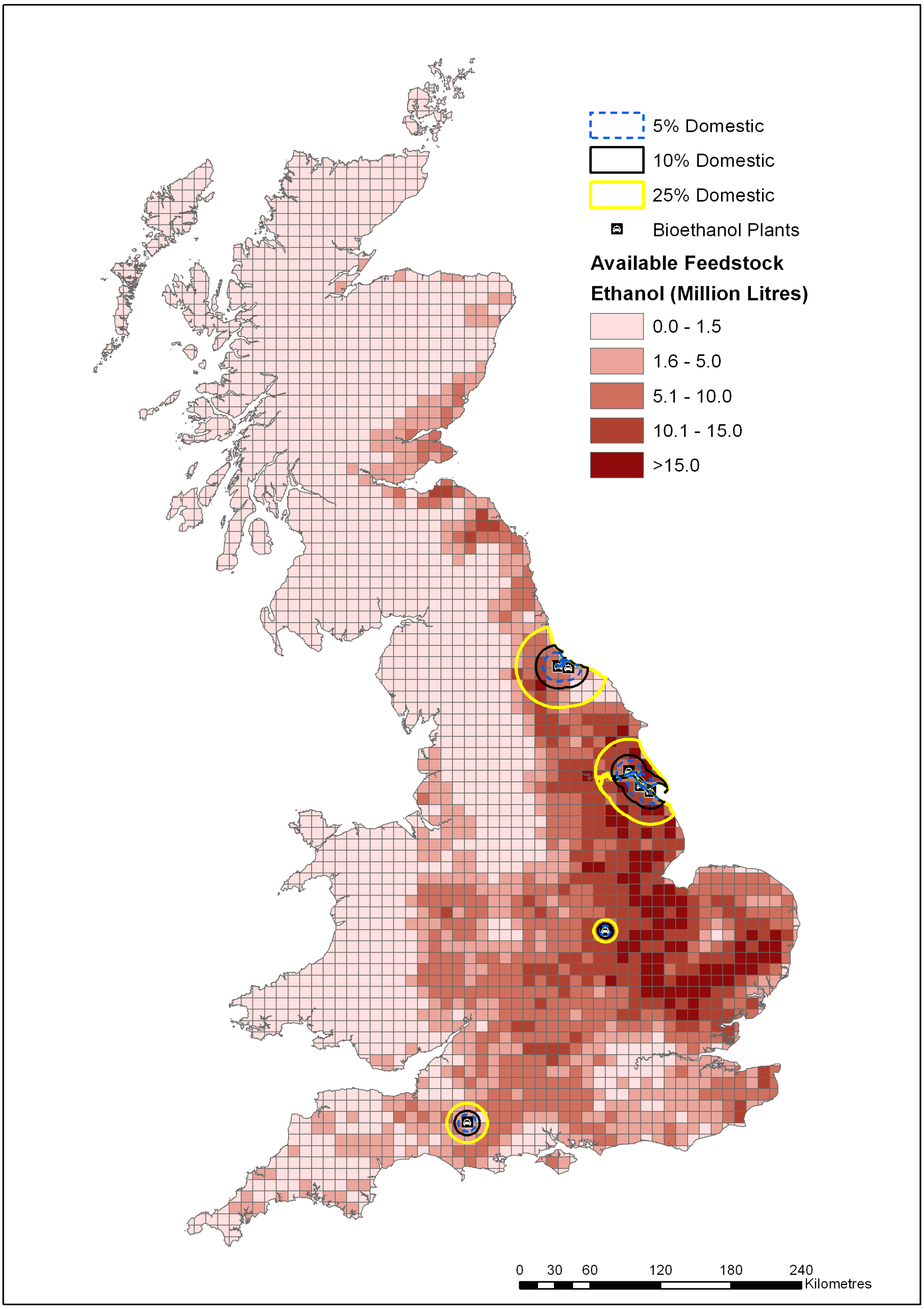


Figure 15 Supply zones for wheat for bioethanol production in 2010 given that 5 per cent, 10 per cent and 25 per cent of the total feedstock capacity for the plant is derived from locally grown wheat and plants are operating at full capacity.

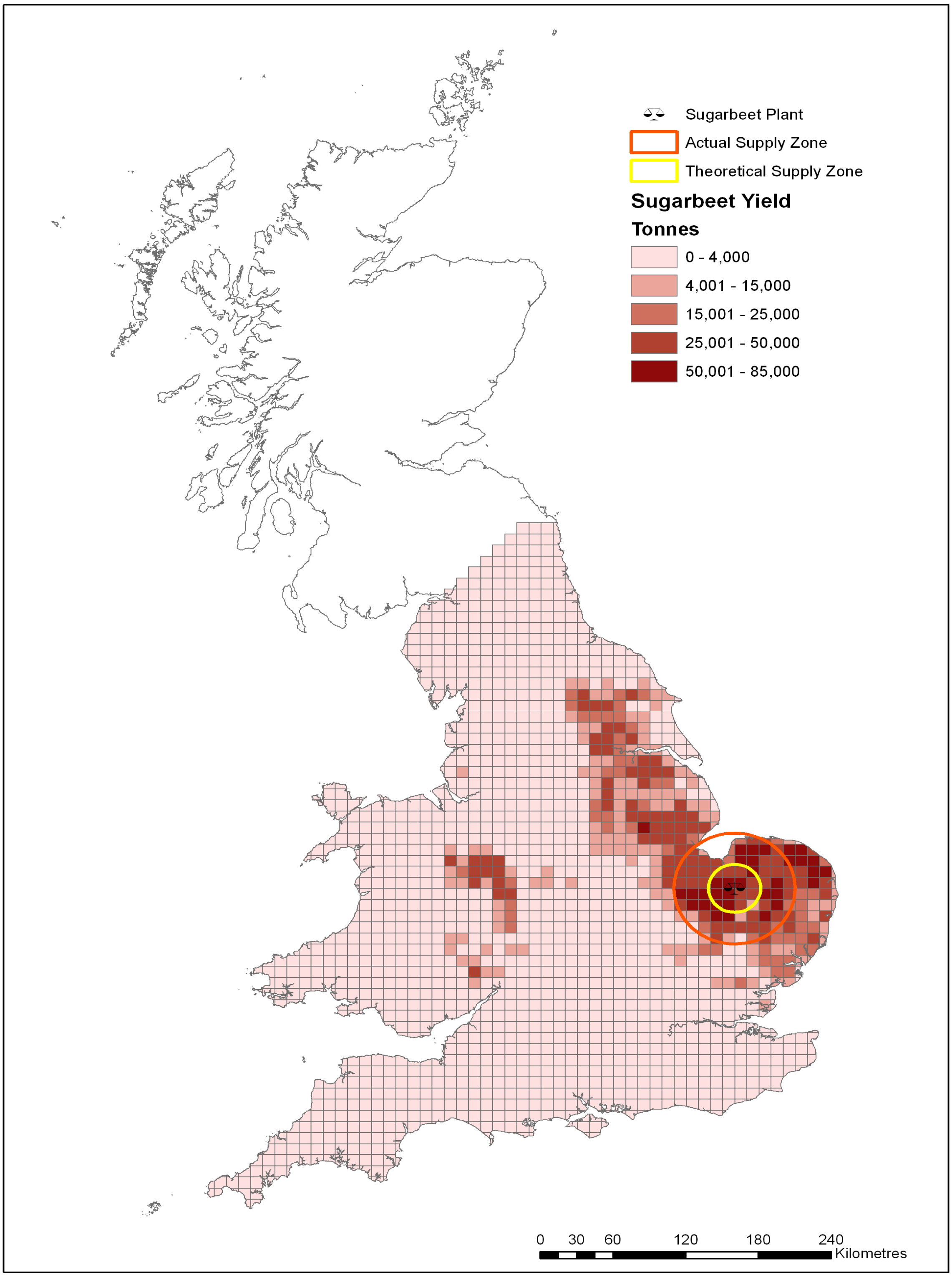


Figure 16 Supply zones of sugar beet bioethanol production in 2010 given that 100 per cent of the total feedstock capacity for the plant is derived from locally grown sugar beet and the plant operates at full capacity.

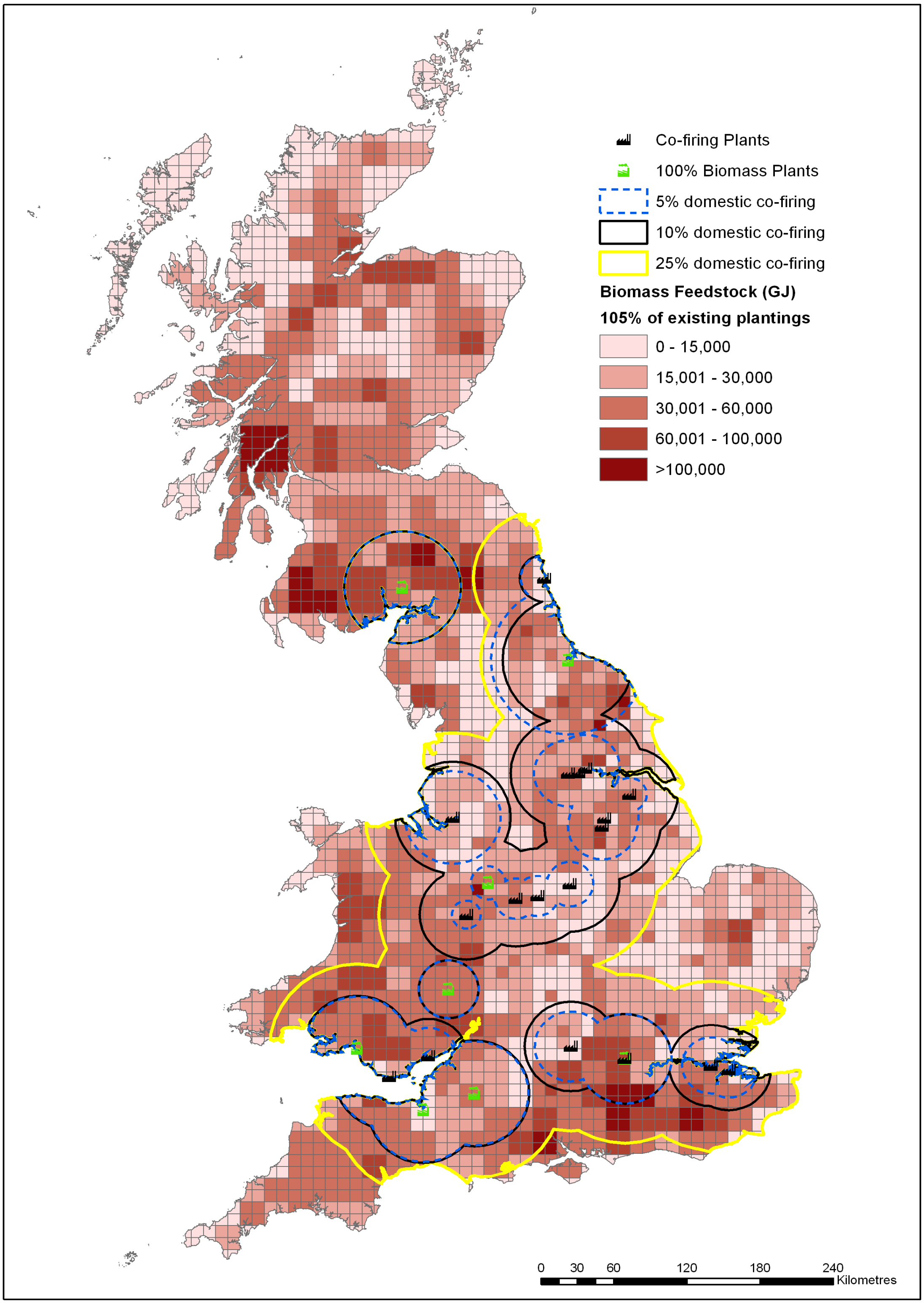


Figure 17 Supply zones of biomass co-firing and dedicated biomass combustion in 2010 assuming that 5 per cent, 10 per cent and 25 per cent of the demand is derived from home-grown products and that there is an increase in energy crop plantings 5 per cent above current levels.

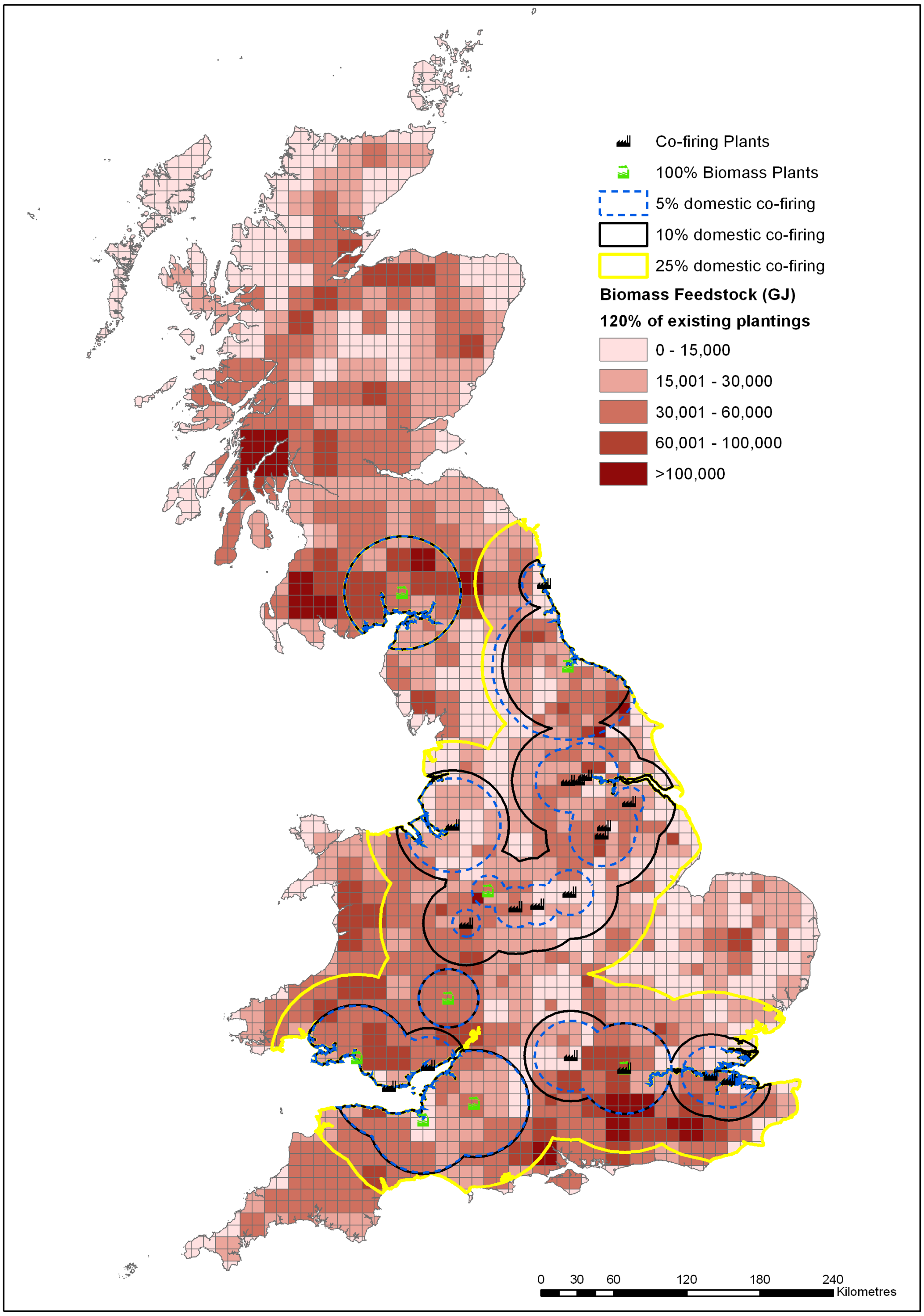


Figure 18 Supply zones of biomass co-firing and dedicated biomass combustion in 2010 assuming that 5 per cent, 10 per cent and 25 per cent of the demand is derived from home-grown products and that there is an increase in energy crop plantings 20 per cent above current levels. ***Although this looks very similar to Figure 17 there are very small differences (see overlap areas in N Yorks). A 15 per cent increase in a small area remains a small area when viewed nationally.***

