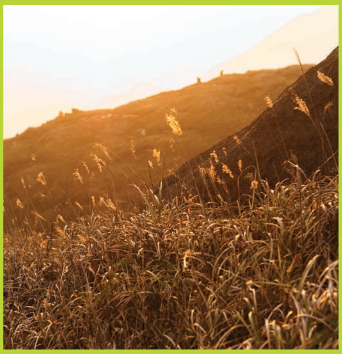
Modelling energy systems



How much bioenergy feedstock can by grown sustainably in the UK?

wholeSEM

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This report presents the outcome of the wholeSEM UK Land Energy NexuS (LENS) workshop held at the University of Cambridge on the 30th of September and 1st of October, 2014. The workshop brought together 40 stakeholders involved in bioenergy and natural resource management from research, academia, industry, agriculture, civil society groups and government agencies.

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Executive Summary

Energy policy in the UK, which seeks a balance between costs, security of supply and commitments to reduce greenhouse gas emissions, is influenced by the forecasts of whole system energy models. The value of these forecasts depends on predictions of costs and technical capability, and practical deployment constraints. At present, bioenergy plays a prominent role in future energy planning in the UK, although it currently contributes only around 4% of the primary energy requirement. Whilst most of the feedstock used in the UK is currently sourced from UK waste, the crop/plant-based component is mostly imported. The potential contribution of domestic bioenergy feedstock to future supply depends on the competition between domestic food production, bioenergy and other land-based services. It also influences water stress, biodiversity and net greenhouse gas emissions.

Through exploring these trade-offs, this report shows that:

- 50,000 hectares or 0.8% of UK arable land area is currently devoted to energy crops (first and second generation). The UK bioenergy strategy projects that this might increase to up to 900,000 hectares, but some of this could be 'marginal' land, which constitutes approximately a third of the UK's land area.

- Actual yields of 10-13 dry tonnes of biomass per hectare per year (t/ha/y) are, less than the minimum yield of 15 t/ha/y anticipated in current strategy. Improvements of around 10% per decade could be achieved through breeding and selection, better management practices, and from the increased temperatures due to climate change, but this could have unwanted environmental effects.

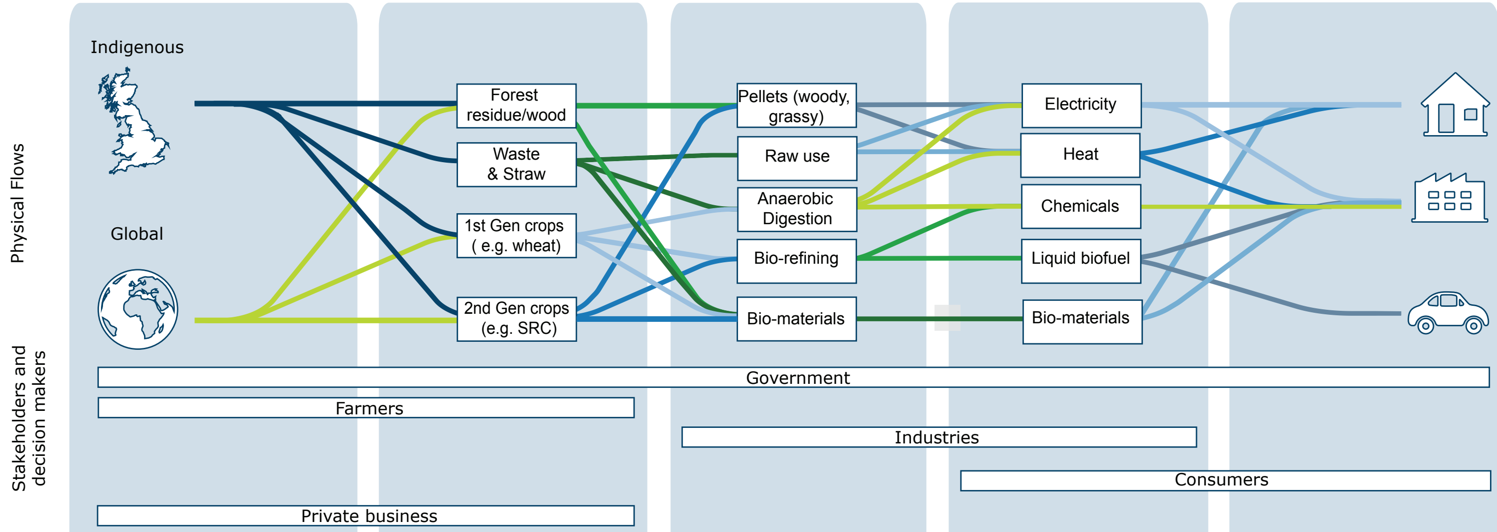
- The benefits of using bioenergy depend on whole life cycle GHG emissions, including the impact of land use change. The evaluation method stipulated for bioenergy projects funded under the Renewables Obligation fails to take this approach and, as recommended by DECC, should be revised.

- UK demand for bioenergy may cause trade-offs with food production, biodiversity and reforestation programmes in other countries. Water use for irrigation and biofuel refining may add to the stress in certain areas.

This report suggests that it should be possible to commit up to 900,000 hectares to bioenergy feedstock production in the UK without undue land stress, with limited impact on biodiversity and a net benefit in reducing GHG emissions. However, the question of whether the UK will develop bioenergy production up to this level depends on a combination of government and business actions and on the farmers' perceptions of long-term policy, subsidies or contracts. Additionally there is a need for in-depth field observations that provide evidence of the environmental benefits and other negative impacts that could result from deploying bioenergy at this scale. Policy discussions and future development of energy models should in future address the physical constraints on total land commitment in the UK, a wider range of sustainability criteria in the assessment of impacts of bioenergy production, uncertainty about the consequences of UK imports, and the requirements for long-term incentives to drive significant change in agricultural practice.

Bioenergy supply chains

There is a complex network of different potential bioenergy pathways that serve the full range of energy services: electricity, heat and transport. A host of energetic, economic, environmental, social, ecological and compound performance metrics have been developed to assess the relative benefits of these supply chains. The commercial case is driven partly by the relative efficiencies of the paths but also by a range of drivers and barriers that are summarised here.



Drivers and barriers

- Competition from cheap hydrocarbons including shale gas
- Imports from less land constrained countries
- Ready supply of forestry products from abroad (especially US) due to the decline of pulp paper industry
- Competition for subsidies with other renewable energy providers
- Disincentives caused by government support for agriculture for food (CAP)
- Alternative markets of bioenergy feedstock
- Improved waste management leading lower feedstock from waste
- Availability of suitable land for energy crops
- Availability of sustainably sourced feedstock
- Cultural issues
- Demography (average age of farmers)
- Availability of adequate harvesting machines
- Yields

- Potential economic use for by-products and agricultural residues that would otherwise be treated as waste
  Intermediaries can offer RPI-X linked contracts that give a steady certain income compared to a highly volatile wheat market
- Potential cashflow problems for farmers due to lag between planting and harvesting for perennial energy crops
- Infrastructure equipment for planting and harvesting can be prohibitively costly especially for SRC willow
- Investment in R&D is required to realise yield improvements and so manage the competition for resources between food and fuels.
- Lack of agroeconomic knowledge amongst farmers for novel crops and lack of information and networks for trade in agricultural residues can be a problem
- Storage (constraint)
- Co-benefits of bioenergy crops (biodiversity, flood protection)
- Net GHG emissions different for different feedstocks
- Quality of feedstocks
  Public attitudes to land use change can be negative including NIMBYism

- Intermediaries pool supply from multiple sources to serve the power sector
- The low energy density of crops means they must be pelletised close to source in order to make transport and supply chain storage more economic
- Low quality, low value biomass such as bark can be used to fuel small-scale local processing near the grower
- Local hubs can share pelletising and costly harvesting equipment. In the UK such hubs are developing in the South West and the North West.
- Ease of storage
- Availability of conversion routes

