Global biomass markets

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Executive summary

Modelling of the global bioenergy resource indicates that potentially large quantities of forestry resources could be available for supply to the UK from several regions around the world. Similarly, if the market is right, internationally supplied energy crops could be a significant resource in the future. However, the extent to which these potential resources may be realised though natural market development is unclear.

This report aims to increase understanding of the availability of international biomass. It looks at diverse situations by evaluating options for different types of biomass in different regions. This has allowed key barriers to the development of biomass supply chains to be identified, and how they vary by region and type of resource. As part of this work, the main environmental and socio-economic impacts from biomass supply have been considered along with the high-level means by which these could be mitigated.

Biomass costs and prices

The potential price of pellets derived from available forestry resources and accessible energy crops imported into the UK from a range of countries was estimated. These were found to be within the current range of prices for biomass being paid by the UK market. The estimated future price of pellets produced from UK energy crops were also identified as having potential to also fall within the range of current market prices.

Future expansion of pellet production from a range of regions not yet contributing to global supply is possible but would require the use of biomass resources that were more expensive to cultivate or collect and transport than resources used for current supplies. This will lead to small increases in the estimated price of imports (typically likely to be a few percent). However, development of the market could also lead to investments that improve the efficiency of the pelletisation process and transport logistics. These have the potential to enable increased supply within current price ranges. In the case of energy crops, production costs could be reduced through investments to develop higher yielding varieties, reducing establishment and harvesting costs, and moving to contract farming.

The development of international biomass supply chains requires policies that support the development of a stable, long-term market, and ensure environmental and social impacts risks are managed effectively. History shows that private-sector investment and interest will not be available until supporting policies are in place. This presents a challenge for governments to establish a policy framework in advance of a market and in the hope that the markets will respond as required.

Key barriers

There are a number of key barriers that exist in most regions that could have a large impact on supply if not addressed. The most fundamental are those related to market development.

A key market barrier is the availability of finance on terms that enable producers to achieve an attractive rate of return. This is related to perceived risk and is likely to vary by region. Finance will be more readily available in regions where the market and price for biomass are clear and the institutional environment is stable. This means that raising finance may be difficult to support biomass supply in developing and emerging economies (such as Africa or South America), where political risks and/or currency risk/volatility may be higher.

Energy crops could provide considerable biomass resource, but they present specific challenges: there are upfront costs in establishing the crop and returns are only achieved over the longer term. For this situation alternative financing models are required. For instance, finance could be provided by the end user of the fuel or by investors that are able to take a longer-term outlook, such as pension funds.

A major barrier to development of biomass can be the financial burden to the farmer or landowner of initial investment in planting material or machinery. To address this, alternative approaches, such as contract farming approach will also be required. In the forestry sector, solutions used to mitigate risk and gain access to finance include encouraging inward investment from large international companies that can take on the risks in the biomass supply chain, and the use of joint ventures between biomass producers and energy plant developers. Joint ventures between biomass producers and biomass processers (e.g. pellet plants) are also being considered.

In general terms, while price increases may help to diminish market barriers, stakeholders consider that this is only important where it leads to the development of a large-scale, stable market for biomass.

A key market barrier that is very difficult to address is competition for biomass supply, for example from domestic demand in the supply region and competing markets for the feedstock. Competing markets can include energy (such as the emerging low carbon energy markets in Asia), or demand for other products, such as the use of the feedstocks in biorefineries.

Ironically, another potentially significant barrier in the future is reduced productivity due to climate change. This barrier may be hard to overcome, especially for energy crops. However, increased prices for biomass could provide the impetus needed for funding research and demonstration of varieties better adapted to changed climatic conditions.

Secondary barriers that have been identified relate to understanding and introducing sustainability and technical standards, infrastructure necessary for the biomass supply chain (harvesting equipment, storage, pellet plants, etc.) and capacity building (development of skills etc.). These barriers can all be addressed in the short-to-medium term given adequate investment, good market opportunities and the will to introduce good practice. Progress in some aspects (e.g. sustainability certification) may be considerably more difficult in regions where governance is weak and the provision of robust evidence that meets international standards is less feasible.

Environmental impacts

A condition of Government support for biomass use in the UK is that the biomass, whether produced domestically or imported, must meet minimum sustainability standards. This requires uses to demonstrate that the use of the biomass achieves minimum greenhouse gas (GHG) savings, and for suppliers to demonstrate that it has been produced sustainably. This means that the harvesting rates are sustainable, biodiversity has been protected and land-use rights for indigenous populations are respected. Therefore, any expansion of biomass supply has to meet these criteria.