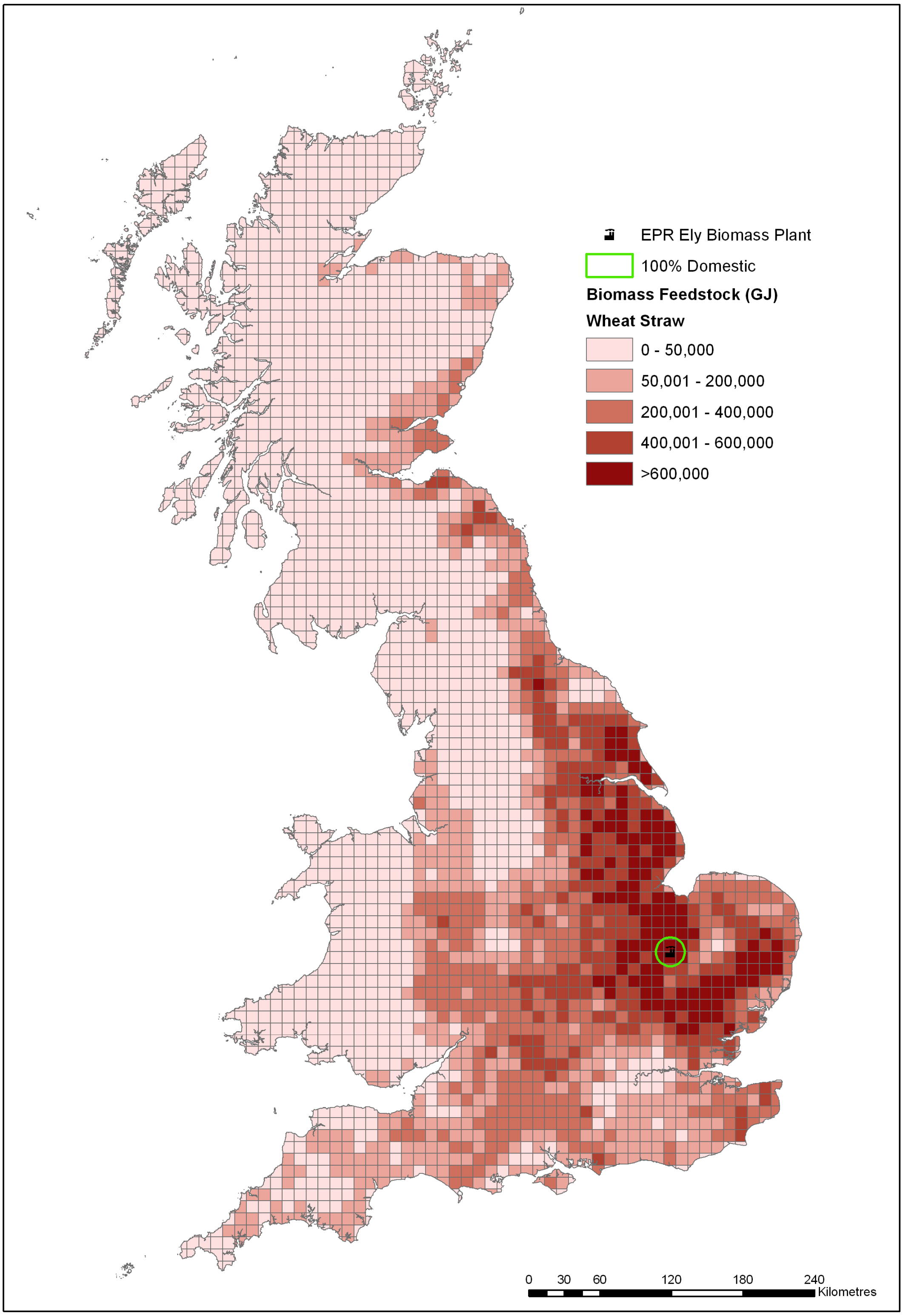


Figure 19 Supply zones of dedicated biomass combustion of straw at 2010. This figure assumes 100 per cent domestic supply and 100 per cent consumption in the area shown, and assumes only wheat straw is used. In reality, small amounts of rape and Miscanthus straw may be also burned.

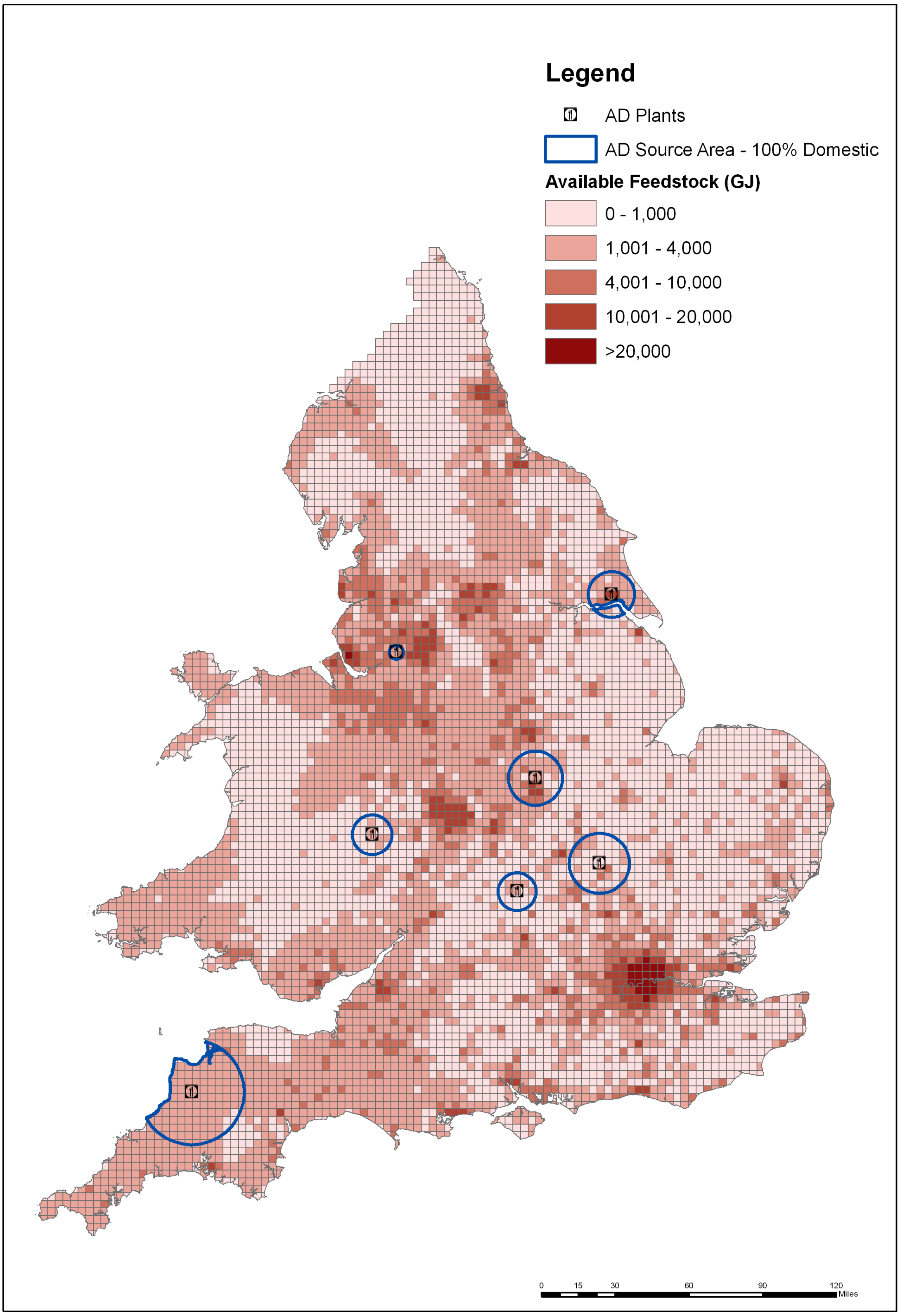


Figure 20 Supply zones of anaerobic digestion facilities in 2010 assuming that 100 per cent of the feedstock is locally sourced.

Table 7 Areas encompassed by the supply zones in Figures 13 and 14 for biodiesel production assuming that 5 per cent, 10 per cent and 25 per cent of supply is met from domestic production of oilseed rape and given production at half or full capacity.

	Full Capacity			Half Capacity		
Domestic Supply (%)	Area (km^2)	Feedstock required (tonnes)	% of Domestic demand 2010*	Area (km^2)	Feedstock required (tonnes)	% of Domestic demand 2010*
5	38,388	135,657	8.5	17,908	61,588	3.9
10	77,221	290,575	18.2	38,388	135,657	8.5
25	117,452	778,288	48.7	86,136	375,300	23.5

* Feedstock requirement for each scenario in 2010 has been calculated by adjusting the 2004 census data for OSR area for 2010 in accordance with Table 6, multiplying this figure by an average yield of 3.42 tonnes per ha to get a production figure for 2010 and calculating the percentage of the 2010 production required under each scenario.

Table 8 Areas encompassed by the supply zones in Figure 15 for bioethanol production assuming that 5 per cent, 10 per cent and 25 per cent of supply is met from domestic production of wheat.

Domestic Supply (%)	Area (km^2)	Feedstock required (tonnes)	% of Domestic demand 2010‡
5	1,402	246,256	1.2
10	2,665	518,734	2.72
25	7,278	1,436,986	7.52

‡ Feedstock requirement for each scenario in 2010 has been calculated by adjusting the 2004 census data for wheat area for 2010 in accordance with Table 6, multiplying this figure by an average yield of 7.71 tonnes per ha to get a production figure for 2010 and calculating the percentage of the 2010 production required under each scenario.

Table 9 Areas encompassed by the supply zone in Figure 16 for bioethanol from sugar beet assuming 100 per cent of supply is met by domestic production.

100% Domestic supply	Area (km^2)	Feedstock (tonnes)
Theoretical supply zone	1,458	700,000
Potential supply zone	7,850	3,138,143

Table 10 Areas encompassed by the supply zones in Figures 17 and 18 for biomass combustion assuming that 5 per cent, 10 per cent and 25 per cent of supply is met from domestic production for co-firing and 100 per cent domestic production for dedicated biomass plants and assuming an increase in plantings of SRC or Miscanthus either 5 per cent or 20 per cent above current levels.

Dedicated biomass	Co-firing	120% existing SRC/Miscanthus plantings		105% existing SRC/Miscanthus plantings	
Domestic supply (%)	Domestic Supply (%)	Area (km^2)	Feedstock required (tonnes)	Area (km^2)	Feedstock required (tonnes)
100	5	52,868	1,110,293	53,721	1,109,840
100	10	70,142	1,392,212	71,266	1,385,704
100	25	117,526	2,341,980	118,856	2,338,019

Table 11 Area encompassed by the supply zone in Figure 19 for straw combustion at EPR Ely assuming 100 per cent domestic production and 100 per cent utilisation of wheat straw.

Domestic Supply (%)	Area (km^2)	Feedstock required (tonnes)
100	1,058	153,611 odt

Table 12 Areas encompassed by the supply zones in Figure 20 for anaerobic digestion assuming that 100 per cent of feedstock is domestic.

Domestic supply (%)	Area (km^2)	Feedstock capacity (GJ)
100	563,003	6,611

2.3.6 Environmental impact maps

In the maps which follow, we have overlaid the supply zones for each of the bioenergy facilities for 2010 onto a series of maps which highlight environmental issues relevant to the Environment Agency's remit and which can indicate potential areas of interest regarding potential land use change or increased cropping.

The bioenergy scenario maps have been overlaid onto:

- The current NVZ map to show the areas where any potential issues which could affect water quality may arise as a result of bioenergy cropping or utilisation. Ongoing consultation on extending NVZs to a greater area of England could significantly alter this pattern for 2010.

- Maps of water-stressed areas to show area where there could be any issues relating to water availability as a result of land use change in response to increased bioenergy production.

- Current quality assessment maps that show the status of water catchments in terms of nitrate, ammonium, biological oxygen demand (BOD) and phosphate in relation to the 'demand circles' around the bioenergy and biofuel facilities.

- A map of soil organic carbon to assess whether there are any areas for which planting of perennial biomass crops would be especially beneficial.

The scenarios for biomass bioenergy utilisation and biofuel production have been represented separately on each of the environmental impact maps to facilitate presentation. Many of the areas contain demand for both arable crops for food or feedstock, and for biomass. Differentiation of land use occurs through decisions at the individual farm level taken as a result of perceived economic benefit and land suitability. More detailed catchment analysis is needed to determine where pockets of intensive land use change may occur to an extent that may impact on the mapped environmental criteria.

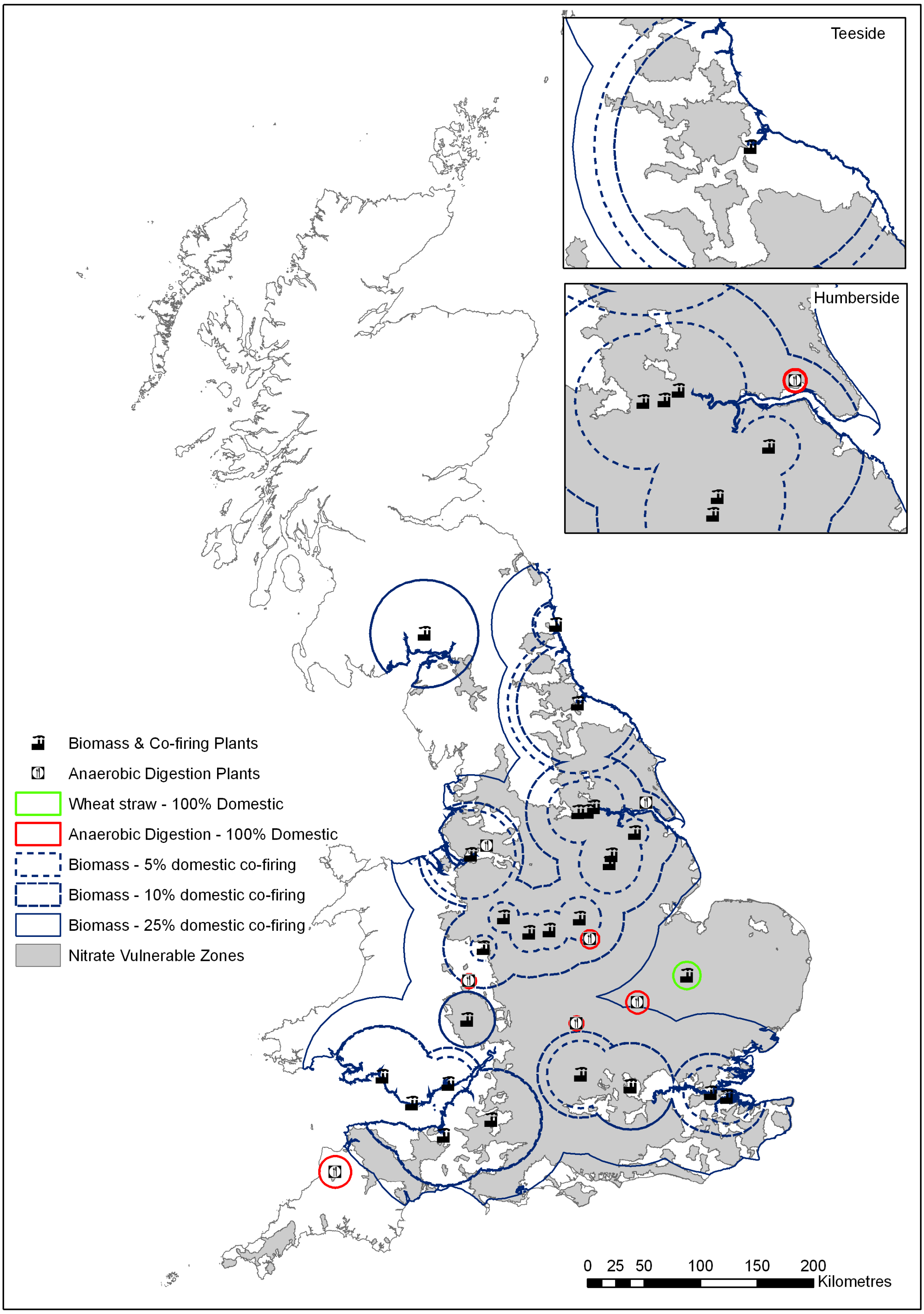


Figure 21 Scenario map for 2010 indicating feedstock supply areas for bioenergy facilities and how these relate to current nitrogen vulnerable zones (NVZs).

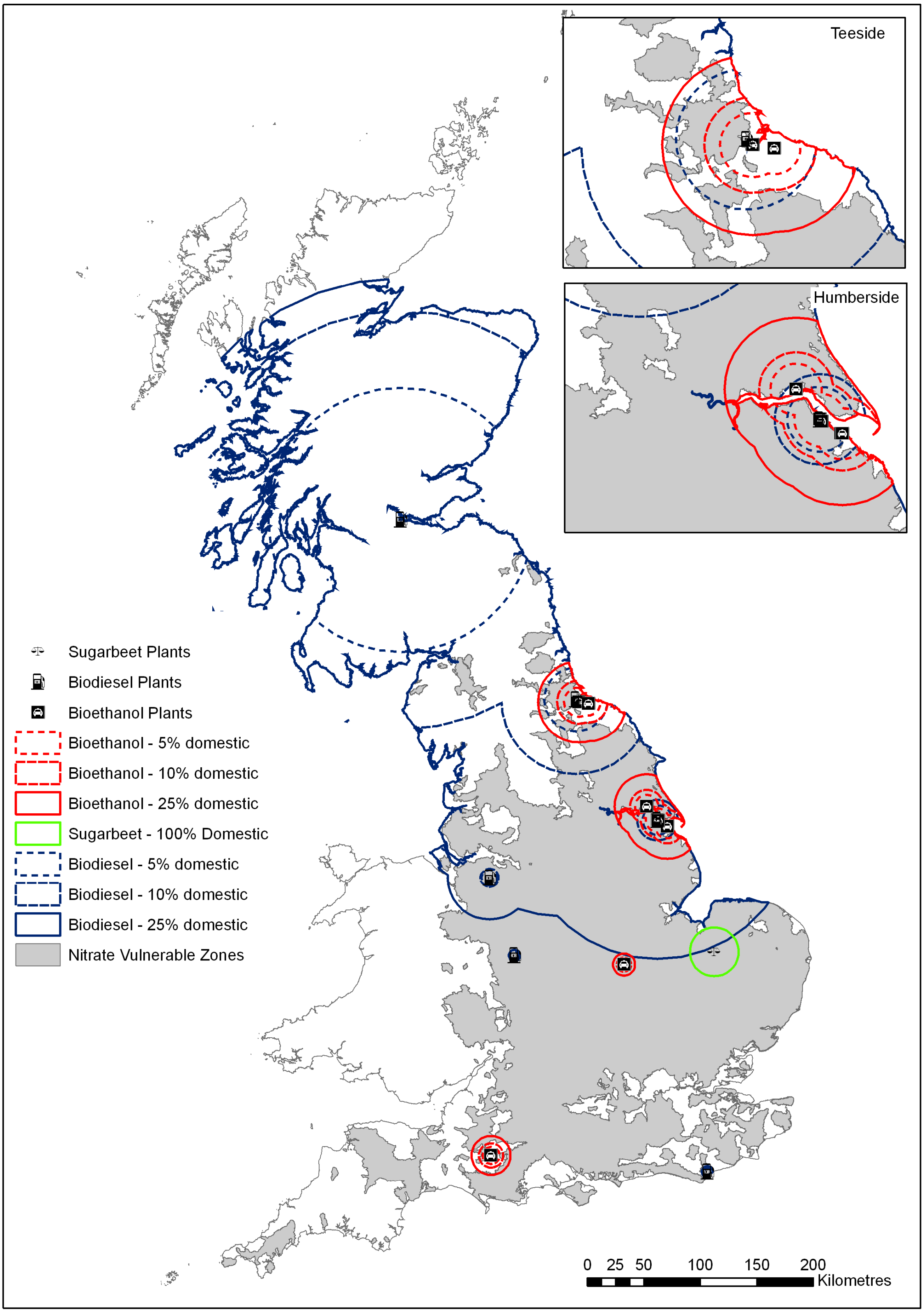


Figure 22 Scenario map for 2010 indicating feedstock supply areas for biofuels facilities and how these relate to current nitrogen vulnerable zones (NVZs).