- Biomass electricity is schedulable and so can play an important role in a low carbon grid that has a greater share of intermittent renewable energy e.g. from wind and solar
- Less efficient biomass power markets need volume supply at a low price whereas more efficient biomass heat markets can afford higher prices
- Scalability and availability of CCS technology
- Decarbonisation of heat
  Short term drivers: RED, LCPD
- Long term drivers CCA 2008, Strategies to 2050, EU2030 targets

- Biomass is a particularly good solution for off grid heat
- Heat demand is geographically dispersed and difficult to service
  Current infrastructure (barrier)
- Availability of bioenergy conversion devices
  Deployment of district heating
- Air quality issues due to emissions from biomass conversion device

Current policy targets for the use of bioenergy in the UK

Bioenergy currently plays a relatively minor role in the UK energy system accounting for approximately 4% of UK primary energy resources in 2013. The majority of this is fuelled by imported feedstocks and UK waste (together accounting for approximately three quarters of UK bioenergy feedstocks). Indigenously sourced bioenergy crops fuel the remaining share. There is great uncertainty over how the UK energy system will evolve over the coming years and so how these shares will change in the future.

The binding constraints on the system are the UK Climate Change Act and its interim carbon budgets - which together require that emissions are reduced by 80% relative to 1990 levels by 2050 – and the EU Renewables Energy Directive – which requires that 15% of UK final energy consumption is delivered from renewable resources by 2020. The Carbon Plan, published in 2011, sets out a range of possible pathways that would achieve these commitments.

Figures 1 and 2 show the role that bioenergy plays in these scenarios. All pathways considered require a significant increase in bioenergy deployment ranging from 17% to 40% of primary energy demand by 2050. The pathways also differ in the final uses of these bioenergy sources, with the 2050 "Higher Nuclear, less energy efficiency" (2050-HNuc) pathway relying heavily on bioenergy for transport and the "Higher Carbon Capture and Storage (CCS), more bioenergy" (2050-HCCS) pathway relying heavily on bioenergy combined with CCS to generate electricity and heat.

The different roles that bioenergy plays across these pathways demonstrates the potential versatility of this energy source.

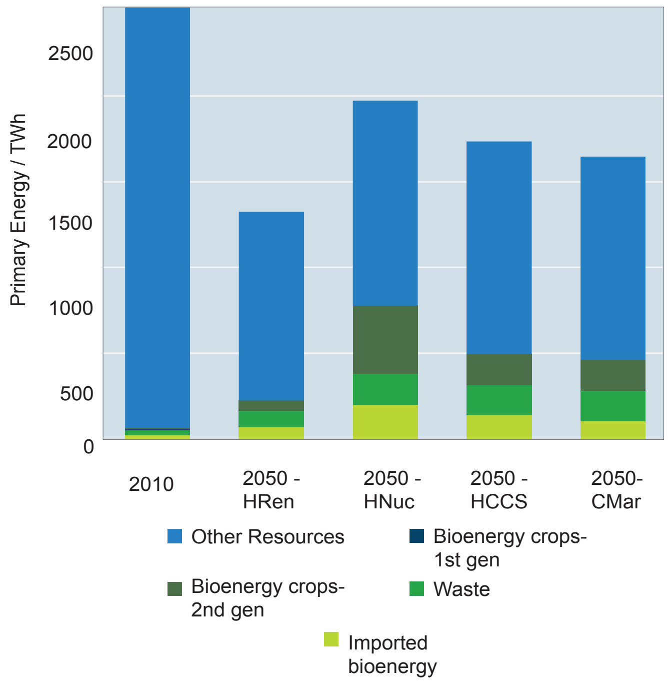


Figure 1: The contribution of bioenergy to UK energy supply under different UK Carbon Plan scenarios. See text for scenario abbreviations.

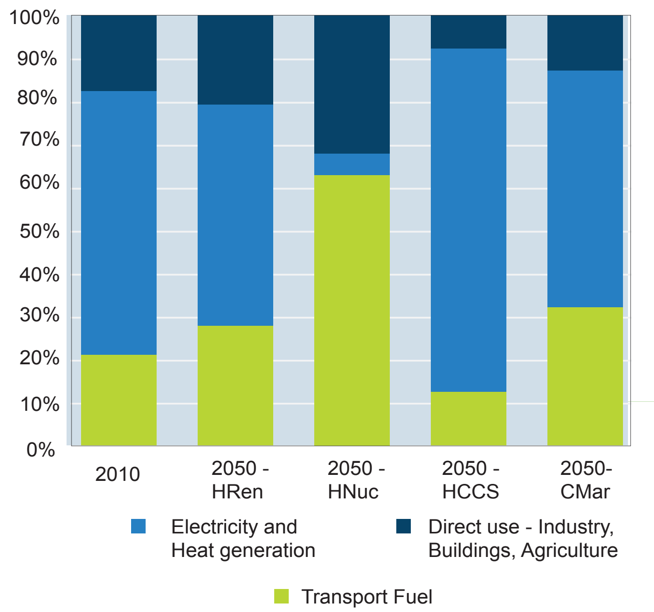


Figure 2:End-use demand for bioenergy under different carbon plan scenarios. See text for scenario abbreviations.

Technical Potential for UK bioenergy crop production

The potential for UK bioenergy crop production in future depends on the availability of suitable land, on yield improvements and on the commercial case for producing bioenergy crops. In this chapter, the availability of UK land for bioenergy crop production will be discussed, followed by future yields projections for different bioenergy crops in the UK. The commercial case is discussed later in this report.

The role of the land system

Given that bioenergy currently plays a relatively small role in the UK energy system and is fuelled predominantly from imported bioenergy crops and from waste, it follows that the demands currently placed on UK land by the sector are small, with approximately 0.4% of agricultural land in 2010 devoted to bioenergy crops. This land is used to grow grassy crops, such as Miscanthus, and woody crops, such as short rotation coppice willow. As shown in Figure 3, these crops are predominantly planted on arable land. However, they can also be grown on less fertile, marginal land and so in future it is likely that these crops will also be planted on lower grade grassland.

The role that the UK bioenergy sector will have depends on international competitive pressures and on the commercial case for growing bioenergy crops on suitable land in the UK. The analysis reported in the UK Bioenergy Review anticipates that, under ambitious yield improvement scenarios, up to 6TWh (8-11% of primary energy demand) could be sourced from UK energy crops by 2020 and 64TWh by 2030. This could require a land area of 0.3 to 0.9 Mha (up to approximately 2.5% of UK land). These are conservative estimates relative to previous studies reviewed by UKERC (2010). By comparison, the 2050 Pathways Analysis (HM, 2010) considers scenarios of up to 17% of UK land being devoted to bioenergy crops by 2050.