For this reason, this study examined the GHG emissions and other environmental impacts on soil, water and biodiversity caused by the supply of a variety of biomass resources from a number of regions. Impacts on air quality are not examined as these are mainly associated with the combustion of biomass at its point of use and this report is concerned with supply of biomass. A review of these combustion impacts is provided in the Air Quality Expert Group's 2017 report and reduction strategies are being examined within the Clean Air Strategy[1].

This review clearly demonstrates that not only are environmental impacts dependant on the type of biomass and local conditions in the region where it is produced, but also on production methods. In the case of GHG emissions, existing and many underdeveloped biomass supply chains have the potential to meet the current GHG criteria set under the Renewable Heat Incentive. However, if the criteria were tightened to that proposed in the recast of the Renewable Energy Directive, the carbon intensity of some imported pellet supply chains would need to be improved to enable them to meet the higher GHG savings required.

Compared to arable crops, cultivating energy crops can have beneficial effects on soil quality, including soil carbon and water quality. Deleterious effects can often be avoided or mitigated if best practice guidance on appropriate areas for planting, cultivating and harvesting are followed.

[1] https://consult.defra.gov.uk/environmental-quality/clean-air-strategy-consultation/

Cultivating energy crops may also have biodiversity benefits, provided that management intensity is reduced compared to that for arable crops and that intensification of agricultural production elsewhere is not required to release land for energy crop cultivation.

In the case of forestry resources, the impacts on soils from removing forest residues can vary widely and are dependent on the amount and type of residues removed, site characteristics, species and harvesting methods. Mitigation of any impacts is best achieved by understanding specific impacts for the national or sub-national level and creating specific sustainable forest management plans that prevent the removal of too many residues. Such plans can also ensure that removal of residues is not at a level that will reduce biodiversity.

Therefore, in summary, providing long as appropriate governance is applied, a good guidance framework is in place, all socio-economic and environmental issues are considered, and the impacts are monitored, it should be possible to expand biomass supply in a sustainable way.

Acknowledgement

The authors would like to thank the stakeholders who gave their time to provide information and feedback on issues that influence biomass supply chains.

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1 Introduction

1.1 Background

In 2015, Ricardo Energy and Environment updated the modelling of UK and global biomass resources for The Department for Business, Energy and Industrial Strategy (BEIS)[2]. The results of this modelling indicated that resources are available now, including forest resources and agricultural residues. It showed that these resources could be increased in the future if the market is right and that biomass energy crops could be a significant resource in the future. The estimates were based on best current estimates – on modelling of forestry inventory, estimates of agricultural residues produced at harvest and conservative estimates of land potentially available for energy crops. The extent to which these resources may be realised through natural market development is not clear and there are considerable uncertainties in some of the estimates. Furthermore, they do not provide an understanding of:

- The circumstances that will enable these technical potential estimates to come to pass.
- Whether these circumstances vary depending on the region.
- Affordability and sustainability risks.

This report examines these points in more detail, specifically:

- Factors that influence market development, including financial and non-financial issues.
- Barriers to expanding biomass supply chains.
- Strategies to overcome these barriers.
- The impact of global biomass expansion on market prices.

Additionally, it examines the environmental and socio-economic impacts of increases in biomass supply. It does this by drawing on stakeholder input and through studying specific regional issues that provide representative assessment of barriers and requirements for biomass supply chains.

The amount of biomass resource available is uncertain. In this work, the study team sought to achieve a realistic understanding of the strengths and weakness of the evidence relating to the availability and cost of biomass, and a high-level understanding of the barriers relating to access to UK and imported biomass under a range of biomass demands.

To understand how the estimates of availability can become an available resource, it is necessary to understand:

1. The costs/price of biomass resources.
2. The barriers to production of biomass (policy, capacity, logistics and market failures).
3. Local demand for biomass and markets that compete for the use of biomass resources.
4. Where environmental risks could and should constrain supply.

1.2 Aims and objectives

This study aimed to reduce the gap in understanding of the availability of international biomass resources by looking at diverse situations (types of biomass and regional factors) to examine the following issues in more detail:

- What the barriers are to biomass in different markets.?
- To what extent can increasing the biomass price alone overcome barriers?

[2] The modelling assumes that waste reduces over time and that resources will be used domestically . It also assumes that other UK resources will be used in the UK. It does not include an estimate of in-country production of biomethane that could be imported.
https://www.gov.uk/government/publications/uk-and-global-bioenergy-resource-model

- How significant are barriers that cannot be easily influenced by the biomass price?
- Are there inherent factors that make biomass from one region or one type of feedstock less likely to be accessible than another?
- What the important impacts are that would need to be mitigated as part of the process.