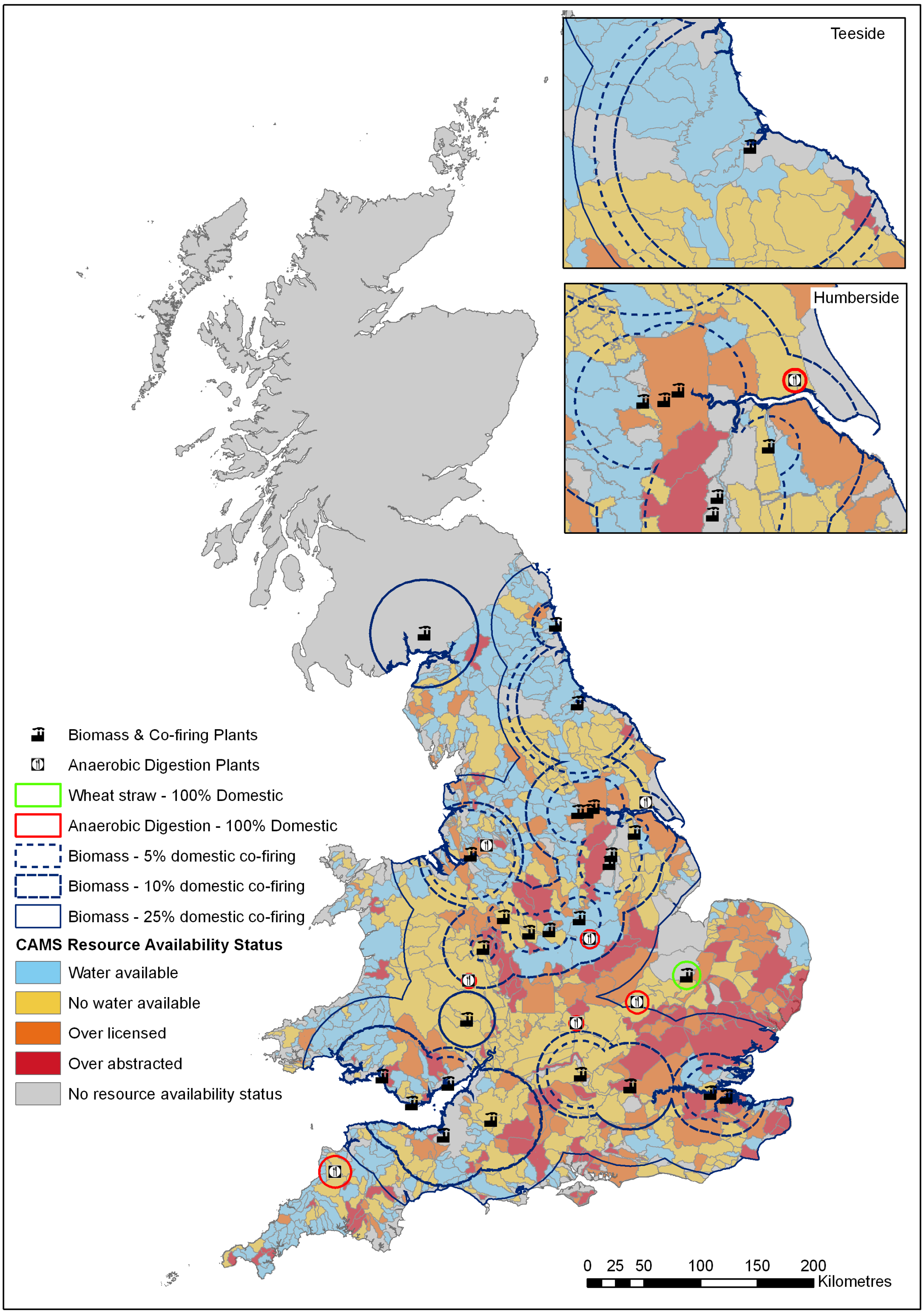


Figure 23 Scenario map for 2010 indicating feedstock supply areas for bioenergy facilities and how these relate to current water stressed areas. Base map supplied by the Environment Agency.

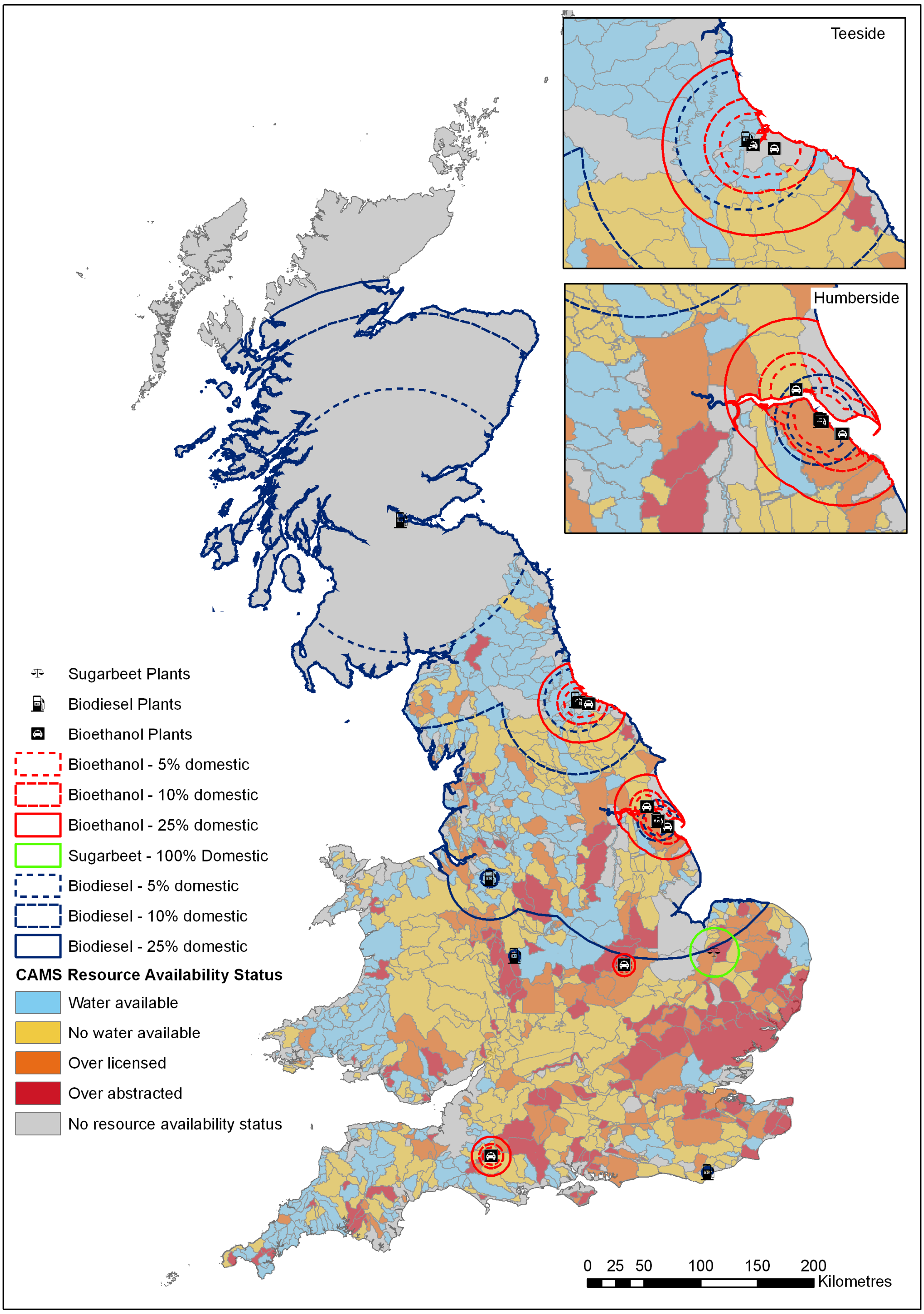


Figure 24 Scenario map for 2010 indicating feedstock supply areas for all biofuel facilities and how these relate to current water stressed areas. Base map supplied by the Environment Agency.

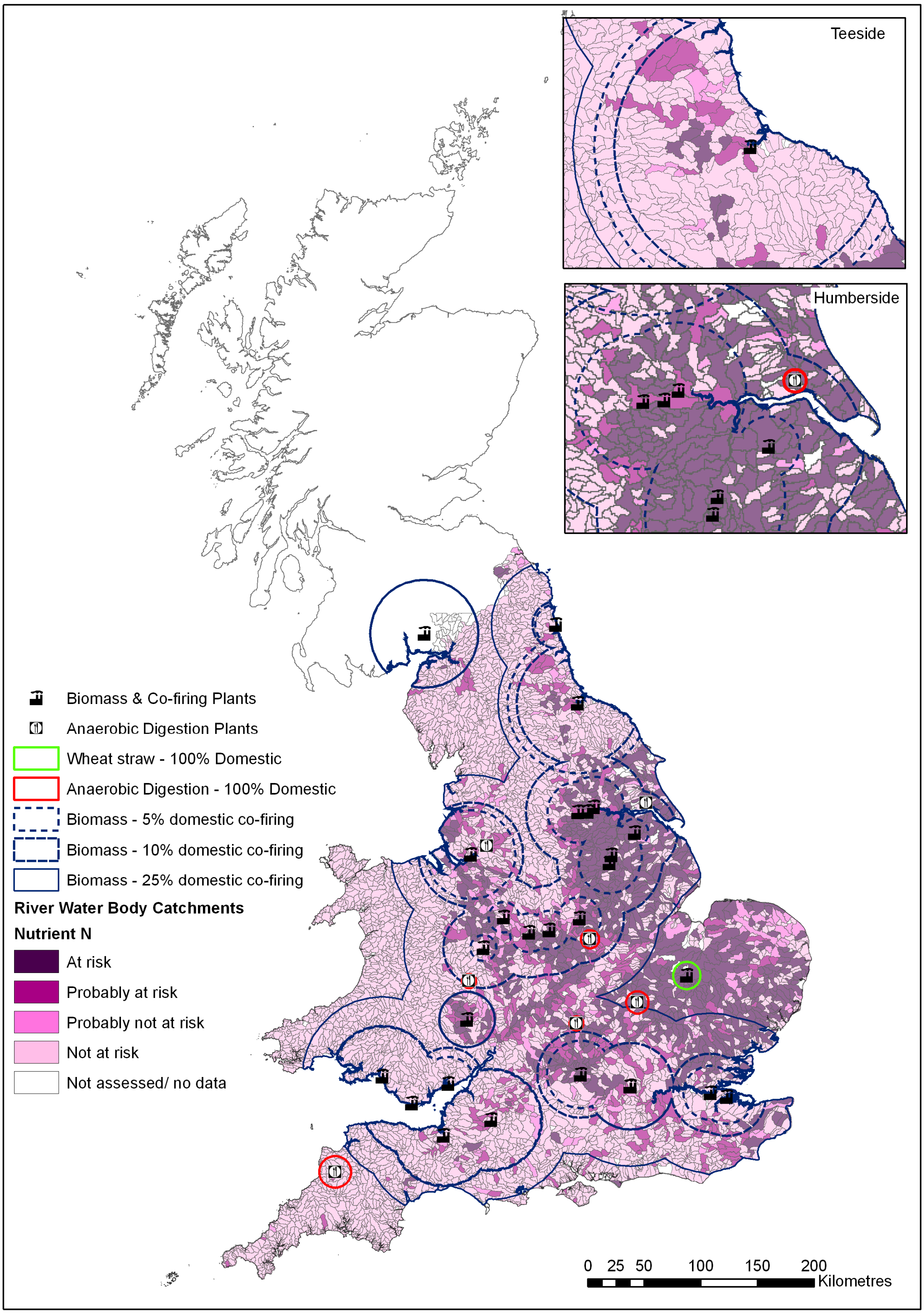


Figure 25 Scenario map for 2010 indicating feedstock supply areas for all bioenergy facilities and how these relate to rivers with current nitrate issues. Base map supplied by the Environment Agency.

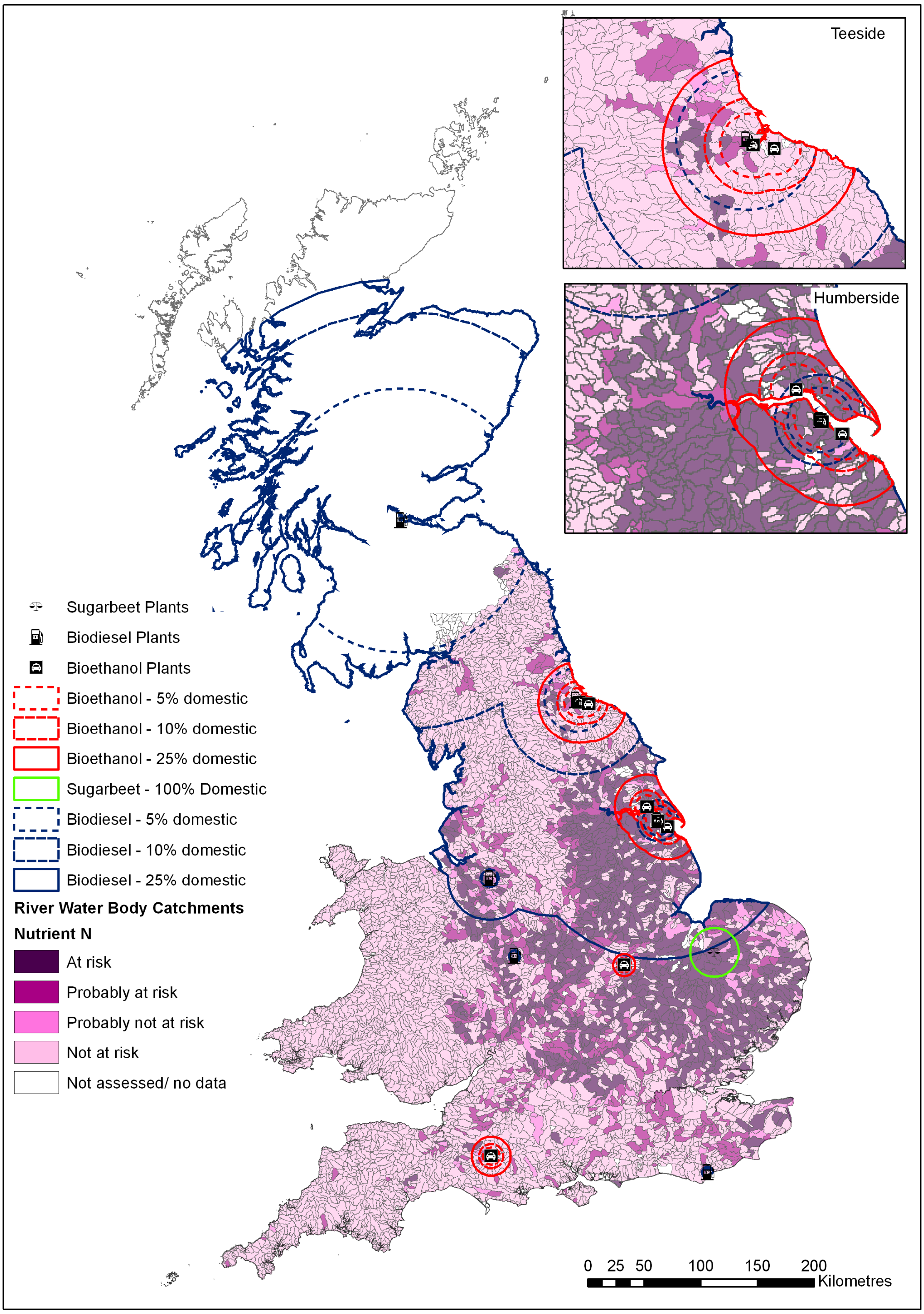


Figure 26 Scenario map for 2010 indicating feedstock supply areas for all biofuel facilities and how these relate to rivers with current nitrate issues. Base map supplied by the Environment Agency.