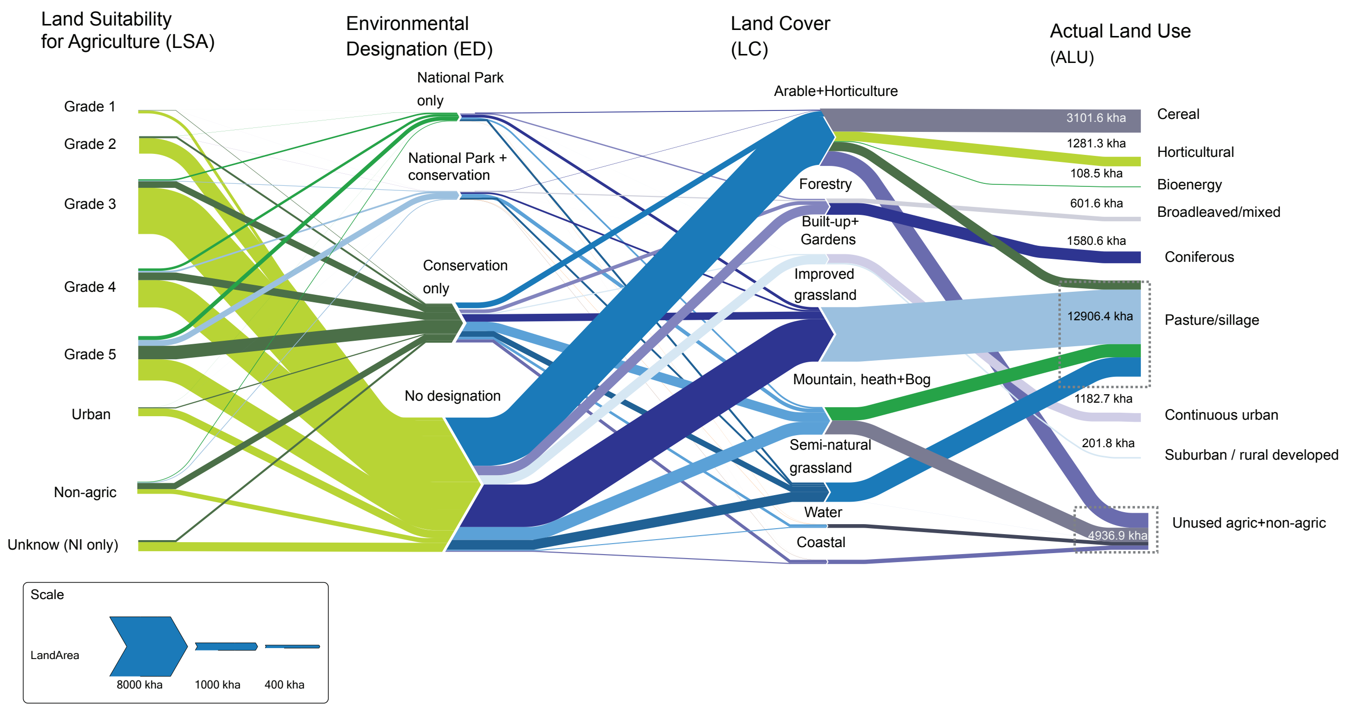


Figure 3: UK land-use flows from agricultural suitability to final use

The role of crop yield improvements

The term "yield" is used to describe the amount of bioenergy crop (usually measured in dry weight harvested biomass) produced on a given area of land, over some period of time. Evidence from 11 studies of woody crops, such as short rotation coppice willow and poplar, and grassy crops such as Miscanthus, showed average yields for grassy and woody energy crops at 13 dry t/ha/year and 10 dry t/ha/year respectively, but with a large variance. These figures are low compared to the assumptions of the Bioenergy Strategy (DECC, 2012), which assumes a minimum energy crop yield of 15 dry t/ha/year. The next section looks at options for addressing this difference.

Improving crop yield can enhance the business case for crops and may reduce competition for resources. There is currently a significant difference between the full genetic potential of a crop with optimum irrigation and nutrition, and actual yields. A recent estimate of the yield gap may be as much as 15 tonnes ha-1 y-1. However, yield improvements can be costly to achieve and may carry an environmental burden if they require fertilizers, water for irrigation and other resources. It is therefore important that the quest for yield improvement enhances resource use efficiency and environmental sustainability - so called "sustainable intensification" (Allwright and Taylor, 2015). This includes improved biodiversity and maintenance of ecosystem services, better crop-GHG balance and less nitrogen and water input. Yield improvements of at least 10% per decade are required in order for bioenergy to make a significant contribution to energy supply in the UK.

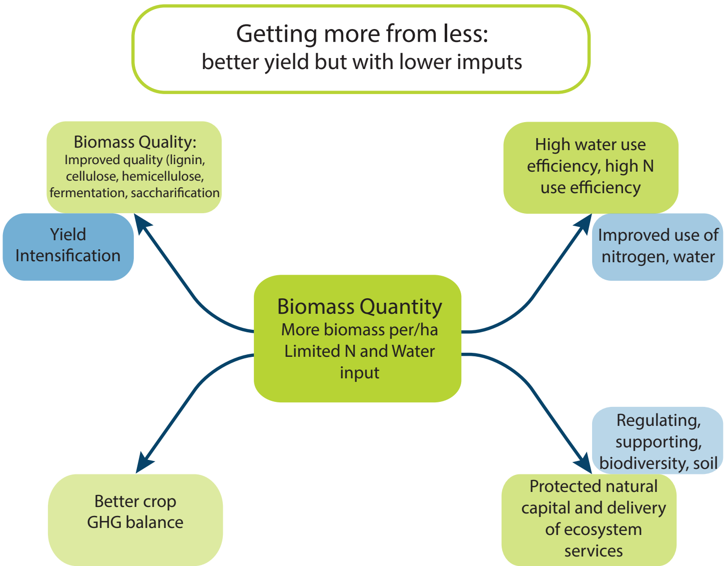


Figure 4: The multiple objectives for improved bioenergy crops (see Allwright and Taylor, 2015, for a consideration of breeding targets; see Sims et al, 2006, for the sustainable intensification of bioenergy yields).

Three potential routes to sustainable intensification have been suggested: i. genetic improvement; ii benefiting from the increased temperatures, atmospheric CO_2 concentration and rainfall associated with climate change; iii better management and agronomy. Figure 5 shows the past yield improvement through traditional breeding developments, as well as likely yield improvements from more advanced marker-assisted breeding methods and new genome editing. The figure shows that yield improvements of 10% per decade could be achieved from traditional approaches alone. However, although this is a reasonable target for annual food crops, for perennial crops with long establishment and breeding cycles, it may be unrealistic because the market penetration of novel crops is likely to be slower for perennial crops that are replaced over longer cycles. Rising temperatures could improve crop yields, but this effect is likely to be small in the UK. Pests and plant diseases may affect projected yield improvements.

Bioenergy crop yield on marginal land in the UK

Economically marginal lands that are poorly suited to conventional food and fibre crop production classified in the UK by: shallow soil; poor drainage; texture extremes (Sand, Clay); high stone content; Slope (>15%); pH (extremes); de-graded lands (erosion, black grass etc.); compaction; chemical contamination (e.g. salinity; awkward areas that are unsuitable for sustainable intensification). Second-generation bioenergy crops can grow on such marginal lands. A UK-wide assessment of Miscanthus yield using the MiscanFor® model estimated harvested yield on marginal lands at 9.5 dry t/ha, compared to an average of 13 dry t/ha on conventionally productive lands. Yield of Short Rotation Coppice (SRC) on marginal lands are estimated at 8.5 dry t/ha, compared to 10 dry t/ha on productive soils. These estimates are spatially variable (Hastings et al., 2014). Using economically marginal lands, avoids the trade-off between food and bioenergy production (Valentine et al., 2012). Lovett et al. (2014) estimate that 8.5 million hectares (Mha), ~37% of UK land area could be used for second generation bioenergy crops in Great Britain.