It did this by:

- Working with international experts with experience of biomass resourcing in Europe, North American, South America and Africa.
- Evaluating data on international biomass resources, ease of doing business, rule of law, governance, etc.
- Undertaking a high-level evaluation of barriers to international biomass supply and opportunities for developing a sustainable supply.
- Examining specific examples of markets with significant potential, but which are underdeveloped.
- Assessing the potential environmental and social impacts from the use of these sources of biomass.

Using insights gained from this analysis, work was then carried out to look in more detail at:

- The key factors that may influence global biomass supply and its access by UK energy markets.
- Financial and non-financial factors that may enable or prevent this taking place and how these factors may vary across regions.
- Whether it is possible to mitigate environmental and social impacts, and to encourage or enhance any benefits from biomass supply.

This report summarises the findings of this analysis.

1.3 Sources of biomass

The biomass sources examined in this study were limited to those that could be potentially important to global market development and, as part of this, to UK supply. The study did not consider wastes and agricultural residues that may be important locally and globally but could be too costly to collect and process for the international market. The main considerations for this report were restricted to two potentially important sources of biomass:

- Forest residues produced from plantations or actively managed forests. Resources from tropical rain forests, designated forests (e.g. forests in national parks) or naturally regenerated forests that were not under active forest management were excluded. The resources that were considered for use in bioenergy only included sawmill co-products without an alternative market and forest residues that could be removed without harming forest productivity.
- Energy crops that could be grown on marginal land that is not used for agriculture or that returns poor agricultural yields. Land that is designated or of high biodiversity importance was excluded. As current sustainability criteria do not allow the felling of forests or conversion of wetland to grow energy crops, it has been assumed that this will not happen. The energy crops assessed are perennial energy grasses such as miscanthus, woody crops such as short rotation coppice (SRC) and crops such as energy cane planted for a food and energy product.

2 Results

2.1 The biomass resource

2.1.1 What the supply chains look like

2.1.1.1 Current imported supply chains

The UK has imported biomass for bioenergy since the start of the Renewables Obligation in 2002 when power stations imported agricultural residues and wood pellets for co-firing. This use has been monitored by Ofgem since 2009. In addition, the Digest of UK Energy Statistics (DUKES) publishes a timeseries of data on imported wood, which is shown in Table 1[3].

From these sources, it can be seen that the following supply chains have been used for importing biomass into the UK:

- Agricultural residues such as olive cake pellets and pumice from Spain, palm kernel expeller from Asia and sunflower husks from the Ukraine – all imported for co-firing at coal-fired power stations.
- Wood pellets imported from the EU and North America for co-firing, electricity generation and heat production (under the Renewables Heat Incentive (RHI)). The main EU countries importing into the UK are Latvia and Portugal; the main countries outside of the EU importing into the UK are Canada and the USA.

Forestry supply chains have included sawmill co-products, forest residues, bark and forest thinnings, which have been used in the production of pellets for import to the UK.

Table 1 UK imports of wood pellets and other wood for energy use

Year	Pellets		Other wood		Total
	EU (kt)	Rest of world (kt)	EU (kt)	Rest of world (kt)	All (kt)
2008	181	142	323	26	672
2009	42	3	90	136	271
2010	40	511	109	42	702
2011	115	900	97	7	1,119
2012	123	1,364	107	3	1,597
2013	391	3,041	108	5	3,545
2014	968	3,789	96	21	4,874
2015	1,785	4,734	146	60	6,725
2016	1,398	5,671	172	57	7,298

Source: Digest of UK Energy Statistics 2017: Foreign Trade Statistics

2.1.1.2 Current UK supply chains

UK supply chains have been more diverse than imported supply. This is because there are sources that would be difficult to import because of the low energy density of the fuel and resulting transport costs of material or because it is a waste that is usually treated locally. So, in addition to the use of virgin wood fuels (pellets and chips), UK supply chains have included:

- Energy crops used for electricity generation and heat.
- Straw used for electricity generation and heat.

[3] See https://www.gov.uk/government/statistics/dukes-foreign-trade-statistics

- Waste used for electricity generation and combined heat and power (CHP).
- Waste wood used for electricity generation and CHP.
- Arboricultural arisings used in electricity generation.
- Oat husks and similar residues used in electricity generation.