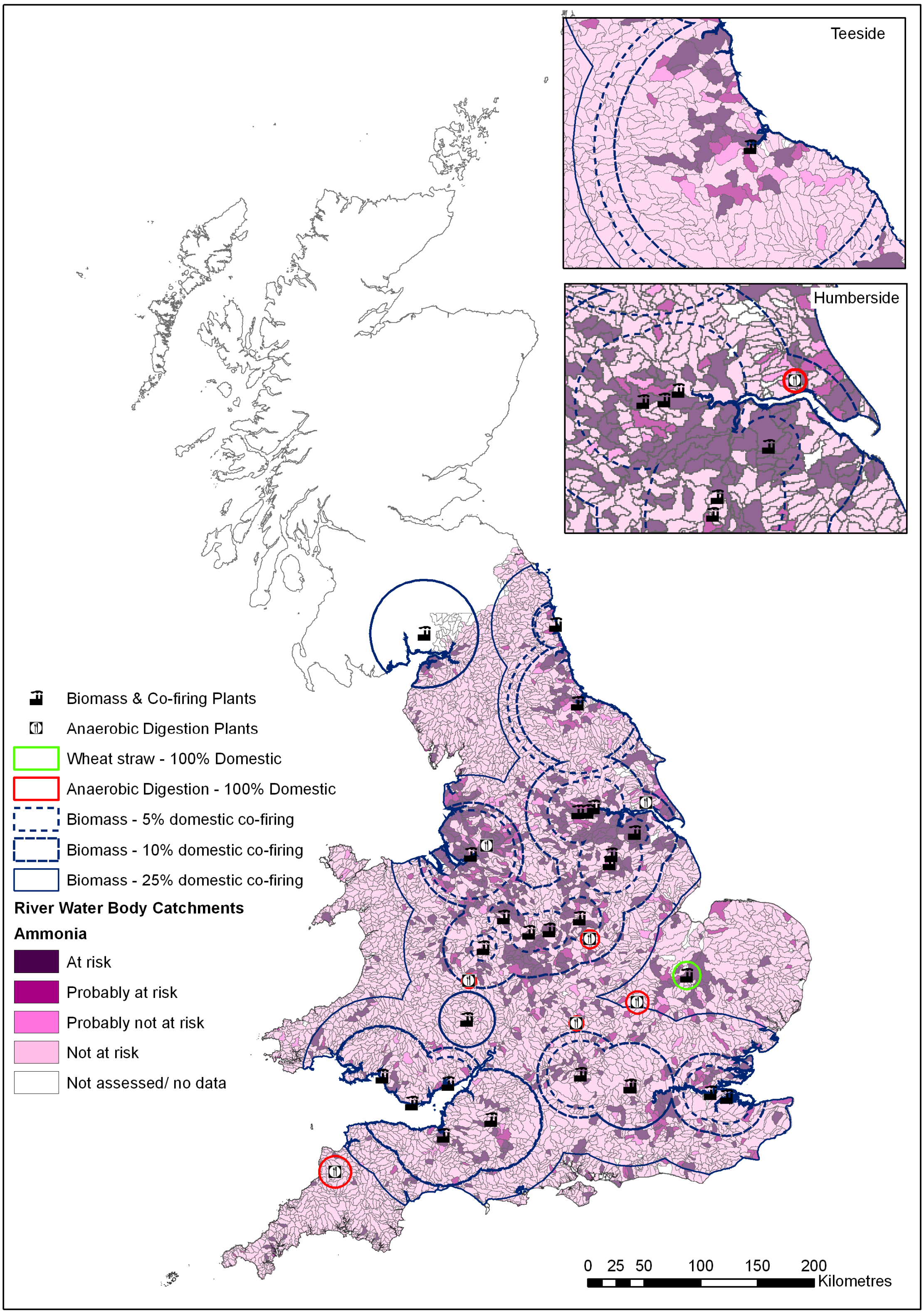


Figure 27 Scenario map for 2010 indicating feedstock supply areas for all bioenergy facilities and how these relate to rivers with current ammonium issues. Base map supplied by the Environment Agency.

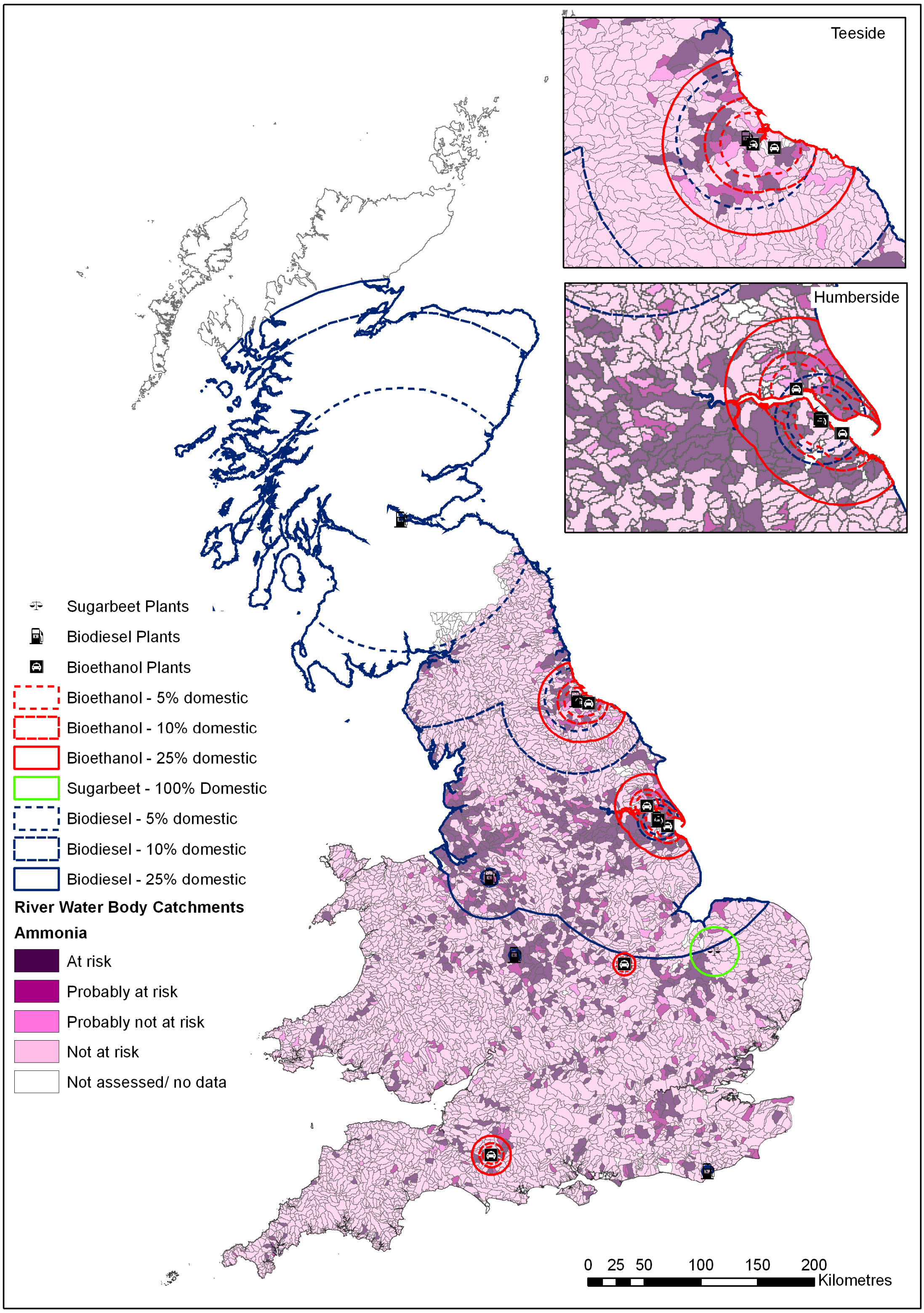


Figure 28 Scenario map for 2010 indicating feedstock supply areas for all biofuel facilities and how these relate to rivers with current ammonium issues. Base map supplied by the Environment Agency.

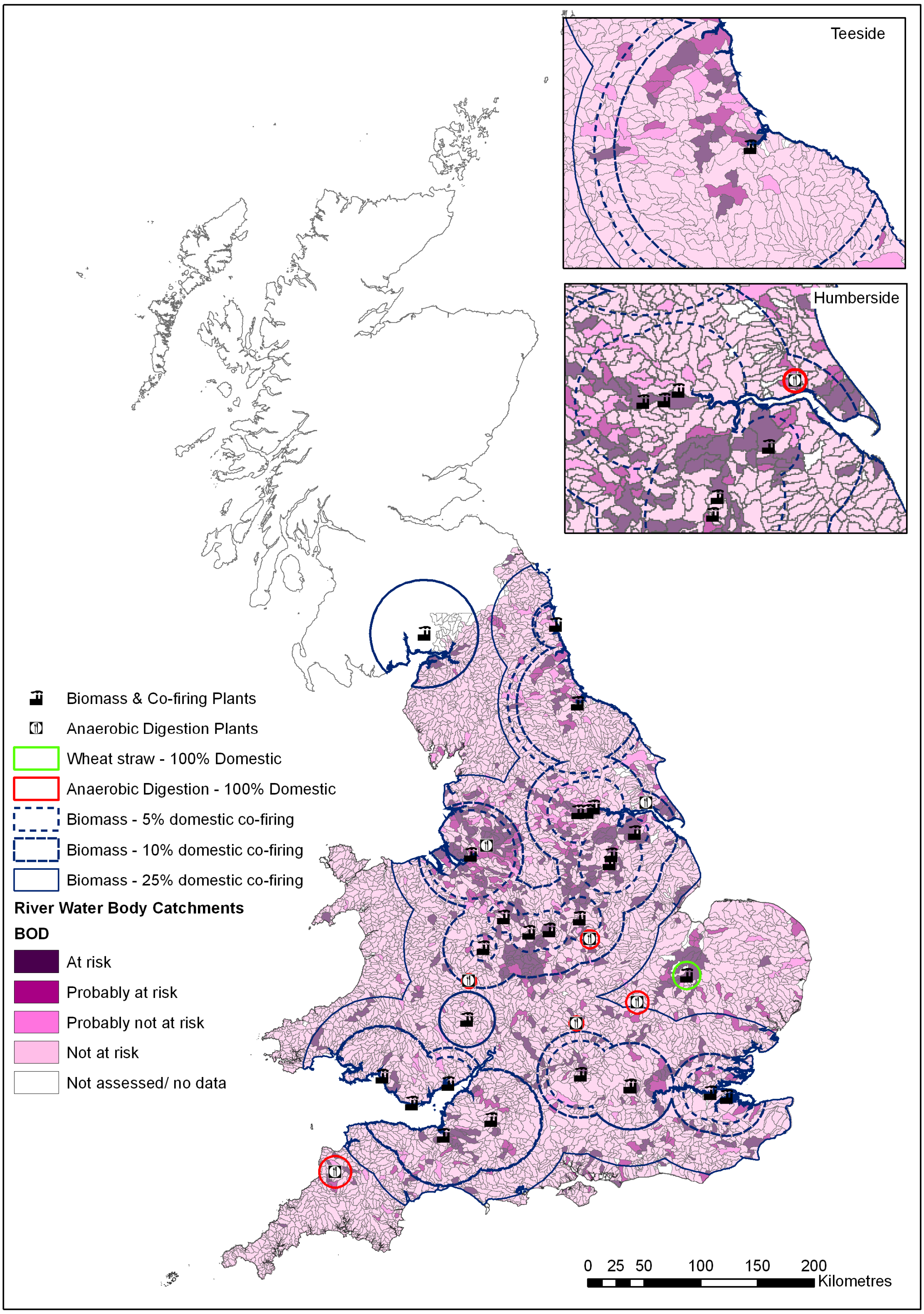


Figure 29 Scenario map for 2010 indicating feedstock supply areas for all bioenergy facilities and how these relate to rivers with current BOD issues. Base map supplied by the Environment Agency.

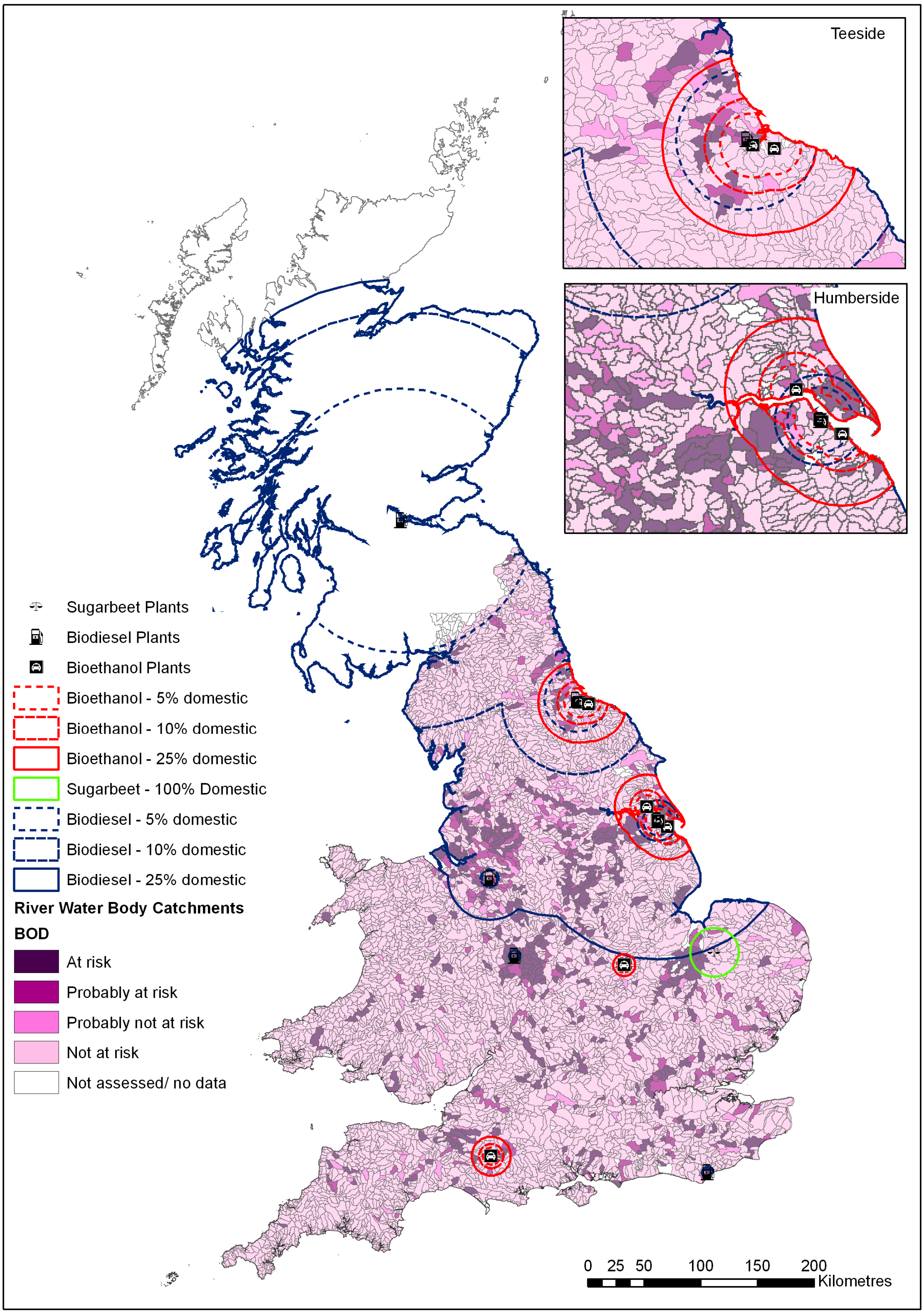


Figure 30 Scenario map for 2010 indicating feedstock supply areas for all biofuel facilities and how these relate to rivers with current BOD issues. Base map supplied by the Environment Agency.