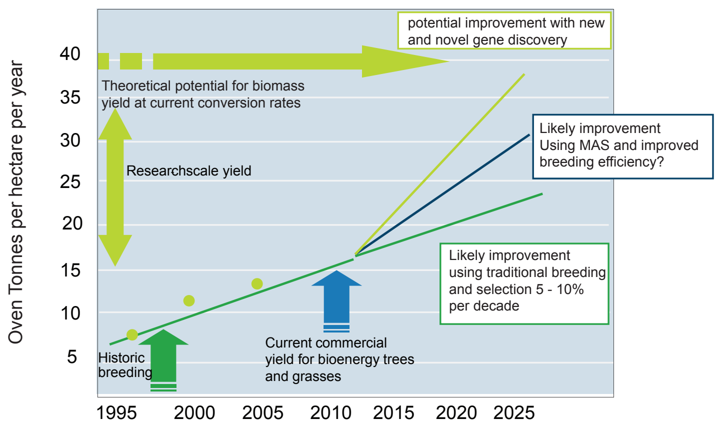


Figure 5: Historic yield improvements through traditional breeding and likely yield improvements more advanced methods (after Taylor, 2006)

Sustainability assessment of UK bioenergy crop production

Evidence presented at the workshop suggested that the relatively conservative estimates of up to 0.9Mha of land for bioenergy crops could be allocated from unused marginal lands and that this could be achieved with limited impact on food supply or detrimental effects on ecosystem services (Aylott et al., 2010; Manning et al., 2015). The total feedstock that can be obtained from these crops will depend on future changes in crop yields. However, while land availability and crop yields dictate the physical limits to bioenergy crop production, further assessment is needed to establish if this can be carried out in an environmentally sustainable way (Holland et al., 2015). Bioenergy chains should only be considered sustainable if they have no net negative impact on the provision of ecosystem services to humans.

Figure 6 illustrates how bioenergy crops might influence ecosystem services in the UK. Although recent research by ETI ELUM and NERC carbo-BioCrop projects among others has explored the link between ecosystem services in particular pests and disease pressure and water use, more empirical evidence is required to quantify the impacts of bioenergy planting.

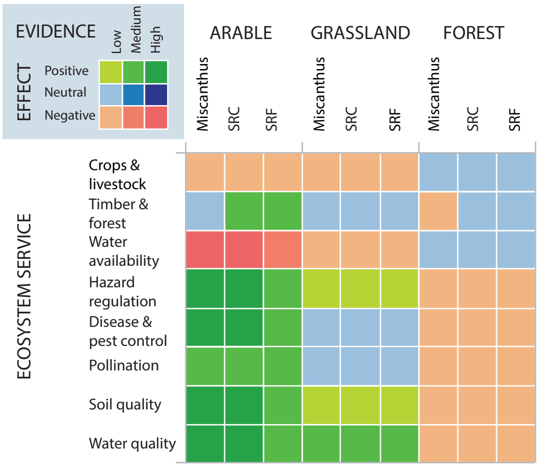


Figure 6: Impact matrix of effects on priority ecosystem services of land use transitions to second-generation feedstocks. Impacts are scored positive where there is an increase in the service, negative with a decrease, and neutral where there is no significant effect reported. Confidence is assigned based on the weight of evidence as described in the main text. (SRF – Short Rotation Forestry)

GHG Emissions Balance

The promise of greenhouse gas (GHG) emissions savings has been the main driver for policies promoting bioenergy in the developed world, but there remains great uncertainty over the measurement and realisation of these savings. Thus, policies aiming to increase the use of bioenergy in the UK should be evaluated by full life cycle accounting of GHG emissions across the entire supply chain. This section explores the whole system approach to calculation of the GHG emissions associated with bioenergy.

Planting bioenergy crops can reduce GHG emissions to the atmosphere by adding to soil carbon stocks. However, the balance of GHG emissions associated with land use change

Table 1: Soil Carbon and CO2 emission dynamics under 2nd generation energy crops (Miscanthus and SRC) and SRF in the UK [Presentation by William McNamara (CEH)] Key: ↔ No net change; ↓ Net sink.

Original land use	Bioenergy Crop	Soil carbon change at depths		CO_2 emission balance
		0-30cm	0-100cm	
Arable	SRC	↔	↔	↓
	Miscanthus	↔	↔	↓
Grassland	SRC	↓	↔	↓
	Miscanthus	↓	↔	↓
	SRF			↓

depends on the amount of organic carbon stored in the soils and vegetation of the original land use, as well as the tillage practices and crop type after the change., The GHG emissions associated with conversion of arable land and grasslands to energy crops - Miscanthus, SRF and SRC (willow) have been tracked for a fixed period of time in field trials. All forms of land conversion were found to be net carbon dioxide sinks (soil & crop), with the greatest savings achieved by planting wood SRC or SRF crops on grassland (Table 1). The results also suggest that there are net reductions in methane and nitrous oxide fluxes but these made only a small contribution (Rowe et al., 2013). Separate studies have found that planting bioenergy crops on depleted agricultural soils and marginal land could also enhance soil carbon sequestration (Clifton-Brown et al., 2007). On the other hand, conversion of carbon-rich lands to bioenergy cropping may lead to soil and vegetation carbon losses.

Overall, conversion of grasslands to bioenergy crops leads to a net sequestration of carbon in soils and crops and may lead to some capture of other GHG gasses (methane and nitrous oxide) (Harris et al., 2014).

Biodiversity impacts

The conversion of grassland and arable land to either woody or grassy bioenergy crops leads to a significant change in farm structure and land management. This change has the potential to increase landscape biodiversity but can also put certain species at risk, especially if bioenergy crops are deployed on a large scale (Rowe et al). Technical studies have identified some of the biodiversity “winners” and “losers” associated with a switch to three crop types: Short Rotation Forestry (SRF), Short Rotation Coppice (SRC) and Miscanthus.

The evidence summarized in this chapter suggests that bioenergy crops can be produced in the UK without worsening

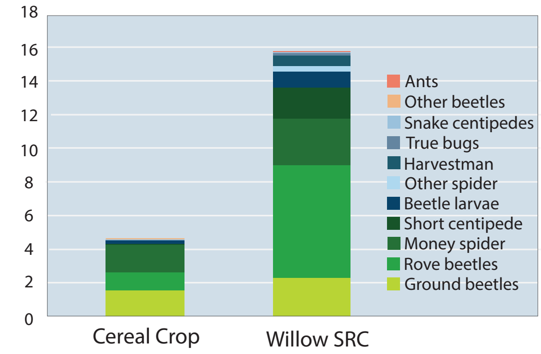
Biodiversity winners	Biodiversity losers
Plants	**Plants**
SRC - change in species composition **Miscanthus** - depend on crop patchiness, Dauber (2014) fields yielding > 9.8 odt ha−1 yr−1 had similar plant species richness as arable fields **SRF**- species dependent	Plant species of concern that may be negatively affected include rare arable plants: cornflower, corn buttercup, pheasant's eye, Venus'-looking-glass, weasel's-snout, shepherd's needle.
Invertebrates	**Invertebrates**
SRC - higher abundance and diversity of epigeal predatory invertebrates, but no impact on predation rate **Miscanthus** - abundance of spider was found to be positively linked to patchiness but not ground beetles (Dauber 2014) **SRF** - Will depend on species selected and location, limited data.	Species of concern that may be negatively affected include nectar and pollen feeding invertebrates; Spp. of Butterflies, hoverflies, bees SRC willow does produce catkins and stem feeding pest produce sugar dew.
Mammals	**Mammals**
Higher small mammal diversity, abundance and breeding in SRC willow compared to arable land Higher small mammal abundance in Miscanthus than in arable crops (S.J. Clapham (thesis)). All provide shelter for larger mammals	Within Miscanthus plantations food resources for some herbivore species may be limited. Rabbits will consume both SRC and young Miscanthus, good for the rabbits, but high rabbit populations can affect food/crop production and can lead to over grazing of natural habitats.
Birds	**Birds**
SRC is associated with a high abundance and diversity of bird spp. warblers, reed bunting, snipe, woodcock, wren, blackbird, song thrush Young Miscanthus plantations are associated with higher abundance and diversity of bird spp. than arable fields, but benefits may diminish with crop age.	Bird species of concern that can be negatively affected include bird spp. associated with open farmland: yellow wagtail, grey partridge, stone curlew, lapwings, sky larks, raptors.

the GHG balance or biodiversity, if second-generation bioenergy crops are used, high-carbon marginal lands are avoided, and "land sparing" practices are used.