Wood, typically from sawmill residues, forestry thinnings or residues, is the most used solid biomass fuel, followed by agricultural residues such as straw. Energy crops including miscanthus and short rotation coppice (SRC) have been used, but in relatively small quantities (less than 60,000t/year).

2.1.1.3 Potential forestry resource supply chains

Regions that are exporting significant quantities of wood pellets and chips include the USA, Canada, Russia and, within the EU, the Baltic states and Portugal. The UK and global model used by BEIS[4] indicates that international forestry could provide increased biomass supply. Wood from tropical rain forests or other unmanaged naturally regenerating forest is excluded from this model.

Wood used for biomass comes from production chains developed for other wood products, mainly sawn timber production. Wood pellet production uses wood that is not suitable for other wood product chains. This includes forest residues and small roundwood cut at the time of harvest, thinnings cut in the management of forests and from co-products (e.g. chips and sawdust) generated in sawmills. These co-products and small roundwood are also used for other forest products, notably pulp, paper and panel board. The source of fibre for wood pellet production is reliant on these supply chains and integrated with them because the market value of the wood used for energy is not sufficient to drive harvest in itself (or to drive the establishment of plantations). It was assumed that the use of wood for bioenergy would continue to be integrated with the supply chains for other forest products in the way that it is at present. This means that wood pellet production for large-scale import will continue to be influenced by the market for other forestry products and the source of wood used for pellets will depend on global markets for these other products.

Two forestry-pellet supply chains that could be used for UK imported supply are shown in Figure 1. These are modelled on established or potential supply chains where wood for pellets comes from two sources:

1. The use of co-products that are not used in other wood product supply chains.
2. The use of residues that are left in the forest after harvest. These residues may be left in the forest and be part of the management of soil, water and erosion on site. Alternatively, they may be piled at the roadside and are often burnt as part of managing disease and fire risk.

In this study, it has been assumed that any supply chain using sawmill co-products is likely to be in use now and that a secondary supply chain (the use of forest residues) is an option for extending supply in the future. This was based on examination of current pellet supply chains from sawmill residues and the increasing use (and interest in) forest residues for energy in North America.

The stakeholders important to each part of these supply chains include:

1. The forestry sector, already supplying saw logs and pulpwood to conventional forest markets. This sector controls access to forest residues and is fundamental to their supply.
2. Sawmill operators who control access to sawmill co-products.
3. Transport companies, important for transporting raw materials to pellet plants and pellets to ports. In some chains, these companies can also act as aggregators of supply.
4. Pellet plant operators.
5. Port operators who access port-side loading and handling facilities and storage at port.
6. Shipping freight operators.

[4] https://www.gov.uk/government/publications/uk-and-global-bioenergy-resource-model

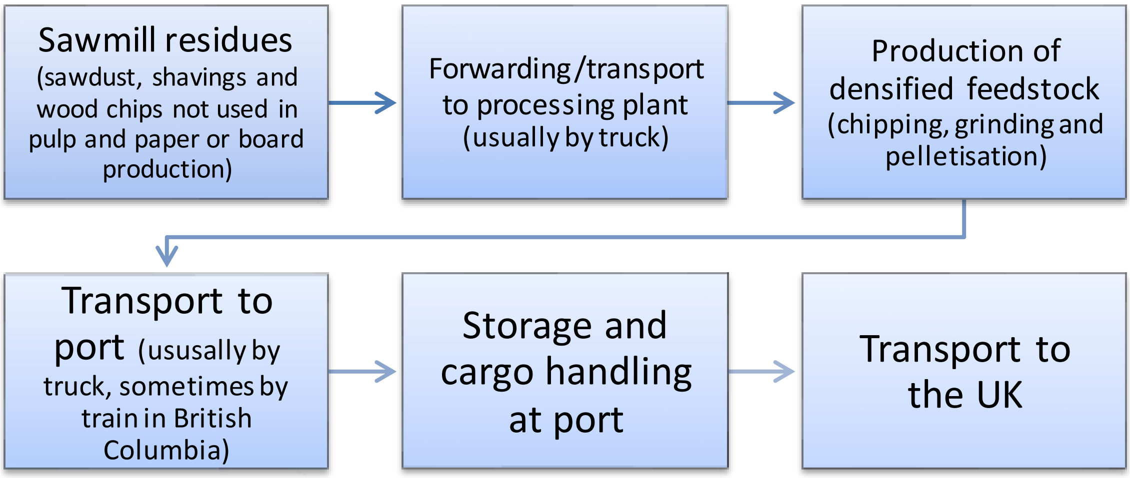
7. Investors in bioenergy or pellet plant supply chains.