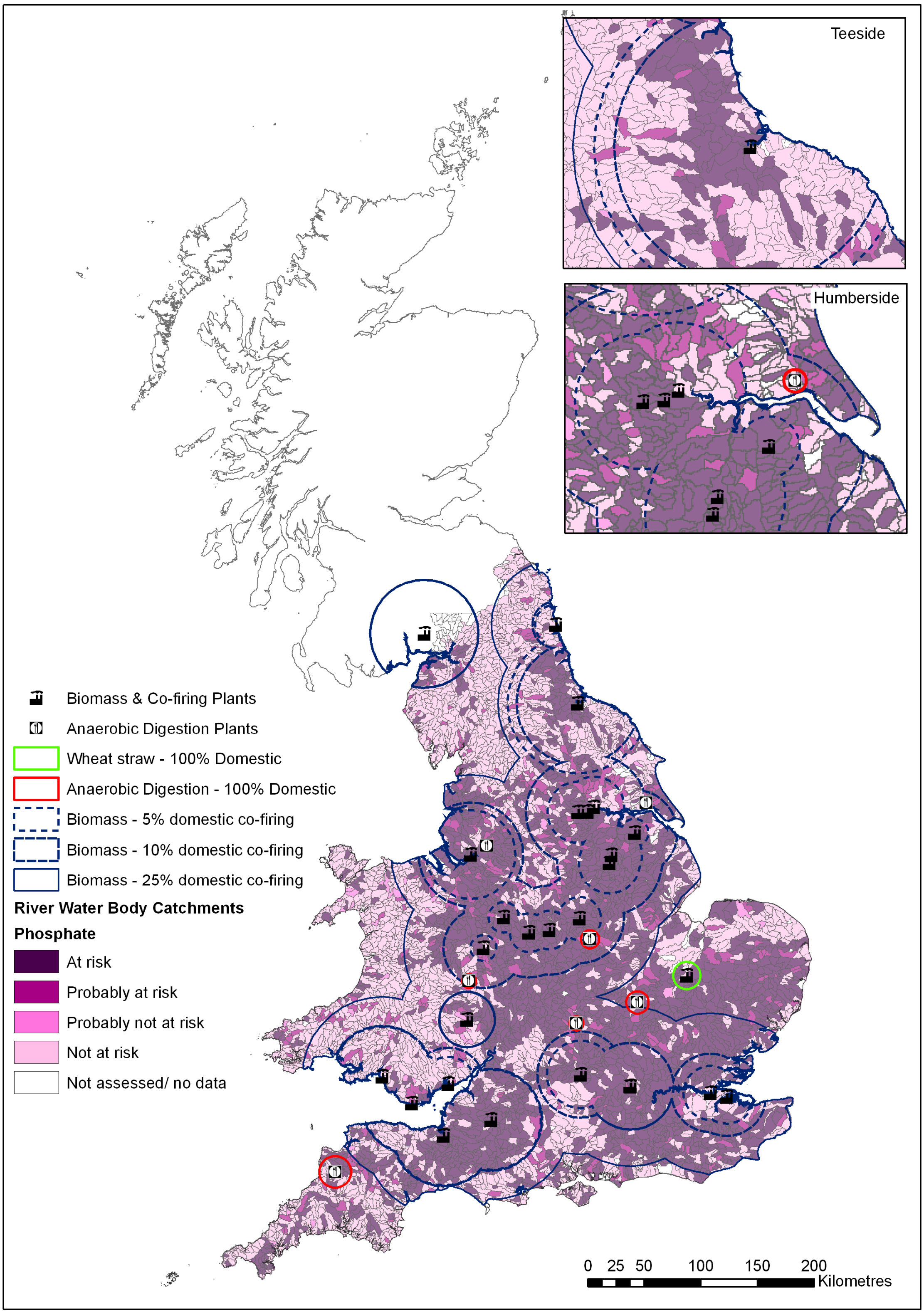


Figure 31 Scenario map for 2010 indicating feedstock supply areas for all bioenergy facilities and how these relate to rivers with current phosphate issues. Base map supplied by the Environment Agency.

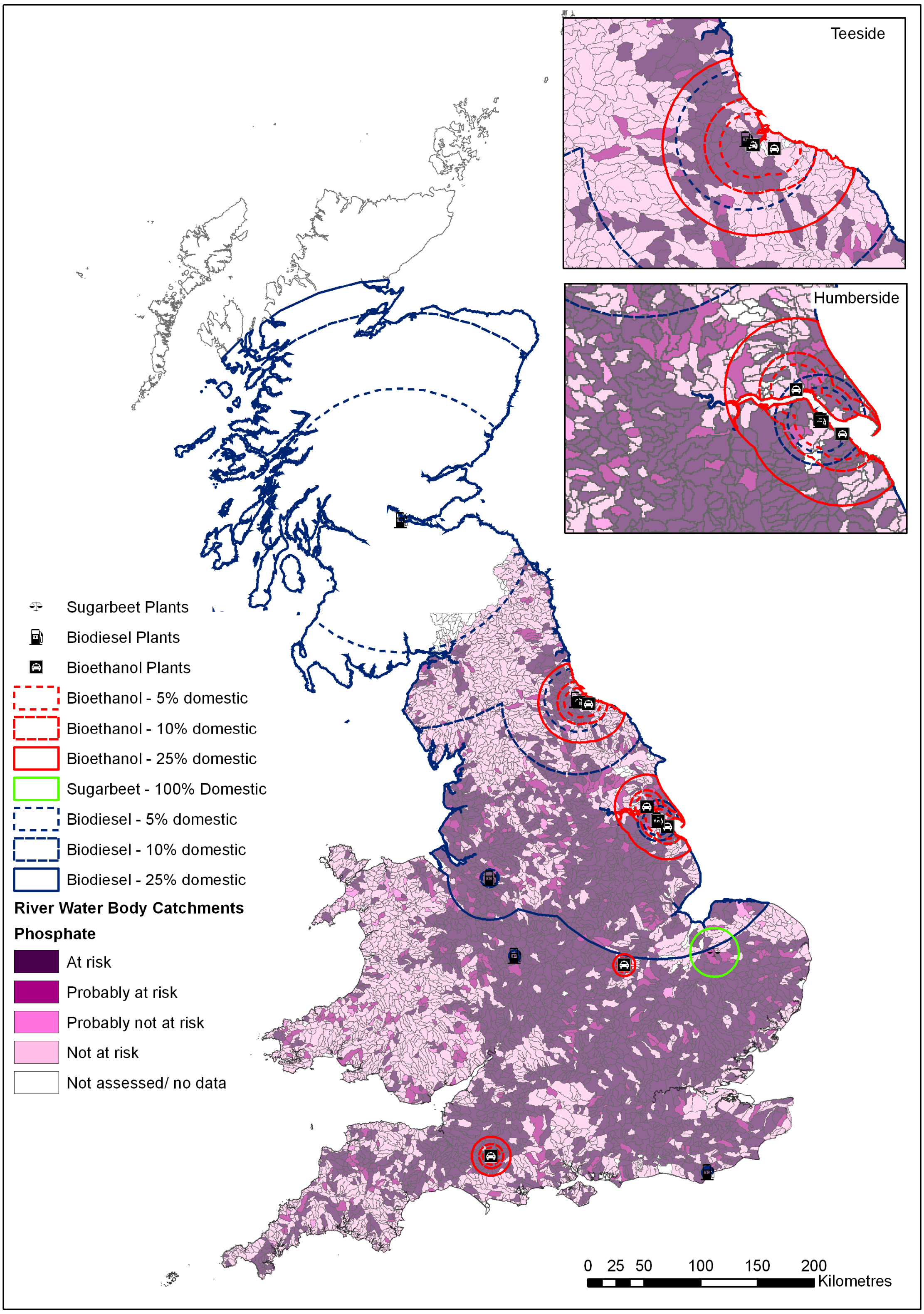


Figure 32 Scenario map for 2010 indicating feedstock supply areas for all biofuel facilities and how these relate to rivers with current phosphate issues. Base map supplied by the Environment Agency.

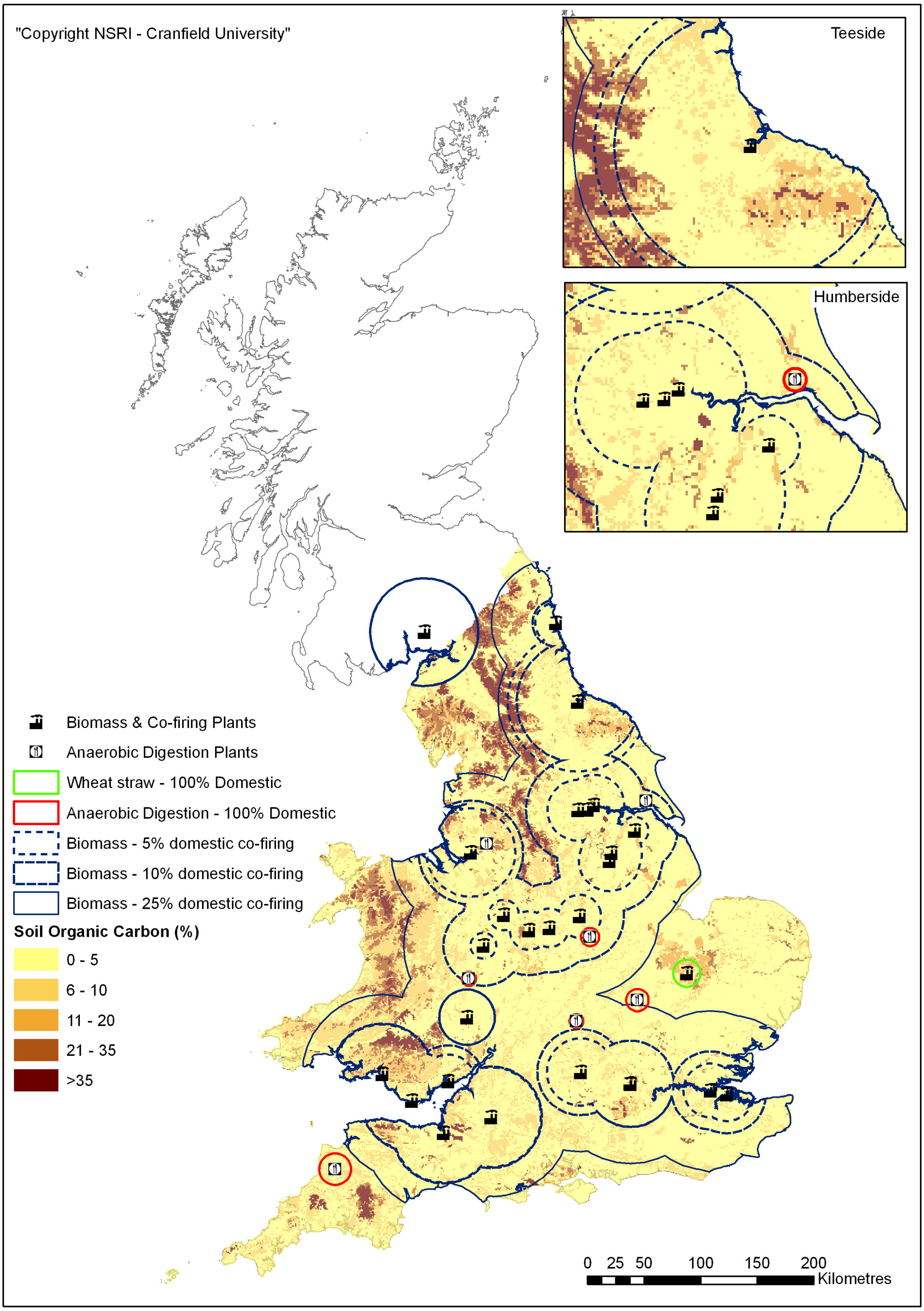


Figure 33 Scenario map for 2010 indicating feedstock supply areas for all bioenergy facilities and how these relate to soil carbon content. Base map supplied by the Environment Agency under licence from Cranfield University.

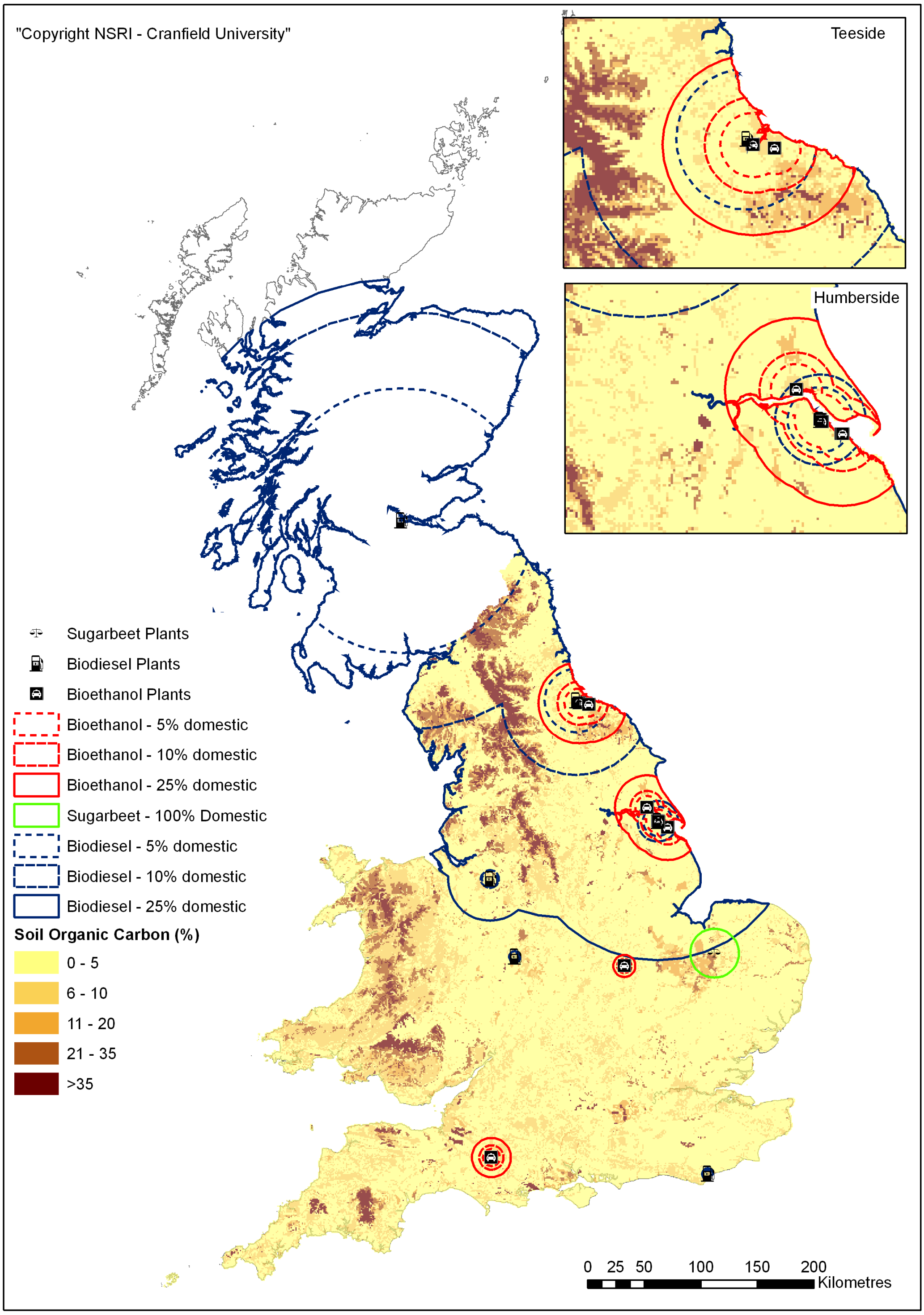


Figure 34 Scenario map for 2010 indicating feedstock supply areas for all biofuel facilities and how these relate to soil carbon content. Base map supplied by the Environment Agency under licence from Cranfield University.

3 Analysis and discussion

The production and utilisation of biomass for bioenergy purposes can have beneficial, detrimental or neutral effects on the environment. This section aims to highlight the environmental impacts of bioenergy production and, with reference to the scale and location of bioenergy facilities described earlier, highlight how these may impinge upon areas of Environment Agency interest.

3.1 Introduction

The land management practices for bioenergy production are essentially standard farming and forestry practices. A good summary of the underlying regulatory requirements is given in Annex III and IV of EC Council Regulation 1782/2003. The relevant aspects are listed in Appendix 1. Compliance is achieved through national legislation for the UK Good Agricultural and Environmental Conditions (GAEC) whilst guidance is provided by Codes of Practice. Failure to comply results in support funding under the Single Farm Payment (SPS) scheme being withheld.

The location of processing plants is generally a compromise between the logistical requirements for the efficient operation of the plant (transport links, grid connections, quay access and so on) and the logistics of feedstock supply. The plant locations on the maps above are a diagrammatic expression of the outcome of this compromise. The final outcome will depend on the interaction of many of the above factors; legislative pressure, soil type, environmental risks, crop profitability, agronomic expertise, new equipment costs and investment, and above all the attractiveness of the market 'pull' for the bioenergy.

3.2 Description of scenario maps

Biodiesel production

Domestic feedstocks for the production of biodiesel are limited to tallow, RVO and oilseed rape, and all three feedstocks (together with imported oils) are used in the UK biodiesel industry. Information on the location, capacity and feedstock use of existing and planned biodiesel facilities was provided by AEA (Bates *et al.,* 2008) and these were shown in Figure 1. In our scenario maps for 2010 we have mapped only OSR production and the plants potentially using OSR in this period. Since we started this report, D1 Oils has announced that it is ceasing production at its Bromborough and Teeside plants, so we have excluded these plants from the 2010 scenario maps and subsequent analysis.

The biodiesel scenario maps clearly show the limitations on increasing the proportion of domestically produced OSR in biodiesel production, especially in areas where OSR is not grown extensively. The planned Ineos plant in Scotland was located in such an area, with production of OSR limited to the Eastern fringes of Scotland and Northern England. Commensurate with this disparate distribution, the buffer areas required to source sufficient OSR are correspondingly large, especially when assuming the plant is running at full capacity and using 25 per cent domestic feedstock. At half capacity, and assuming 25 per cent of the feedstock is domestically sourced, there is considerable overlap between the supply zones for the Grangemouth and Teeside plants, which makes the supply zones required to satisfy demand considerably larger. At full capacity, the supply zones increase further and there is considerable overlap between the requirements for the Teeside plant and the planned Grangemouth plants with facilities at Humberside and Cheshire.

At the full capacity scenario and assuming 25 per cent of feedstock is sourced domestically and all planned facilities are built (and there are no closures), a large proportion of the UK production of OSR will be diverted to biodiesel production. As OSR production is already closely balanced to demand under current cropping patterns and a high level of feedstock requirement, with only small export surpluses each year, implementation of these scenarios would use a significant proportion of the UK OSR cropped area. This would have implications for the production of OSR for food and for other industrial purposes in the UK (and abroad). Intensification of production, through tightening of rotations and growing OSR on previously set aside land close to areas of demand could, at least theoretically, help increase supply, but could have significant agronomic and environmental implications which are discussed further in section 4.3. Equivalence trading, particularly within the EU, may offset some of these impacts. Under this arrangement, 1,000 tonnes of OSR sold for fuel production in the UK could be 'swapped' on the books of a company operating in two countries for 1,000 tonnes sold for food. The UK OSR can then be crushed for food oil, whilst the swapped 1,000 tonnes is made into biodiesel in say, Germany.