Whether or not the total physical potential of 0.9Mha of land for second-generation bioenergy crop production is feasible when considering a broader range of sustainability criteria must be confirmed with further research using more detailed carbon accounting, spatially explicit land and biodiversity data and a wider range of sustainability indicators. However, given the relatively modest targets for UK bioenergy crop production, significant imports may be required. Thus the impacts of bioenergy feedstock growth in the rest of the world must also be considered.

Land-sparing activities to reduce the biodiversity and GHG impact of bioenergy policy

Land use change towards bioenergy crops can reduce biodiversity, particularly when natural or semi-natural habitats are converted (Balmford et al. 2012). It follows that any assessment of bioenergy policy must properly account for these land-use effects so that society can make an informed choice. Land sparing might be a useful framework under which to assess these trade-offs. Land sparing involves targeting sustainable increases in the yields of food (and energy) crops to reduce the land area required for food (and energy) production (Green et al, 2005; Phalan et al. 2011). The 'spared' land can then be managed for biodiversity, carbon storage and other ecosystem services by restoring natural habitats. Anthony Lamb at Cambridge University suggests that a focus on a 'sustainable intensification' approach under a land sparing strategy might offer a pathway towards minimising any detrimental trade-offs involved in an expansion in energy cropping.



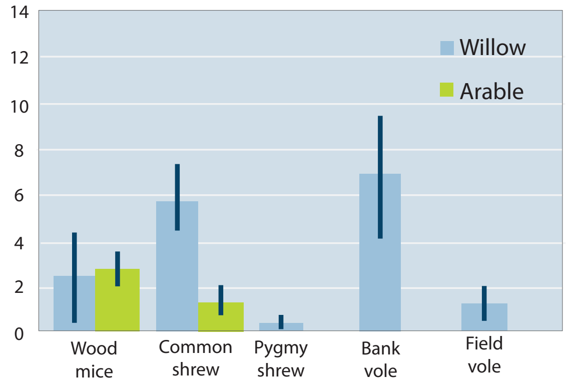


Figure 7a and 7b: Comparison of biodiversity and abundance under cereal crops and SRC willow invertebrates and small mammals

Global impacts of UK bioenergy targets

Global concerns over greater reliance on bioenergy include possible conflicts with food security, environmental sustainability and other related socio-economic consequences. Assessments of these issues have been inconsistent; if food security is measured by availability, access, utilization and/or stability, bioenergy appears to have negative impacts; however, if measured by causes such as poverty and infrastructure needs, bioenergy appears to be more beneficial.

The UK could manage its global supply chains for bioenergy to maximize these positive impacts.

Whole system GHG emissions

The net GHG emissions of using bioenergy are determined by the whole supply chain, from crop through emissions to final energy use. It is not possible to benchmark biomass resources consistently, although it is possible to identify the key processes and activities that determine the GHG intensity of bioenergy. An approach to doing this is proposed in DECC's Biomass Emissions and Counterfactual Model (BEAC) (DECC, 2014) which is described in Figure 9 and in the Box Story on estimation of GHG emissions from bioenergy feedstocks.

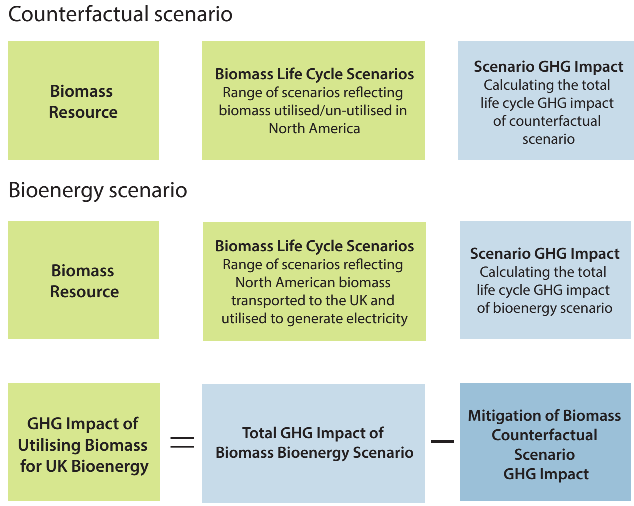


Figure 9 Holistic approach to bioenergy GHG emissions accounting: main scenario for the feedstock production and use, and alternative land use scenarios (Source: Tyndall Centre for Climate Change Research, 2015)

Food, fuel & reforestation on a global scale

Land is a scarce resource. If bioenergy production encroaches on existing forests, it rarely achieves a net positive carbon balance. Globally, demand for food is increasing faster than improvements in crop yields, which suggests that any additional cropping for fuel could contribute to cropland expansion, and therefore deforestation. In North America and Western Europe cropland area is shrinking, freeing up land for other uses, but this is due to increased food imports.

The growth in demand for cropland is driven by increasing populations and changes in diets, particularly increases in meat consumption. In addition, in some countries, livestock is increasingly fed via feedlots (grains and pulses), as opposed to grass from pastures. The fate of global pastures is thus less certain than that of cropland. A future key question is whether

Estimating GHG emissions from bioenergy feedstocks (DECC, 2014)

New sustainability criteria published by DECC in 2013 set a limit of 200 kg CO_2eq/MWh for electricity generated from solid biomass for projects supported under the Renewables Obligation scheme. Under this scheme emissions are calculated by the LCA methodology set out in the Renewable Energy Directive (RED, 2009/28/EC) which accounts for emissions from cultivation, harvesting, processing and transport of the biomass feedstocks and from direct land-use change. However, this methodology does not include changes in the carbon stock of a forest, foregone carbon sequestration of land, or impacts on carbon stocks from indirect land-use change.

Imported wood pellets from North America are the primary fuel currently used to generate electricity from biomass in the UK. In response to concerns raised over the sustainability of these feedstocks, DECC analysed the GHG impacts and energy input requirements (EIR) of a range of North American feedstocks, using a methodology that includes impacts omitted by the EU RED methodology. Twenty-nine different scenarios for future use and sources of biomass were considered and DECC's Biomass Emissions And Counterfactual Model (BEAC) was used to estimate the GHG intensity and EIR of each scenario, taking into account the counterfactual land use in each case, i.e. what the land would be used for if it were not used to grow the bioenergy feedstocks.

The results showed that if GHG emissions are calculated using the methodology stipulated by the Renewables Obligation, it may be possible to meet the UK's demand for solid biomass for electricity generation in 2020 using North American feedstocks. However, using the more holistic BEAC methodology the emissions for electricity produced from biomass could be higher than those from coal. The analysis also showed that biomass from a number of different supply chains could have higher EIR than the alternative use of fossil fuels or other renewable sources for electricity generation. The energy input requirements of the supply chain could be reduced with shorter transport distances, which could support local production.

marginal lands released from food production should be used for reforestation other than for bioenergy feedstocks.

Finally, if the technology to produce fuel from lignocelluloses becomes viable, crop residues could become another possible fuel feedstock, allowing synergistic production of food and fuel. By weight, the total production of crop residues is comparable with harvested food. However, crop residues are currently used for soil protection, water retention and carbon sequestration, so further evaluation will be required.

Bioenergy in a developing world context - Brazil

About 8.7 million hectares (2.6%) of the all land in Brazil is committed to sugar cane cultivation for ethanol production. The social and economic impact of this crop for the local population is thus important.

A recent study on the social impacts of Brazil's Sao Paulo State sugarcane ethanol program between 2005 and 2009 by Bacchi and Caldarelli (2014) suggests that increasing the sugarcane production leads to increased employment and income in the region, although the effect on education and health was not considered.