Other UK feedstocks for the production of biodiesel are tallow and RVO and utilisation of these 'waste' products could reduce the pressures on land for oilseed rape production. Dale *et al.*, (2008) suggest that the amount of tallow available in the UK and Ireland is circa 250 kt per annum. Tallow utilisation is already at capacity so we see no further expansion of the utilisation of tallow for biodiesel by 2010 beyond that which is already used, without impacting upon existing industrial uses for this resource such as in the oleochemical and personal care markets. The British Association for Biofuels and Oils (BABFO) suggests there is a potential resource of around 100,000 tonnes of RVO available per annum in the UK although it is unclear how much of this is collected. Several small- and medium-scale producers across the UK are already using RVO for biodiesel production as shown in Figure 1. The first figures of monthly production (April-May 2008) from the Renewable Fuels Agency (RFA, 2008b) give a figure of 3.2 per cent for biodiesel supplies sourced from UK recycled vegetable oil and less than 1 per cent from UK tallow (2.81 and 0.35 million litres respectively). Supplies of RVO are dispersed and economic collection can be considered service for VO users.

Bioethanol production

At the time of writing this report, there was only one bioethanol plant in the UK, situated in Wissington, Norfolk. The feedstock supply issues for this plant are interesting since theoretically, whilst demand for bioethanol could be met by using 700,000 t of sugar beet from an area of 1,458km^2 around the Wissington area as shown in Figure 16, the reality is that bioethanol can be produced from any of the sugar beet going into the Wissington plant, so the supply area is actually around 7,850km^2. The production of bioethanol at Wissington was initiated to provide a market for the sugar from UK surplus C quota beet which, due to sugar sector reforms, was unable to be traded on world sugar markets. Quotas for C quota beet production were held throughout England, but the equivalent tonnage to C quota beet grown for example in Nottinghamshire can be swapped for an equivalent tonnage destined for Wissington. The source area for bioethanol production for Wissington is more correctly that which supplies the whole of Wissington intake.

A number of bioethanol from wheat facilities are planned to come on line for 2010, with three planned for Teeside, three on Humberside and one each in Corby and Somerset. Assuming all current production is diverted to bioethanol production in the vicinity of these plants, that all are operating at full capacity and assuming 5 per cent, 10 per cent and 25 per cent of the feedstock capacity for the plant is met by domestic production, the areas theoretically required for supplying each plant are reasonably small compared to OSR as wheat is the predominant crop area within existing rotations. In reality however, the existing milling and starch industries are already located in areas of high production and for the Teesside, Humberside and Corby plants competition from existing markets in and around these supply zones will mean that the feedstock will probably need to be sourced from a greater area. The planned Roquette plant at Corby is a prime example of this; it is close to an ADM flour mill and the Roquette starch plant, so all these plants will draw upon the same feedstock pool. The size of these conflicting markets, and the economic incentives to supply these plants, will have a direct effect on feedstock catchment areas due to competition between food, fuel and industrial crops.

The intensification of wheat production around these areas may help reduce some of the competition arising in an area from using the resource for food, industrial and fuel needs. This could, theoretically, result from bringing previously set aside land back into production, although the suitability for this will vary from area to area and depend upon the motivations of the farmers involved. The removal of compulsory set-aside land removed the restrictions imposed on end use of the products, and many farmers may wish to grow wheat for non-specific rather than a dedicated market such as biofuels production. Even before the end of compulsory set-aside, companies like Greenergy stipulated that OSR for biodiesel production should be grown on non set-aside land, presumably because this afforded flexibility in trading the end product to different markets if required. There seems little scope for tightening rotations to increase the number of wheat crops grown since the production of wheat is already optimised on many farms, although continuous wheat crops have been grown at ADAS Boxworth for 40 years and the area has continued to produce acceptable yields. The environmental impacts associated with increased wheat and OSR cropping for biofuels markets are discussed in section 4.3

Biomass

Biomass can be used in both co-firing and dedicated installations. Whilst co-firing can accept a wide range of fuels, dedicated biomass combustion is often limited to one of two key feedstocks. For this reason, we have produced Figure 17, with wood, SRC and Miscanthus as feedstocks, and only plants utilising these feedstocks have been shown in the scenario. The scenarios show either 5 per cent, 10 per cent or 25 per cent utilisation of domestic biomass (SRC, wood, Miscanthus) for co-firing and 100 per cent biomass utilisation for dedicated schemes since these figures are broadly representative of the current feedstock supply situation.

The scenario maps clearly show the constraints towards increasing the amount of domestic biomass used in co-firing applications.

The biomass maps clearly show the constraints to further uptake of biomass fuels in the UK, as the 25 per cent total use from domestic biomass catchment covers most of England and Wales.

Anaerobic digestion

AD plants can be classified as being either farm-based AD (using livestock slurries and manures) or centralised AD (using both livestock slurries and the organic fraction of municipal solid waste (MSW)). There are examples of both facilities in the UK currently and planned for 2010, and these were shown in Figure 2.

Information on the location and energy output of these plants was supplied by AEA (Bates *et al.,* 2008). The scenario maps use the total available GJ in an area from both livestock wastes and from MSW, and the proportion of feedstock from each source could vary accordingly depending upon the location of the AD plant. In our scenario maps we have assumed that all feedstocks for AD plants will be sourced from the immediate locality because both MSW and livestock wastes are bulky and costly to transport.

There are approximately 30 AD plants in the UK scheduled to be in operation by 2010; seven of these are shown in Figure 20. The feedstock supply zone to these plants is generally small at between 20 and 600km^2. The greatest supply area for the Holdsworthy AD plant in Devon reflects the larger energy output of this plant. The locations of these plants are scattered, have no discernable patterning and are not necessarily related to areas of highest feedstock availability.

The scenario map also highlights the huge potential for future expansion of AD in England and Wales based on *existing* livestock waste and MSW production assuming all available feedstock is processed. The areas of greatest potential are located around large urban conurbations such as London, the West Midlands and Merseyside/Manchester, where organic MSW fractions are available, and also in more rural areas towards the west of England and Wales where dairy livestock production is prevalent. This area includes the South West, Northern Cumbria and West Wales. However, given the range of scales at which AD can be employed; it is difficult to rule out other areas.

AEA suggested that the development of centralised AD be the focus of planning to 2010 subject to adequate grant support being available because, as a previous report (Mistry and Misselbrook, 2005) showed, these plants are not economically viable without financial assistance. Under an increased support for bioenergy scenario, AEA suggests a further 10MWe be planned, and with an increased focus on electricity and heat, a further 45MWe could be developed. The environmental constraints involved in siting AD plants, and utilisation of the digestate product produced, may limit the areas where these plants could be located in the future.

3.3 Environmental effects of bioenergy production and use in 2010 under various scenarios

In the following sections we describe the effects of bioenergy production on water, land and air. This is followed by an analysis of the environmental scenario maps derived in this work. We then describe the effects on each of these scenarios of growing crops for bioenergy or the utilisation of wastes for anaerobic digestion.

3.3.1 Water

Introduction

Farming accounts for approximately 60 per cent of nitrates, 25 per cent of phosphorous and 70 per cent of sediments found in surface water supplies in England and Wales (DEFRA, 2007f). Excess nutrients can adversely affect both the quality and biodiversity of water courses, and thus reduction of levels is desirable.

Two pieces of legislation affect the quality of water in the UK: the EU Nitrates Directive and the EU Water Framework Directive (WFD). In an attempt to control nitrate pollution in England and Wales, a number of nitrate vulnerable zones have been identified in which a series of current action programme rules apply. These include the recommendation that the quantity of nitrogen applied to each field should not exceed the crop requirement, and should take into account existing soil nitrogen levels. Despite introduction of the NVZ action programme, a Defra report (ADAS, 2007) has highlighted that nitrate concentrations are still high in many areas and in some cases have increased. This has lead to proposals for increasing NVZ coverage from 55 per cent of England to 70 per cent, alongside further reforms of the NVZ rules (Defra, 2007g). Both the WFD and NVZ rules are included in the broader Catchment Sensitive Farming voluntary initiative, which aims to reduce water pollution from agriculture. This scheme considers the wider effect of farming on water quality and encompasses both the nitrates directive and water framework directive regulations, including pesticides, herbicides, soil erosion and nitrates in 40 catchments within England and Wales.

Effect of AD plants on water quality

Summary of environmental issues relevant to the Environment Agency:

- Microbial water quality can improve where AD digestate is spread rather than livestock wastes. A study by Chesshire and Ferry (2006) showed that mesophilic digestion at 37°C resulted in a 10- to 100-fold decrease in faecal indicator organisms (FIO), and thermophilic digestion at 50 °C resulted in a 10,000-fold decrease. Incorporation of a pasteurisation phase (as would be required when treating food wastes) resulted in low or undetectable levels of FIO. There was little increase in FIO numbers during post-treatment storage of the digestate.

- Chemical oxygen demand (COD) and biological oxygen demand (BOD) are reduced compared to untreated slurry. Hobson *et al.* (quoted in FEC, 2003), quoted reductions in BOD of 75 per cent for pig slurry, 55 per cent for cattle slurry and 80 per cent for poultry slurry. COD was reduced 50 per cent for pig slurry, 35 per cent for cattle slurry and 50 per cent for poultry slurry.

- There is no significant difference in nutrient loading since total nitrogen and phosphate contents are the same as pre-digested materials.

- Separation of solids and liquid digestate can increase infiltration into the land if applied appropriately, and can reduce runoff to water courses.

- AD can result in an increase in the release of phosphate from organic forms, resulting in an increase in the water soluble phosphorus form. Such results were inconsistent in a study of farm scale AD plants and can vary by site, but have been shown to increase significantly elsewhere (Smith *et al.*, 2007). An increase in water soluble phosphorus can increase the vulnerability of phosphate loss via run off or by-pass flow.

- AD has been shown to result in the conversion of organic nitrogen in the feedstock to the more available ammonium form (average 26 per cent increase), but this is variable and can change according to retention time, bacterial growth and carbon to nitrogen ratio of the substrate. Conversion of ammonium to nitrate in the soil can result in losses to surface and ground surface waters.

- There is conflicting evidence as to whether AD digestate can act as a better fertiliser source than livestock manures (Smith *et al.*, 2007).

- Increasing the MSW feedstock content of an AD plant can result in an increased availability of nitrates in the digestate and hence potential for runoff problems.

Analysis of environmental issues based on 2010 scenarios:

The spreading of AD digestate to land in place of manures and slurries can have a beneficial effect on water quality through the reduction of FIO, BOD and COD. These benefits would be most apparent in areas of large manure production where there is no option other than spreading to land and where there are currently issues with these parameters.

The increased availability of both ammonia and phosphate in digestate compared to slurries and manures, and their potential detrimental effect on ground water and surface water runoff, requires careful planning of storage and application methods to ensure that environmental risks are minimised.

This will be particularly important around the existing Holdsworthy plant in Devon, and the South Shropshire and Hull plants which are located in areas of high phosphorous losses and high ammonium emissions.

Effect of annual biofuel crop production on water quality

Summary of environmental issues relevant to the Environment Agency:

- Pesticide regulations as enshrined in Directive 91/414 are currently under review, but 91/414 has supported the on-going review of active substances and the revocation of use of those presenting unacceptable environmental burdens. Triazine herbicide use has been revoked and June 2009 saw an end to the use of isoproturon (IPU), one of the most widely used herbicides in the cereal sector (HSE, 2007). The main areas of cereals shown would previously have been expected to be sources of water contamination from IPU. The continuing review process and possible regulatory overhaul should be expected to reduce pesticide loads from even the most intensively farmed bioenergy producing areas.

- The use of inorganic fertiliser for bioenergy crops is largely focused on arable crops. Nitrate regulations, codes of practice and fertiliser recommendation standards are aimed at efficient use of nutrients and the avoidance of loss to ground water.

- Soil erosion possibly associated with winter harvesting operations could lead to the deposition of particulates and dissolved nutrients in watercourses.

- Turley *et al.,* (2005) reviewed the potential impact of replacement of natural regeneration set-aside with wheat or oilseed rape crops. Despite the increased inputs of fertiliser and pesticides, impacts on water quality are unclear – the effect of nitrate leaching was not clear-cut as set-aside has high residual nitrogen levels which are subject to loss over winter, whilst on the other hand, there may be a small increase in soil erosion and phosphate loss.

- Typical nitrate losses on free draining soil following oilseed rape are 70 kg/ha, 50 kg/ha for cereals and 30 kg/ha for sugar beet. This compares to 100 kg/ha for potatoes and 150 kg/ha for rotational set-aside (Lord *et al.,* 1999). How much leaches is dependent upon the over winter rainfall and soil type.

Analysis of environmental issues based on 2010 scenarios:

It is unlikely that the environmental impact of cultivation of annual arable biofuel crops will differ greatly, at least in the 2010 timeframe investigated in this project, from existing counterparts. Initiation of carbon assurance schemes as part of the RTFO from 2010 and the introduction of sustainability assurance from 2011 may provide some incentive for altered farm management decisions, if a farmer is growing for a dedicated market and there are sufficient economic incentives to do so. However, with the current high price of both OSR and wheat, farmers may choose to trade on spot markets rather than commit to long-term specific contracts, and so avoid changing management practices to suit a particular market.

Larger environmental impacts are expected if production is intensified, either through utilisation of previously set-aside land, or through tightening of rotations. Neither may be completely due to increased demand for feedstocks for biofuels in the UK. High commodity prices are sufficient to encourage increased planting regardless of the end market. Tightening of rotations to increase production of a specific crop may have detrimental impacts on yield due to disease build up and nutrient depletion. Also, to maintain yields increased inputs of both pesticides and fertilisers can be required with possible implications for water quality, although effective pesticide review procedures should minimise this.

Effect of producing perennial energy crops on water quality

Summary of environmental issues relevant to the Environment Agency:

- A study on SRC supply to the ARBRE project (Hilton *et al.*, 2005) showed nitrate-N concentrations declined rapidly in the winter following SRC establishment and continued to decline during the second and third years after planting. Levels were generally below 1 mg/l 18 months after planting, much lower than would be expected from arable land, 30 times lower than that recorded at the start of the study and a factor of ten lower than the EC limit.

- Both SRC and Miscanthus take up heavy metals in the soil and concentrate them in biomass. Therefore they can be used for bioremediation of contaminated soils and can be useful crops for biosolid application as neither crop enters the food chain. However, studies as part of the ARBRE project showed increased nitrate N where slurry was applied through the first winter, peaking at over 80mg/l with the pattern repeated during the following two winters with peaks of 176mg/l and 248mg/l respectively.

- Mature perennial crops sequester nutrients over winter in their rhizomes and root systems so that nutrient leaching is less than for arable crops or grassland. The extensive roots also help uptake of nutrients from the soil. In Miscanthus, mobilisation of nutrients from the roots to the stem in the spring means no additional nitrogen is needed.

- High-yielding SRC and Miscanthus crops will have a higher water uptake than conventional crops for growth (10 to 20 per cent greater, for example (Hilton *et al.,* 2005)) so the scope for use in flood or drought prone catchments needs to be evaluated. The year-round presence of soil stabilising perennial vegetation and its impact on water run-off or retention could also effect catchment management.

Analysis of environmental issues based on 2010 scenarios:

After the establishment phase, the relatively low inputs required by perennial biomass crops are potential environmental benefits from growing the crops. Similarly, their use for bioremediation offers scope for use on a range of reclaimed sites. Indeed, some interest is being expressed in the use of these crops in integrated waste management processes. With increasing costs of fertilisers, the ash from biomass combustion is an increasingly valuable by-product. Those planning biomass production on sites where there is a risk of bio-accumulation of contaminants need to be aware of the mass balance and movement of elements in the crop production and utilisation processes, with appropriate quality audit and testing procedures. Plants that act as bio-accumulators when burned may produce ash and flue gases containing elements accumulated from the soil. Monitoring and appropriate disposal systems are therefore needed.

High yields of any crops require higher water consumption. Concerns over higher water use of biomass crops need to be tempered with acknowledgment that the increased need for higher yields over the next 30 to 40 years will push up crop water demand generally. The impact of larger scale plantings than those achieved hitherto needs to be evaluated in both drought- and flood-prone areas.

Perennial biomass crops provide benefits from carbon accrual relative to arable cropping on the same land. However, the need to harvest the crop after sequestration of nutrients back into the roots and rhizomes means field operations are carried out in winter. Once strong root networks are established, the plants themselves provide a significant load carrying root mat that helps support tractors and harvesting machinery. Good practice in the management of field operations should ensure the soil management requirements of GAEC are complied with.

3.3.2 Air

Introduction

Air pollution can occur from both biomass production and utilisation and have detrimental effects on both the environment and human health over both the short and longer terms. The National Air Quality Standards are indicators which determine the levels at which a particular contaminant becomes a health risk and over how many days this occurs. The pollutants included within this indicator are ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide and particles (PM_{10}). Crucially, as well as the effects on human health, several of these pollutants are potent greenhouse gases (GHGs). The release of greenhouse gases into the atmosphere is a worldwide concern and the Kyoto Protocol requires that the UK reduces its GHG emissions by 20 per cent. Agriculture and forestry are the second largest source of greenhouse gases, together accounting for seven per cent of emissions. Nitrous oxide is the greatest problem, accounting for two-thirds of emissions on a carbon dioxide equivalence basis, with methane (as CO_2 equivalents) accounting for almost all of the remaining third. Carbon dioxide accounts for only one per cent of emissions. Nitrous oxide emissions result from soil processes and the production and application of inorganic fertilisers and manures. Methane results from the natural decomposition of organic waste, or from ruminant digestion. Ammonia emissions arise from livestock manure and slurry management.

Air quality from combustion is regulated under a number of acts including the Clean Air Act of 1993, the large combustion plants directive and Integrated Pollution Prevention and Control (IPCC) guidelines. Although bio-energy production essentially recycles atmospheric carbon dioxide in a cycle time of just a few years, carbon dioxide is nevertheless returned to the atmosphere rather than removed through long-term sequestration on a semi-permanent basis. The primary driver for a reduction in GHG emissions from agricultural production of bioenergy crops arises from the introduction of carbon and sustainability standards as part of the RTFO.

Effect of AD plants on air quality

Summary of environmental issues relevant to the Environment Agency:

- The AD process can significantly reduce odour in the final product. The Farm Energy Centre quote odour levels of 223 odour units/m^3 for treated slurry and 1,100 odour units/m^3 for untreated slurry. The reduction of odour is due to the reduction of volatile fatty acids by around 93 per cent during the process.

- Odours for the site operations result from material brought and stored at the site, freshly discharged feedstock and gas leakage or uncontrolled venting.

- Emissions of oxides of nitrogen and sulphur from AD plants can be significantly reduced through abatement strategies. Emissions of nitrogen oxides were 11.2µg/s without abatement and 0.74µg/s with abatement. ADAS studies of AD plants show emissions of sulphur oxides were 1.9µg/s without abatement, and 0.34µg/s with abatement.

- The AD process results in an increase in ammonium nitrogen over slurry (Smith *et al.,* 2007), which increases the potential for ammonium losses to the atmosphere and the potential to adversely affect sensitive habitats upon deposition. Thus, AD digestate should be kept covered to reduce emissions of ammonia and residual methane prior to spreading.

- Ease of spreading is facilitated by separation of the solid and liquid digestate phases. Careful spreading can help mitigate the potential GHG emissions resulting from digestate use – this has been shown to be reduced significantly through either direct injection or through umbilical spreading through dribble bars.

Analysis of environmental issues based on 2010 scenarios:

Air quality benefits accruing from the deployment of AD technology mainly arise through the decrease in odour on spreading the digestate versus spreading slurries and manures. As such improvements are highly dependent upon the locality, the locations of such improvements are difficult to map in a study such as this. Needless to say, we believe that the greatest improvements in local air quality with regard to odour will arise in areas where there are already odour problems associated with spreading livestock wastes and this may prove especially beneficial where statuary nuisance abatement orders are in place. This applies to both existing and planned facilities.

The potential for increased losses of ammonia from digestate storage and spreading requires careful consideration, both for its effects on fragile ecosystems and as a potent GHG. The effects of ammonium deposition are more of a local issue whilst as a GHG, the issue is national and global. The reduction of ammonia in both cases is desirable. Careful consideration of the siting of planned plants should seek to minimise potential biodiversity implications from increased ammonia emissions (and subsequent deposition) by seeking to site planned AD plants away from areas such as Sites of Special Scientific Interest, National Parks and other important habitats. Education of landowners as to how to best use digestate to minimise airborne ammonia losses could be beneficial in this regard, especially if the digestate is to be used near sensitive areas. This will become especially important when the PAS110 digestate standard is introduced, which will allow digestate to be sold and utilised as for any other fertiliser product. Ammonia losses have the potential to be greater from the spreading of digestate from centralised anaerobic digestion (CAD) rather than farm-based digesters. This is due to the greater potential for conversion of nitrogenous compounds to ammonia in high nitrogen/low ammonia feedstocks such as organic MSW than in already high ammonia materials such as slurries.

More work is needed to quantify the differences in ammonia losses to air as a result of spreading digestate as opposed to spreading livestock wastes. Given that AEA has suggested that CAD plants with a capacity of between 10 and 45MWe may be planned within the 2010 timeframe depending upon the level of policy and economic support for such schemes, the Environment Agency needs to be aware of the environmental implications, locally, nationally and internationally, on air quality during the planning process for these plants and ensure sufficient mitigation measures are introduced

Effect of producing annual biofuel crops on air quality

Summary of environmental issues relevant to the Environment Agency:

- Over 50 per cent of the GHG cost of making biodiesel from OSR and bioethanol from wheat is associated with the growth and harvesting of the crops (Elsayed *et al.*, 2003).
- The largest effect on the GHG balance is caused by the utilisation of fertiliser nitrogen, which accounts for approximately 90 per cent of the GHG cost of producing an oilseed rape crop for biodiesel and 80 per cent of the GHG cost of producing a wheat crop for bioethanol (Woods *et al.,* 2008).
- Over 60 per cent of the growing costs of producing a crop for ethanol are due to the indirect emissions resulting from the production of the fertiliser nitrogen and direct emissions resulting from its use.
- Considerable uncertainty surrounds the measurement of GHG impacts of crop production, especially surrounding the emissions of nitrous oxide.
- Twenty per cent of the total GHG cost of producing a crop is due to on-farm fuel use, seed supply and pesticide inputs (Woods *et al.,* 2008).

Analysis of environmental issues based on 2010 scenarios:

The predominant effects of growing annual crops for biofuel markets on air pollution relate to emissions of GHG. Emissions of any GHG are almost irrelevant on a local scale, as their real importance lies in their contribution to the national and global reductions and this is the focus of this section of the report.

There are likely to be few differences in air quality (GHG emissions) as a result of the production of annual crops for biofuels. With volatile commodity prices and no clear buying signals from the biofuel sector (higher prices), growers may chose to manage their crops in the conventional food production way, choosing the food or fuel market once the crop is harvested. This would mean that farmers may not seek to fulfil anything other than general market requirements for their crop. Although the introduction of carbon and sustainability assurance as part of the RTFO provides an incentive for biofuel producers to reduce the GHG cost of their biofuel, these improvements need to be encouraged throughout the supply chain. Without appropriate knowledge of how changes in agronomic practices can affect the final carbon balance of the biofuel and the introduction of specific premia to change practices, growers are unlikely to make changes spontaneously.

Intensification of land for biofuel production (or any tillage crop) could lead to greater GHG emissions on a national basis, particularly as a result of increasing nitrous oxide emissions arising through fertiliser nitrogen use, and the cultivation of permanent set-aside land has the potential to release sequestered carbon into the atmosphere.

Increased cropping of wheat and OSR crops will lead to the increased production of straw. Whilst this could be incorporated into the ground as a fertiliser source and soil conditioner (as discussed in Section 3.1.1), the greatest impact arises through the combustion of straw as already practiced at Ely. Assuming 1 tonne of wheat straw sequesters 1.467 tonnes of carbon dioxide equivalents, a baled yield of 4 tonnes of straw (*c*.1 ha) is equivalent to 2.4 tonnes of coal, saving 5,468kg carbon dioxide equivalents emissions (in effect sequestration by proxy). In comparison, incorporation of straws into soil results in only 183kg CO_2e/ha/yr/tonne (12.5 per cent) sequestered into soil organic carbon (SOC). Given that soil carbon sequestration is limited and requires permanent practice to be maintained, increased utilisation of straw for combustion would have positive effects on GHG emissions. The positive benefits of straw combustion on GHG balances must however be offset against the need for increased fertiliser inputs for a crop where straws have not been incorporated and the GHG effects this results in.

Effect of perennial biomass production and combustion on air quality

Summary of environmental issues relevant to the Environment Agency:

- If burned in open air, some biomass feedstocks can emit relatively high levels of nitrogen oxides (because of the high nitrogen content of the plant material), carbon dioxide and particulates. If biomass is grown on contaminated land, conventional combustion of biomass may release toxins such as dioxins and heavy metals (Royal Commission on Environmental Pollution, 2004). However, the combustion of biomass results in fewer nitrogen oxide and sulphur dioxide emissions than fossil fuel systems (Bullard and Metcalfe, 2001).

- Dust exposure at wood storage facilities can be as result of fine wood particles and dust, and fungal spores. The storage conditions and the unloading and handling environments affect the levels produced and operator exposure. Garstang *et al.* (2002) recorded no evidence of significant health risk from monitoring studies of dust and fungal spores at large scale wood stores, but noted Swedish experience suggesting measures should be taken to minimise exposure risk.

- Growing large areas of SRC willow could result in increased levels of volatile organic compounds being released to the atmosphere. Willow is a high emitter of isoprene. It is estimated that a doubling of willow biomass could increase the national emissions of isoprene by 10 per cent (Air Quality Expert Group, 2007).

- Combustion of treated wood can result in the release of halogenated compounds, dioxins, furans, polycyclic aromatic hydrocarbons (PAHs) and heavy metals with resulting implications for health. Treated waste should therefore be burned in a Waste Incineration Directive (WID)-compliant facility to reduce these risks.

Analysis of environmental issues based on 2010 scenarios:

Perennial biomass crops have risen in popularity due to GHG benefits, their low inputs and the favourable energy and carbon balances. Spink and Britt (1998) reported energy ratios of 30 or more for perennial biomass crops, compared to ratios between 8 and 9 for cereal crops and between 3 and 5 for various OSR crops. Bullard and Metcalfe (2001) quote carbon ratios for reed canary grass, switchgrass and Miscanthus of 30, 41, and 53 respectively. Perennial biomass crops are environmentally beneficial in air quality terms provided crop/fuel handling procedures safeguard operators. Best Available Technologies are used to contain nitrogen oxides, sulphur dioxide, hydrochloric acid, and compounds originating from treated woods are burned in WID-compliant plants.

There are, however, some negative aspects of biomass use on air quality. Assessments by AEA (2007) show that increasing the contribution from small-scale wood-fuelled biomass combustion to meet energy requirements in London under the London Energy Partnership scenarios may lead to a potentially substantial increase in nitrogen dioxide and particulate matter concentrations. The potential impact of use in densely populated urban environments could be reduced if biomass combustion was limited to larger district heating or CHP schemes outside the centre of London. For these units it would be cost effective to install efficient abatement equipment to reduce the emissions of particulate matter and oxides of nitrogen.

3.3 Land

Introduction

Land use which leads to erosion or damaged soil not only falls short of GAEC and would jeopardise SPS payment, it is also counter-productive in terms of the production of high-yielding efficient bioenergy crops. Erosion can be very severe on light sands and organic soils where exposed dry soils can blow away; the Fens, Vale of York and Breckland can all see significant amounts of soil moved by wind. Sandy and silt soils on an incline can show free movement of soil in surface run-off water, leading to gully formation in severe cases where terracing or vegetation offer no protection.

Clay soils are less vulnerable to erosion, and in some situations have been used for perennial biomass cropping as the heavier soil texture increases arable cultivation costs. The harvesting of biomass crops in wet conditions on such soils could fail to meet GAEC. Using any machinery in wet winter conditions may be deemed inappropriate, and soil structure could be damaged - although well-developed root systems of perennial biomass crops help carry the weight of machinery. Lighter sandy and organic soils are often used for high value horticultural vegetable crops: salads, leeks, carrots, parsnips, potatoes and so on, with the bioenergy cereals and oilseeds acting as break crops. On the poorer sands such as the Surrey heaths, parts of the Brecklands, Sherwood in Nottinghamshire and parts of the Shropshire sands, scrub and forest are the main use. However, once the land quality is good enough for horticultural use, annual cropping rules out the longer term perennial biomass crops.

Many of the arable soils in the country have some feature which can interact with cropping and bioenergy production. Heavy clays in Essex, the Kent and Sussex Weald, and south-central Midlands have all been used for arable production and move in and out of use depending on crop profitability. The Weald has historically been home to some of the oldest coppicing in the country, and now is home to protected areas of land. The Essex clay farmers were some of the first to use reduced cultivation technology to establish their cereals and as a result were the first to see signs of herbicide resistance. With local markets, perennial biomass may prove attractive to some of these growers.

Effect of AD plants on land quality

Summary of environmental issues relevant to the Environment Agency:

- The solid digestate arising from AD can be used as a soil conditioner. Like any organic amendment to soil it should have a positive effect on soil quality, but as far as we are aware at the time of writing this report, there have been no practical studies on its effect on soil structure, carbon sequestration capacity or effect on GHG emissions from the soil.

- The increase in fertiliser prices makes the utilisation of AD digestate (and slurry) for fertiliser use more attractive economically.

- A Quality Protocol for the production and use of quality outputs from anaerobic digestion of source-segregated biodegradable waste is being developed to simplify the utilisation of digestate on land and facilitate the use of this product as a soil enhancer and use as a fertiliser source in line with RB209 recommendations.

- To avoid an additional nutrient management burden, there needs to be sufficient arable land or grassland (without grazing livestock) in an area to support the utilisation of digestate.

Analysis of environmental issues based on 2010 scenarios:

The incorporation of digestate to land could have beneficial effects in terms of acting as a soil conditioner and increasing soil carbon stores. We are not aware of any work which has been carried out to quantify the effect of using AD digestate as a soil enhancer or, more importantly for this study, comparing it with slurry and manure incorporation, and this is an area in which research would be beneficial.

As with any organic matter addition to the soil, it is likely that effects would be beneficial but reversible if the practice was stopped. Thus unless AD was a long-term solution, any improvements are likely to be short-lived. The lack of research in this area makes it difficult to assess the potential environmental impact of AD compared to slurry and manure spreading under any future scenarios.

Effect of cropping annual biofuel crops on land quality

Summary of environmental issues relevant to the Environment Agency:

- Wheat and OSR pose less of a risk for soil erosion than sugar beet, whilst cultivation of annual crops is more of an issue for soil erosion than perennial crops. But this is an issue for arable crops in general rather than biofuel crops in particular.

- The production of spring-sown cereals and OSR can occasionally lead to soil erosion on vulnerable soils as the ground is exposed during the spring period. Winter-sown cereals and OSR have an adequate root system and ground cover by springtime to mitigate these risks.

- Reduced tillage and no tillage systems can offer considerable benefits in terms of increasing soil organic matter. Bhogal *et al.* (2008) showed that zero tillage can sequester ~1,100kg CO_2e/ha/yr (±660) and reduced tillage can sequester about half that amount. Carbon sequestration is dependent upon continuous practice so is also reversible, and may be reversed by rotational ploughing

- Turley *et al.* (2005) reviewed the benefits of OSR and wheat cropping on biodiversity and showed that OSR can provide a valuable habitat for birds such as skylarks, yellow wagtails, sedge warblers, reed and corn bunting which nest in OSR. Weedy OSR and cereal stubbles can be a valuable habitat for ground nesting birds such as skylarks. Both OSR and wheat have relatively high levels and diversity of invertebrates.

- Straw incorporation can improve soil organic matter. But compared to other materials this is small. Bhogal *et al.,* (2008) estimated that a 6.6t/ha application of wheat straw contained 2.3t/ha of carbon of which only seven per cent was retained in the soil. Maintenance of soil organic matter was dependent upon indefinite continuation of this practice as soil carbon incorporation is reversible and the amount of carbon which can be sequestered in this way is finite.

- Incorporating straw returns some of phosphate and potash to the following crop and thus reduces the costs of buying inorganic sources of these essential nutrients. The value of incorporating straw as a fertiliser source can vary on a site by site basis depending upon the soil type and can depend upon economics. At the time of writing (June 2008), prices for potash and phosphate were almost twice as high as in the previous year. Under such high prices, more farmers may choose to incorporate straw to provide some of the required nutrients and increase their margins.

- Conversion of permanent set-aside or permanent pasture to cropping annual biofuel crops would have detrimental effects in releasing soil organic carbon stores previously built up. The magnitude of such change can be considerable depending upon the time which land had been left fallow and the soil type.

Analysis of environmental issues based on 2010 scenarios:

Cropping of annual crops is one of the most detrimental practices for land quality due to both the intensity and frequency of cultivations regardless of end market, but there is little evidence to suggest that the land quality issues arising from biofuel cropping would differ significantly from traditional uses of these crops.

A map of soil organic carbon reserves is shown in Figures 33 and 34. Most of the existing high soil carbon stocks are associated with the scenic uplands in National Parks and Areas of Outstanding Natural Beauty. Permanent grassland and high organic soils, like the Fens and Somerset levels, are also associated with high carbon. Other than those soils already involved in intensive farming, most of these areas have varying degrees of protection from existing measures. The lack of access and suitability for field work provides perhaps the best and most permanent protection from exploitation.

On better land where feedstocks for biofuel are produced, increased cropping of OSR and wheat would lead to increased production of straw. Straw incorporation into soil can help sequester organic matter although recent increases in inorganic fertiliser prices have made the nutrients in straw increasingly valuable. Any further increase in the amount of straw incorporated into the soil would have beneficial effects but this would only hold up to the equilibrium point carbon sequestration in an arable rotation. The utilisation of straw for combustion as carried out at Ely and planned for Sleaford and Drax would provide an alternative market for the straw and thus in areas surrounding these plants, may not be incorporated. This would result in the reduction in soil organic carbon where it was previously incorporated.

Effect of perennial biomass production on land quality

Summary of environmental issues relevant to the Environment Agency:

- The perennial nature of some biomass crops – SRC and SRF in particular – can contribute positively to the environment with less than annual harvesting. Their contribution in a mixed landscape provides a varied patchwork of habitats for both birds and non-avian wildlife, providing a positive contribution to the aims of Directive 79/409 (see Appendix – Annexes of Regulation 1792/2003).

- Recent global concerns about biofuel production have focused on the loss of natural habitats. In the UK, most bioenergy cropping is likely to be carried out on existing farmed land, so compliance with Directive 92/43 should not be an issue.

- Both Miscanthus and SRC are planted in the spring into bare land. Until established, the ground may be exposed and liable to erosion.