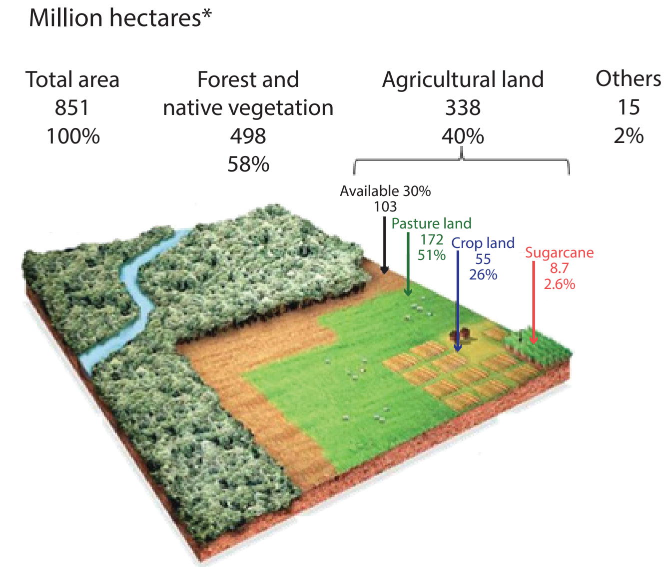


Figure 10: Brazil's land use (Courtesy, Jeremy Wood. Sources: adapted from Icone, Esalq e IBGE. Elaboration: Cosan and UNICA. Note: Area 2009).

Bioenergy and water

In the UK, the Renewable Transport Fuel Obligation (RTFO) is one of the Government's main policies for reducing greenhouse gas emissions from road transport, and contributes to wider European targets for the use of biofuels within the road transport sector. As part of these targets, biofuels feedstock production must reduce greenhouse gas emissions and avoid use of land of high value for biodiversity and carbon.

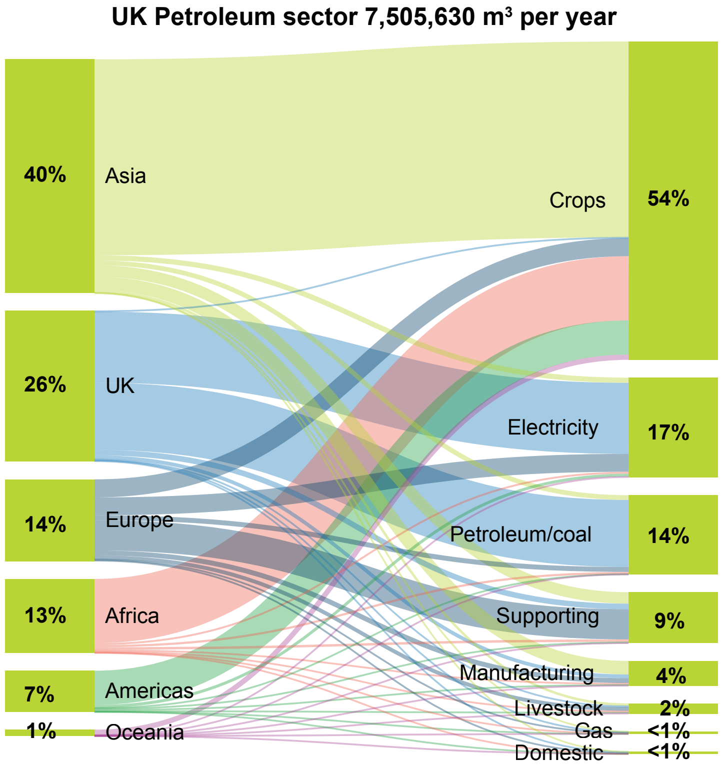


Figure 11 Freshwater consumption associated with the UK petroleum sector, including fossil fuel and biofuel feedstock sources. The high proportion of freshwater consumption associated with crop production is a reflection of the water intensity of this part of the supply chain and not high input of crop materials. (Courtesy: Rob Holland)

An important issue that has so far received little attention in the sustainable production of biofuel feedstock, is the use of freshwater. The International Energy Agency suggests that water consumption associated with energy production may increase by 85%, over the next 20 years primarily driven by increased biofuel production (International Energy Agency 2012). This could increase competition for water resources and put more people at risk of water stress.

The use of fresh water in the UK petroleum sector as a whole is shown in Figure 11, including the water consumption associated with the extraction and processing of fossil fuels and that used in processing biofuel feedstocks. Crop production is by far the most intensive use of fresh water accounting for 54% of fresh water consumption. This analysis also demonstrates that the UK petroleum sector has a global reach: the majority of freshwater consumption is embodied in production outside the UK.

Analysis such as this (and see Holland et al., 2015) helps to identify steps to reduce freshwater stress. Water use would be reduced by planting drought tolerant biofuel feedstock species, and through the adoption of precision irrigation techniques. Biofuel feedstock production could also be restricted to areas with plentiful water resources and good governance.

Fulfilling the technical potential of UK bioenergy crop production

Conversion of UK land to bioenergy crops has been slow and well below the target of 0.9Mha, with second generation bioenergy crops taking up just 8000 hectares in 2013. This section discusses current policies for the bioenergy sector followed by key actions from policy and industry stakeholders that could enable the fulfilment of the UK bioenergy crop production potential. Case studies, where the links along the bioenergy supply chain lead to increased sourcing from indigenous crops, are also presented.

There has been significant uncertainty in future bioenergy targets for the UK energy system. This is in part due to uncertainties in energy policy. This section summarises current policies and subsidies that affect the bioenergy supply chain, followed by key recommendations for policy and the bioenergy industry.

The role of subsidies in the biomass-heat supply chain

Burning biomass for heat is efficient, and can help to heat homes that are not on the gas-grid. The development of this supply chain is supported by the Renewable Heat Incentive (RHI), which pays consumers 12.2p/kWh (for applications prior to 31st of December 2014) for heat generated from biomass boilers for 7 years. At current prices, fuel costs per unit energy for heating oil (the most common option for off-grid properties) and Miscanthus pellets (a hardy grass that is grown and pelletised in the UK for fuel) are approximately equal. After paying for fuel, consumers earn around 7 p/kWh from the RHI when burning Miscanthus pellets. This means that the cost of a £17,000 30kW biomass boiler can be paid off within the life of the scheme.

Long-term contracts are offered to Miscanthus growers by intermediaries such as Terravesta, who commit to buying the harvest at a fixed, inflation linked price for 10 years. Farmers face an upfront establishment cost of £2,200/ha and have to wait 3 years before the first harvest. The last Rural Development Plan included a subsidy under the Energy Crop Scheme worth 50% of establishment costs, which has since been withdrawn. The graph below compares average annual margins for Miscanthus and wheat on fertile and marginal land under different pricing conditions. It shows that, even without the establishment grant, Miscanthus is currently viable as a stand-alone crop, and compares favourably to wheat on marginal land. Miscanthus presents a completely different proposition to wheat as it offers a known return rather than exposure to highly volatile international grain markets. Intermediaries – such as Terravesta – play an important role in this market by offering long-term contracts to farmers as well as expert agronomic advice and access to planting and harvesting machinery. By supporting farmers and pooling supplies from multiple sources, these intermediaries are well placed to secure a steady supply of bioenergy feedstocks for the power sector.

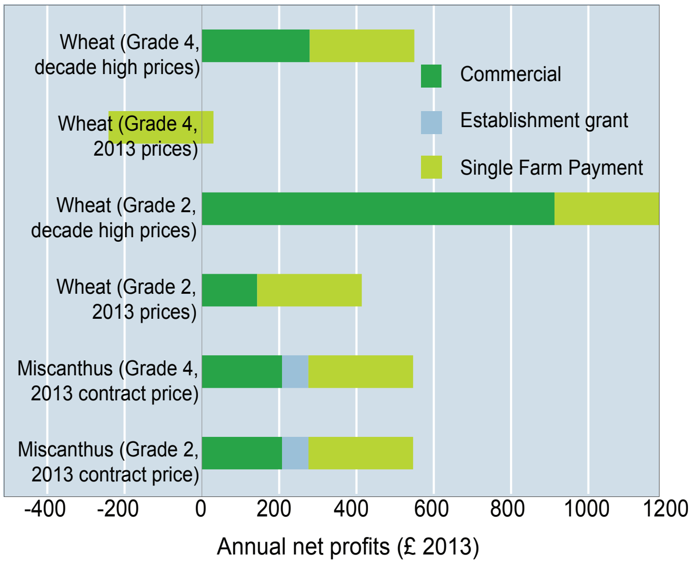


Figure 12: The business case for wheat v. miscanthus (Source: UK Foreseer)

The role of government policy in the UK bioenergy sector

The government's position on bioenergy is influenced by a host of policy priorities including energy security, food security, climate change mitigation and waste reduction targets. The potential role of bioenergy in meeting these, at times conflicting priorities, is complex and fraught with uncertainty. As stated in the ministerial forward to the UK Bioenergy Strategy "Used wisely, energy from biomass can make an important contribution to decarbonisation. But used in the wrong ways, bioenergy can actually confound our aims, releasing more carbon into the atmosphere and putting at risk fundamental objectives such as food security".

In light of these concerns, the UK government has been reticent to set clear targets for the sector. Its Bioenergy Strategy does, however, set out the expectation that bioenergy could sustainably contribute 8 - 11% of primary energy demand by 2020 and 8 - 21% with an average estimate of 12% by 2050. The strategy also outlines four principles that will guide future policies in the sector. They are:

- Policies that support bioenergy should deliver genuine carbon reductions that help meet UK carbon emissions objectives to 2050 and beyond.

- Support for bioenergy should make a cost effective contribution to UK carbon emission objectives in the context of overall energy goals.

- Support for bioenergy should aim to maximise the overall benefits and minimise costs (quantifiable and non-quantifiable) across the economy.

- At regular time intervals and when policies promote significant additional demand for bioenergy in the UK, beyond that envisaged by current use, policy makers should assess and respond to the impacts of this increased deployment on other areas, such as food security and biodiversity.

The policies that are currently in place appear to adhere to these principles. In particular the primary focus has been on demand-side measures that pitch bioenergy supply chains against each other and against other renewable energy sources, and that subject UK biomass suppliers to international competition. The key demand-side policy instruments are the Renewable Heat Incentive (that pulls biomass into heat markets) and the Renewables Obligation and Contract for Difference (that can be used to pull biomass into electricity markets). An example of the use of these subsidies is given in the box story on pages 12 - 13. There are fewer subsidies to the supply side. The Energy Crop Scheme, which was administered by Natural England until 2013, paid 50% of establishment costs for bioenergy crops. This subsidy has now been retracted, however, as shown by the box story on biomass-heat supply chains, the commercial case for growing Miscanthus on marginal land is still strong.

Bioenergy is the only renewable source that is a direct substitute for the main fossil fuel energy vectors and is compatible with current infrastructure in transport, heat and electricity. The Climate Change Committee's Bioenergy Review (CCC, 2011) establishes priorities for bioenergy use, rating heat in industry and biomass in construction (i.e. using wooden beams as an alternative to structural steel in buildings) as the preferred options by 2050 and the use of bioenergy for transport and for power (without Carbon Capture and Storage (CCS)) as the least desirable options. The value of other bioenergy pathways is dependent on implementation of as yet unproven CCS technologies. The more immediate priorities set out in the Bioenergy Strategy reflect the fact that bioenergy can play a more extensive role in the near-term as a transition technology that offers emissions savings relative to hydrocarbons. These priorities or "low risk deployment pathways" set out in the Bioenergy Strategy are: energy from waste (where this does not interfere with the waste hierarchy); industrial and domestic heat; transport (as an alternative to fossil fuels and only in the longer term if advanced technologies for energy from waste and from woody feedstocks are commercialised); and electricity (as an alternative to coal and where possible using combined heat and power to make the most efficient use of biomass resources).

UK bioenergy stakeholders stress the potential co-benefits of bioenergy crops – including the benefit of woodland energy crops such as SRC willow for nitrogen uptake and water quality, their potential use as flood defences and the pollination services they offer (as willow catkins provide pollen for bees at times of the year when little is available from other sources, thus helping to sustain bee populations). Stakeholders call for the sector to be rewarded for these co-benefits (Rokwood, 2014). The fact that indigenously sourced bioenergy could contribute to multiple policy objectives could be an advantage to the UK bioenergy sector, offering additional benefits from growing bioenergy crops on UK land. Sourcing biomass locally has the added advantage of reducing transport distances associated with energy requirements relative to current practices of importing woody feedstocks from abroad. However, as the UK has a relatively low forested area (that could supply low cost biomass) and a relatively high population density as compared to, for example, the USA and Canada, it seems inevitable that a significant share of biomass used to fuel UK bioenergy demand will come from sources abroad. If supply chains are well managed, and demand levels are periodically reviewed, the UK's bioenergy aspirations could contribute to, rather than conflict with, international sustainable development goals.

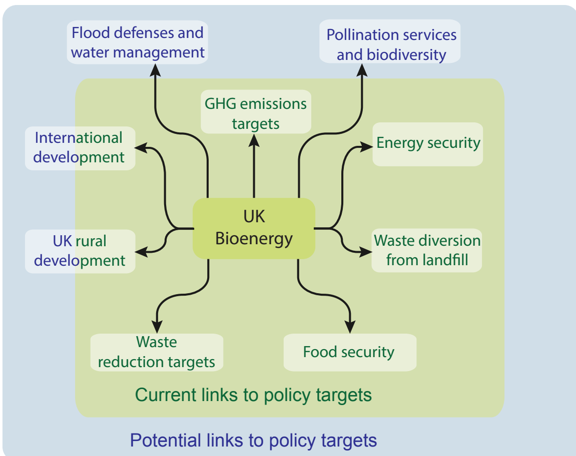


Figure 13: Current and potential links to policy priorities for bioenergy deployment

Moving forward: the role of policy making

Uncertainty in current policy regarding bioenergy targets and conflicting goals from energy and land management have in part impaired the development of UK bioenergy supply chains and bioenergy crop production. The following actions that could contribute to the development of bioenergy in the UK were highlighted during the workshop:

1. **Integrated policy making**: UK bioenergy supply chains are influenced by policies made across a range of government departments that have different, and at times conflicting, objectives. Although there is some formal interaction between DECC and Defra aimed at tackling bioenergy policy conflicts, earlier, higher-level communication to align strategic objectives would be beneficial.

2. **Targeted support to supply chains taking into account co-benefits**: The commercial case for the development of bioenergy supply chains in the UK is dependent on government support. Demand-side measures such as the Renewable Heat Incentive provide adequate incentives for domestic Miscanthus production, but the development of domestic short rotation coppice supply chains would require additional support. Targeted support for short rotation coppice may be justified at the local level to serve off gas grid heat demand especially where these crops offer co-benefits to biodiversity and flood protection.

3. **Policy uncertainty and periodic review of objectives**: The development of UK bioenergy supply chains has suffered from policy uncertainty, however, this uncertainty is driven partly by the complexity of the issues surrounding increased bioenergy deployment. Due to this complexity the UK bioenergy strategy outlines a set of principles that will govern future bioenergy policy rather than setting out clear targets for the sector. The expected role that bioenergy will play in energy system is under periodic review. The government could help to reduce the uncertainty associated with this situation by clearly defining the criteria and review process that will be used to reassess UK bioenergy. aspirations

Role of UK bioenergy industry

The development of the UK bioenergy supply-chain is strongly influenced by actions from the bioenergy industry. Several case studies were presented during the workshop that highlighted the following key areas of intervention from industry:

1. **Local bioenergy hubs**: Despite growing international bioenergy markets, for certain supply chains there are clear advantages to matching supply and demand locally. These include: using "waste" bark to power processing near growers to improve transport density; minimizing transport distance; sharing local pelleting capacity to provide small heat plants; sharing local harvesting machinery for SRC willow and more confidence in locally sourced feedstocks. Within the UK these hubs are currently developing in the South West and the North West where there is ample water and suitable land and where increased bioenergy supply can meet demand from off gas grid communities.