- Soil structure is improved by the presence of perennial crops and the avoidance of the annual cultivation cycle, and strongly developed root mass can help support vehicles.

- Miscanthus and SRC can grow to between four and five metres high and, if not sympathetically planted, can have a significant effect on the appearance of the landscape.

- Miscanthus and SRC are relatively new crops in the UK and their introduction will therefore involve a land change. Introduction onto previously tilled land would increase soil organic matter, while introduction onto previously fallow land would lead to an initial decline in soil organic matter content as the ground was prepared, and then a gradual increase as soil organic matter increased again.

Analysis of environmental issues based on 2010 scenarios:

The cultivation of perennial biomass crops has potentially large and beneficial effects on land quality once established, both in terms of soil quality and biodiversity, given the long-term nature of these crops and the few machinery passes needed to cultivate them. The short-term benefits vary with the land use prior to planting. Reporting on the organic carbon change in first four and a half years of SRC after mature pasture or arable cropping, Hilton *et al*. (2005) noted a loss of 11.02t/ha and a gain of 13.23t/ha respectively.

Despite the potential gains, the significant tonnages sequestered will be lost once land returns to annual cropping. The savings of fossil fuel carbon dioxide emissions from the fuels displaced by the biomass do however represent a net saving of carbon emitted after storage over the epochs.

Conclusions

The developing bioenergy market is likely to have a negligible effect on the UK environment in the timeframe to 2010 considered by this report. This is due to its present small scale, the fact that bioenergy chains are not well established (especially for biomass), the large amount of imports currently used to satisfy demand, and due to the difficulties facing the biofuel industry. This last factor is largely as a result of US trading policies rather than any technical or environmental issues.

Mapped catchment areas for biomass and biofuel plants show there is potential for wide land use to provide this material. It is uncertain at present if and how markets will develop. The first data from the Renewable Fuels Agency show little in the way of sustainability information supporting the first tranche of renewable biofuel submitted under the RTFO[4]. The potential for easier and more reliable sustainability data from domestic production sources will support local production, particularly if economically dissuasive measures are introduced for lack of sustainability data provision for imported material. However, the maps also show the area coverage required to provide 25 per cent of the possible demand is considerable, although for some bioenergy crops – notably SRC and Miscanthus – the national crop area is still very low. There is little prospect for 100 per cent of supply provision (at the demand level as mapped) from domestic sources if imports of adequately sustainable material prove impracticable.

In the short-term (with biofuels derived from food crops) there is likely to be little difference between the environmental impact of feedstock and food production. As commodity crops are traded globally, they move and are traded more freely than say SRC and Miscanthus. Biomass ideally needs to be associated with a plant in the vicinity of the production site; in contrast, once processed, liquid biofuels can be sourced anywhere. The net effect of these differences is that over the coming years as markets develop, the change in biomass production is likely to be a more visible land change than the switch of

[4] The data will be re-reported when the data from blended biofuels have been taken into account.

arable food crops to the biofuel feedstock market. The changes, initially at least, are likely to be more pronounced in the inner circles of the catchments shown on the maps.

Fuel flexibility and the ability to accept multiple feedstocks are desirable for biomass plants as in theory it gives a wider and more flexible supply base. However, as most plants are designed to optimise the performance of specific feedstocks using bespoke fuel feed mechanisms, there is unlikely to be a ‘general biomass’ market. To date, wood chip and to a lesser extent chipped Miscanthus are the closest descriptions of what may be considered ‘general biomass’. Entrainment for co-firing is determined by the furnace injection equipment, which in turn has to optimise the use of the co-fired fuel with (in most cases) coal. The different volatility characteristics of the coal and co-fired fuel may entail joint or separate fuel loading to optimise the combustion, with the biomass being loaded higher in the combustion chamber. The catchment maps assume fuel will be delivered in an appropriate form to the relevant plant. On the biomass maps the overlays have assumed a generalised fuel format across all plants. In reality, the purchasing and pricing policy, along with any logistical considerations, will determine which plants become the dominant operators. If certain individual plants become preeminent purchasers of biomass, the supply boundaries shown on the maps will change.

In the medium-term, the quality and fuel format for second generation biomass/biofuel plants may determine how more extensive biomass plantings may develop.

Although the maps of AD catchments are some of the clearest, the waste ‘market’ is perhaps more complex than the biofuel and biomass markets. Increasing the utilisation of waste is likely to help reduce the overall land use for both land fill and for applications to bioenergy crops. High profile companies like Waitrose are now promoting their use of AD for waste disposal as an addition to their environmental credentials. But the use of waste for energy can divert it from other uses; tallow for biodiesel production takes feedstock from oleochemical markets, which in turn use oils from elsewhere. The production of tallow by renderers generates an oil-based feedstock in significant amounts at one location. This improves the logistics of using it, especially in comparison with RVO which requires an extensive collection network, which in some circumstances could also collect food waste for AD processing. These are complex issues which cannot be fully addressed through mapping. The centralised collection and AD processing of what may otherwise be problematic materials for disposal is similar in some respects to the burning of waste wood in centralised WID-compliant units. In both cases the problematic material can be ‘diluted’ with cleaner conventional feedstock.

Sourcing feedstocks from distant locations in the UK may have detrimental effects on the environment through increasing haulage costs and carbon dioxide emissions. Although the maps show the potential land coverage of supply catchments, it is essential that support measures – whether through ROCs or RTFO – do not encourage supply chains at any cost if these incentives to produce and supply feedstocks reduce or negate GHG savings. Engagement with landowners owning woodland in the vicinity of power plants, including guidance and support on how to manage woodland effectively, would help make best use of existing resources as well as potentially improving the condition and biodiversity of woodlands. But this needs to be offset against market and supply changes due to wood fuel, which could lead to potentially higher prices for sawmilling and other uses.

The maps show the catchments for wood fuel going to the principal bioenergy users where prices will be determined by ROC values and the overall margins in power generation. Other wood fuel will be supplied to the domestic market where higher prices will be paid. The extent of this diversion from co-firing will depend on the domestic supply infrastructure and how domestic users respond to rising fossil fuel and power prices.

Arguably the efficient used of wood fuel for domestic heating provides better use of a resource which, on a national scale, is limited in relation to its potential for deployment across all end uses.

The maps in this report show how varied the demand for land will be for different bioenergy supply scenarios. The situation up to and around 2010 is encompassed by this present collection of maps, but we live in times of rapidly changing energy and food prices. The maps give *an indication* of the scale and location of near future demand for bioenergy crops and how those areas interact with factors of environmental concern.

The maps show how widespread the demand for sources of bioenergy could become in a very short time period, and how the effects lie across some areas where there are already pressures on the environment (though there are some notable exceptions). Although this demand is widespread, for new biomass crops especially, it makes up a small percentage of land use in the affected areas.

To date, progress towards Government targets for renewable energy use has fallen short of many targets, and progress with bioenergy cropping falls into this category. It remains to be seen whether 2010 will see the mapped levels of land use change shown in this report.

4 Recommendations

- Bioenergy is a rapidly changing sector and is likely to have a significant effect on crop and land use. There is a need for systematic collection of data on bioenergy crops nationwide. This could be carried out through Defra's June Survey of the agricultural industry.

- Questions covering the area of biomass crops grown and on the use of already surveyed woodlands for bioenergy could be usefully added to this survey. At the present low uptake of bespoke biomass crops it would be difficult for the June Survey to draw a statistically representative sample. Such a situation can lead to changes and impacts only being detected after the event, unless pre-emptory targeted surveys are used.

- Across Europe and the UK, under-managed woodlands and forest represent both a haven for biodiversity and an under-utilised energy resource. If the demand for wood fuel increases (*cf* map catchment areas for 25 per cent from domestic supplies), pressure will develop to reconcile these two conflicting interests. Effective monitoring of the developing situation is essential.

- All bioenergy production is being aimed at reducing GHG emissions. It would be beneficial to many parties if some measures to monitor the changes in carbon status associated with land use changes were introduced. Many sustainability certification schemes rely heavily on 'book values'. The maps in this report show the wide potential land coverage and carbon status of the current situations. This requires monitoring to provide real data that will support the developing carbon markets.

- With increasing interest in AD and increases in scale of operation, disposal of digestate to land is worthy of further study. There may be scope for optimising any benefits that may accrue for soil, air and water resources. The comments in the fourth bullet point above are also applicable here.

- Fully developed crops of SRC and Miscanthus have been shown to have water demands in excess of conventional crops. The impact of widespread planting on water fluxes, particularly in water stressed areas (Figure 23), needs to be monitored.

- The deployment of biomass through widespread distributed domestic use requires the overheads of a retail distribution network, while avoiding some of the efficiency losses associated with large scale electricity generation and transmission. This justifies further study and will have implications for the feedstock catchments reported here.

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List of abbreviations

AD	Anaerobic digestion
AONB	Area of outstanding natural beauty
BOD	Biological oxygen demand
CAD	Centralised anaerobic digestion
CAP	Common agricultural policy
CO	Carbon monoxide
COD	Chemical oxygen demand
C:N	Ratio of carbon to nitrogen
C&S	Carbon and sustainability
EA	Environment Agency
ECS	Energy crops scheme
ESC	Ecological site classification
FIO	Faecal indicator organisms
fw	Freshweight
GAEC	Good agricultural and environmental conditions
GHG	Greenhouse gas
GIS	Geographical information systems
GJ	Giga joules
GOR	Government office region
ha	Hectare
HEAR	High erucic acid rape
IPU	Isoproturon
J	Joules
kW	Kilowatt
km	Kilometre
m	Metre
M	Million
MMDB	Manure management database
MWh	Mega watt-hour
MSW	Municipal solid waste
N	Nitrogen
NH_4	Ammonia
NIWT	National inventory of woodland and trees
NNFCC	National Non-Food Crops Centre
NO_3	Nitrate
NOx	Mono nitrogen oxides (such as NO, NO_2)
NVZ	Nitrogen vulnerable zone
odt	Oven dry tonne
OSR	Oilseed rape
P	Phosphate
RFO	Renewable Fuels Obligation
ROC	Renewables Obligation Certificates
RTFO	Renewable Transport Fuels Obligation
RVO	Recycled vegetable oil (also known as used cooking oil)
SO_2	Sulphur dioxide
SOx	Sulphur oxides
SPS	Single payment scheme
SRC	Short rotation coppice
SRF	Short rotation forestry
WFD	Water Framework Directive
yr	Year

Glossary of terms

Anaerobic digestion	The breakdown of organic material such as slurries, manures and organic municipal wastes in the absence of oxygen. Produces methane gas which can be burned to produce heat and electricity or, as in several European countries, used to produce a transport fuel. The residual material is known as a digestate.
Biogas	The gas resulting from anaerobic digestion. Biogas is made up of 50-80 per cent methane, 20-50 per cent carbon dioxide and trace amounts of other gases such as hydrogen sulphide, ammonia and hydrogen.
Biomass	Organic materials derived from recently living materials. In this report we use biomass to refer to trees, short rotation coppice, Miscanthus, and livestock and municipal solid organic wastes.
Biological oxygen demand	The amount of oxygen required for breakdown of organic materials in the water.
Break crop	A change in crop in an arable rotation, used as a way to maintain fertility and reduce pests and diseases. Oilseed rape and sugar beet are used as break crops in predominantly wheat-based rotations in the UK.
Centralised anaerobic digestion	Centralised anaerobic digestion (CAD) uses both livestock wastes and organic municipal solid waste arisings such as food processing wastes. CAD plants are usually bigger than on-farm plants and accept wastes from a number of facilities within the immediate locality.
Common Agricultural Policy	European scheme providing financial assistance to farmers.
Carbon and sustainability guidance	A series of guidelines produced for the UK government as part of the Renewable Transport Fuel Obligation to promote the reporting of information to encourage the supply of biofuels that do not have a negative effect on the environment.
Catchment sensitive farming	A programme aiming to tackle the problem of diffuse water pollution arising from agriculture in 40 catchments throughout England.
Clean Air Act	Act introduced in 1993 (amalgamating previous Clean Air Acts in 1954 and 1968) which restricts smoke emissions from premises and limits particulate emissions.
Chemical oxygen demand	Measure of oxygen required to oxidise organic and oxidisable inorganic compounds.
Co-firing	Combustion of biomass alongside fossil fuels. Co-firing in the UK varies from 2 to 20 per cent of the energy content of the plant.
Digestate	Residual material left over from anaerobic digestion of organic wastes which can be spread to land as a fertiliser source or soil conditioner.

Energy Crops Scheme	Provides significant subsidies to offset the initial high costs of establishing the bioenergy crops Miscanthus and short rotation coppice.
EU Nitrates Directive	European Union directive introduced in 1991 which aims to protect waters from pollution caused by nitrate use in agriculture. All areas draining into waters at risk of exceeding nitrate levels in water are designated Nitrogen Vulnerable Zones.
Faecal indicator organisms	Organisms within water which are indicative of faecal contamination. These include total coliforms, faecal coliforms, *Escherichia coli*, enterococci, vibrio and salmonella.
Integrated Pollution Prevention and Control (IPPC)	Introduced in 1999, IPPC is designed to prevent or reduce pollution from industrial and other installations, including some waste management facilities by means of integrating permitting process as based on the application of best available techniques.
Meat and bone meal	Product of the rendering industry; can also include food processing wastes.
Nitrogen Vulnerable Zones	Areas which are, or are at risk of, exceeding nitrate levels in waters as defined by the EU nitrates directive. These areas are subject to a series of regulations which aim to reduce the leaching of nitrate to surface and ground waters by regulating the timing and rate of application of inorganic and organic nitrogen fertiliser sources to their land.
RB209	Defra book which sets out fertiliser recommendations for a range of crops given different soil types, economic conditions and end use markets.
Renewables Obligation Certificate	Renewables Obligation Certificates are allocated for every MWh of renewable electricity which a generator produces.
Renewable Transport Fuels Obligation	The UK interpretation of the EU Biofuels Directive. The RTFO stipulates that an increasing proportion of transport biofuel sales should be from renewable sources: by 2010, five per cent of all transport biofuel sales (by volume) should be renewable.
Recycled vegetable oil	Vegetable oil which has been previously used in catering establishments and food processors. Sometimes called 'used cooking oil'.
Set-aside	Requirement for a certain area of land on farms to be taken out of production, as part of the CAP measures to combat over-production of foods within the EU. Set-aside land could be used for production of crops for industrial uses and for energy crops subject to an end use contract being in place. Compulsory set-aside was set at zero per cent in 2007 and 2008, and it is believed that it will be permanently abolished.

Short rotation coppice	High-yielding varieties of willow which are harvested every three years and used for energy production. Poplar can also be used, although there are negligible amounts grown commercially in the UK at present compared to SRC.
Single farm payment	The principal subsidy mechanism in the EU where farmers and landowners are paid according to the amount of land they have rather than their production. This allows farmers greater freedom to produce according to market demands. Payment of the single farm payment is highly linked to compliance with various environmental schemes.
Tallow	Animal fat produced by rendering which can be used for oleochemical production, combustion or biodiesel production.
Thermochemical processing	In this report this is used as a generic term for a range of conversion systems which allow the conversion of biomass material to fuels, such as vegetable oil hydrogenation, hydrothermal upgrading, pyrolysis, biomass to liquids and torrefaction.
Water Framework Directive	Directive aiming to increase water quality throughout the EU. Also known as Directive 2000/60/EC.
Yield class	An indication of the productivity of a forest species. A tree stand of a species with a yield class of 12 will show an increase of $12m^3$ of material per hectare each year.

Appendix

Annexes from COUNCIL REGULATION (EC) No. 1782/2003 of 29 September 2003 establishing common rules for direct support schemes under the common agricultural policy and establishing certain support schemes for farmers.

ANNEX III
Statutory management requirements referred to in Articles 3 and 4
A. Applicable from 1.1.2005
Environment

1. Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds (OJ L 103, 25.4.1979, p. 1) Articles 3, 4(1), (2), (4), 5, 7 and 8.

2. Council Directive 80/68/EEC of 17 December 1979 on the protection of groundwater against pollution caused by certain dangerous substances (OJ L 20, 26.1.1980, p. 43) Articles 4 and 5.

3. Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (OJ L 181, 4.7.1986, p. 6) Article 3.

4. Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (OJ L 375, 31.12.1991, p. 1) Articles 4 and 5.

5. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild flora and fauna (OJ L 206, 22.7.1992, p. 7) Articles 6, 13, 15, and 22(b).

B. Applicable from 1.1.2006
Public, animal and plant health

9. Council Directive 91/414/EEC of 15 July 1991 concerning the placing of plant protection products on the market (OJ L 230, 19.8.1991, p. 1) Article 3.

11. Regulation (EC) No. 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety (OJ L 31, 1.2.2002, p. 1) Articles 14, 15, 17(1), 18, 19 and 20.

ANNEX IV

Good agricultural and environmental condition referred to in Article 5

Issue	Standards
Soil erosion: Protect soil through appropriate measures.	— Minimum soil cover. — Minimum land management reflecting site-specific conditions. — Retain terraces.
Soil organic matter: Maintain soil organic matter levels through appropriate practices.	— Standards for crop rotations where applicable. — Arable stubble management.
Soil structure: Maintain soil structure through appropriate measures.	— Appropriate machinery use.
Minimum level of maintenance: Ensure a minimum level of maintenance and avoid the deterioration of habitats.	— Minimum livestock stocking rates or/and appropriate Regimes. — Protection of permanent pasture. — Retention of landscape features. — Avoiding the encroachment of unwanted vegetation on agricultural land.

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