2. **Supply chain coordination:** The development of bioenergy supply chains requires simultaneous confidence over the reliability of supply and demand between growers and end-use markets. The need for coordination is amplified by the lag between planting and harvest for perennial energy crops and by the large infrastructure investment needed. Intermediaries such as Terravesta act to coordinate supply and demand in the Miscanthus – power sector supply chain by offering long term Inflation linked contracts to farmers as well as expert agronomic advice and access to planting and harvesting machinery. Other bioenergy supply chains could benefit from this model.

3. **Awareness and information:** If UK bioenergy supply chains are to be developed further information barriers must be overcome. This includes: tackling lack of agronomic knowledge amongst farmers for novel crops; information on costs, availability and handling of specialist machinery; and better information and networks for trade in agricultural residues.

The conversion from coal to biomass at Drax power station

Drax power station is the single largest power station in the UK, supplying around 7% of the UK's electrical power. The coal-fired power plant was built in the mid-1970s and expanded in the 1980s. In 2003, Drax started to introduce biomass fuels to its plants by co-firing coal and biomass using its existing technology. A series of investments in direct injection equipment, wood processing equipment, a straw pellet plant and a 400MW co-firing plant saw the plant burn 4,350kt biomass over the decade 2003-2013, with the share of biomass growing from 1% to 16% in the period. By the end of 2013 Drax delivered an 80% GHG emissions savings relative to the EU fossil fuel comparator (calculated using the UK Solid and Gaseous Biomass Carbon Calculator (Ofgem, 2015)). In 2013 Drax embarked on its first full unit conversion to biomass and for the full year 2014, Drax burned 4.1 million tonnes of biomass producing 7.9TWh of electricity (30% of the total station output). This is almost the same as the amount consumed for entire period 2003 - 2013. In total three out of the six of the 670MW units were due to be converted to biomass fuel by the end of 2015 at an estimated total capital cost of £285m. The business case for conversion from coal to biomass is highly dependent on government support. The Drax conversion has been supported through direct subsidies

Implications for target setting and modelling

The definition of targets for future UK crop-based bioenergy feedstocks should be based on available unused land, future yield changes, and sustainability criteria. Furthermore, rates of change of land to bioenergy crops should reflect empirical evidence. This would lead to more realistic targets that include economic and environmental considerations. Consequently, this could help reduce current uncertainties in bioenergy policies while also addressing the mismatch between energy and land management policies.

Considerable advances have been made to analyse whole supply chains for bioenergy (Welfe et al., 2014a, 2014b). However, these could usefully be integrated with models that simulate the behaviour of key stakeholders. Given the complexity of the issues, whole systems energy modellers could benefit from collaborating with agronomists, sociologists, economists, and land and water experts. This type of collaboration is fostered by research projects such as wholeSEM and research hubs such as SUPERGEN.

Evidence presented during the workshops highlighted further research needs in the following areas:

1. supply-side bioenergy assumptions in whole systems energy models could be improved through a more precise understanding of land availability, and of existing and potential land uses;

2. explicit incorporation of GIS data, already available for land use types and bioenergy yields into whole systems energy models or analysis should be carried out at a more local level (e.g. analysing regions or water basins);

3. consideration of the impact of bioenergy on a wider range of sustainability criteria, including ecosystem services ;

4. methodologies used to evaluate GHG emissions and land-use change associated with bioenergy supply chains could be used to ensure that assumptions in whole systems energy models fall within sustainable.

from the Renewables Obligation and subsequently through a Contract for Difference that offers a guaranteed price of £105/MWh from April 2015. This compares to strike prices of £50-79/MWh for solar farms, and £115-120/MWh for offshore wind farms funded under the first allocation round of the Contract for Difference. The Drax biomass conversion project has suffered from uncertainty in government policy. A government U-turn saw the Contract for Difference, anticipated to apply to two units, awarded to just one unit. This prompted Drax to sue the government, without success, forcing them to finance the additional unit through the Renewable Obligation scheme.

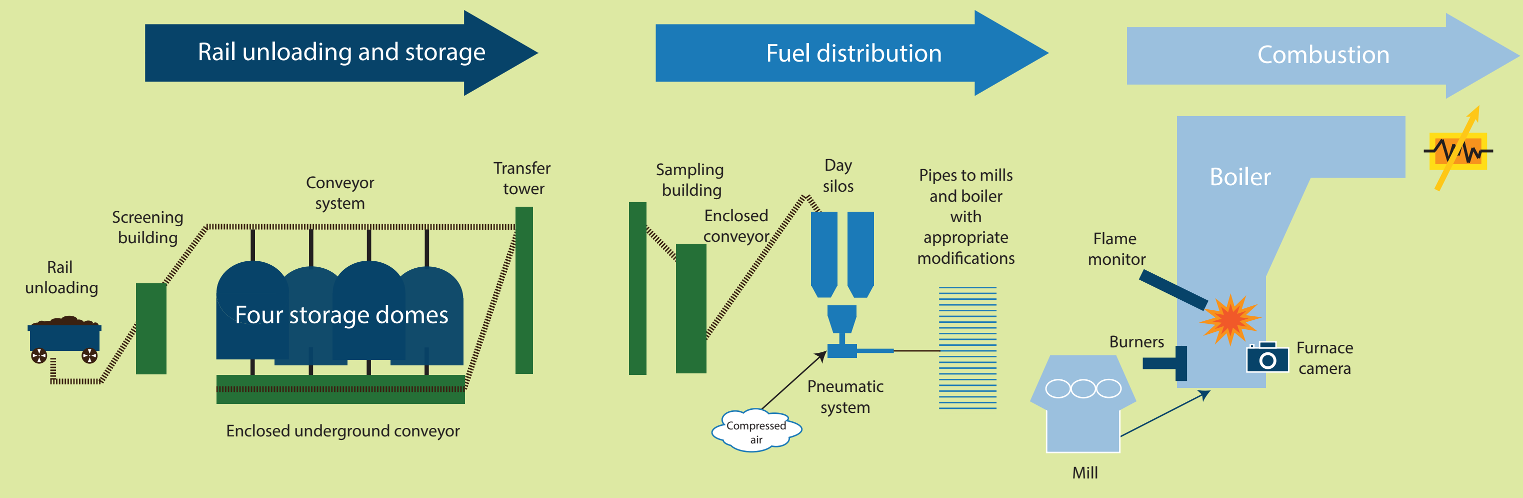


Fig 14: Schematic representation of the conversion from coal to biomass at Drax Power Station (Source: Peter Emery, Drax)

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About wholeSEM

The Whole System Energy Modelling Consortium (wholeSEM) is a ground breaking, multi-institution initiative to develop, integrate and apply state-of-the-art energy models. Our aim is to employ extensive integration mechanisms to link and apply interdisciplinary models to key energy problems.

The aim of wholeSEM is to build and link energy models, providing a foundation for the UK's national strategic energy modelling activity. The initiative will ensure continuity of funding during the period from 2013 - 2017, enabling participating organisations to develop new models and link modelling frameworks in innovative ways to answer new research questions.

wholeSEM is led by University College London and consists of Imperial College London, the University of Cambridge and the University of Surrey. There is further significant engagement with stakeholders in academia, government and industry.

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