For the supply chain to work, the contractual links between these stakeholders should provide benefit to each stakeholder at all stages of the chain. There are examples of integration along the supply chain to improve efficiencies and economics. These include:

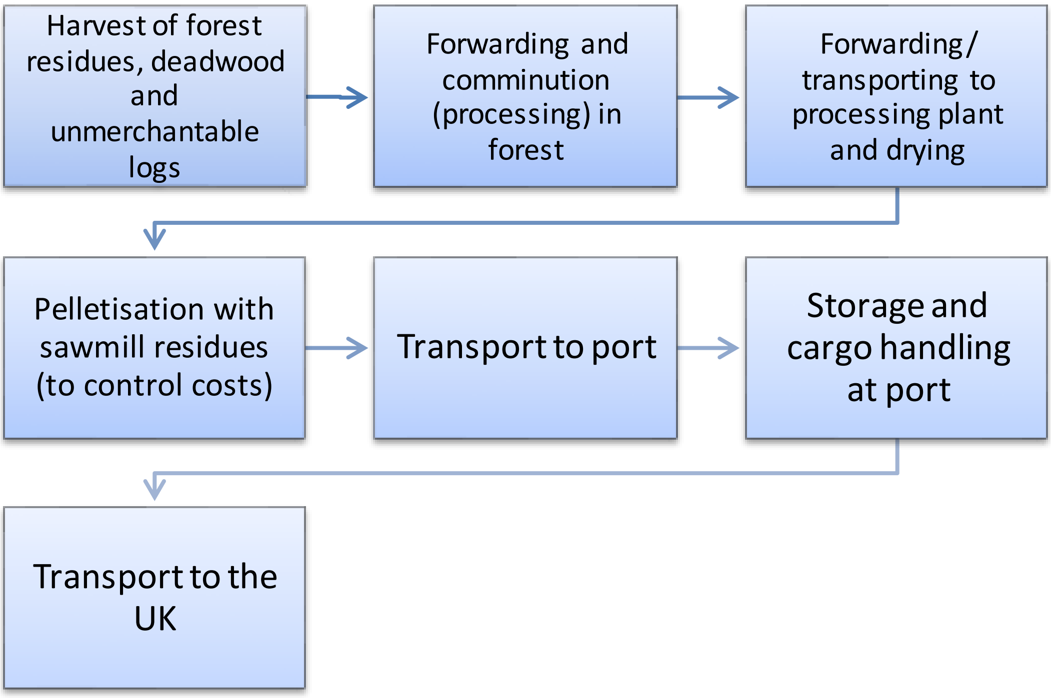
- Forestry companies that have formed joint ventures with investors in pellet plants in Canada.
- Pellet producers that have invested in logistics to ensure efficiencies in transport to ports and in infrastructure at the ports to enable economies of scale in shipping.
- Large-scale users have integrated with parts of the supply chain, including investment in pellet production abroad.
- In the UK, distributors of pellets for heat have formed close links with supply from the Baltic region and Portugal to augment UK sources.

Figure 1 Schematics of forest biomass supply chains

(a) The use of sawmill residues



(b) The use of forest residues[5]



2.1.1.4 Energy crop supply chains.

Energy crop supply chains were examined based on current supply chains in the UK and research available on future supply chains in the UK, Europe and the Americas. Crops include woody energy crops such as SRC willow, poplar or eucalyptus and energy grasses such as miscanthus in the UK and Europe, and giant reed switch grass, energy cane and elephant grass elsewhere. The US Government has supported a lot of analysis on potential energy crop production in the USA, mainly for liquid biofuels production. The Brazilian Government is supporting research into energy cane in Brazil. Energy cane is a hybrid sugar cane crop that has been bred to maintain sugar production and produce additional biomass residue that can be used as a fuel in energy production.

For energy crops, the high cost of establishment and the protracted period from planting to harvest means that crops are generally grown to contract and this is likely to be important in the future. In the UK, the current model is that these contracts are usually with the end user or an aggregator. Future scenarios may involve a greater role for an aggregator as an intermediate to balance supply and demand across several suppliers and end users. This is a plausible model for Europe and North America. This 'aggregated' model also supports a contract farming approach. This is where a third party supplies the planting material and plants it using specialist equipment. This third party then returns at harvest, using specialist mechanisation to harvest the crop. This model effectively results in the land is being 'rented', with the farmer providing local crop husbandry input as the crop develops. The model is efficient economically, as it overcomes costs associated with the need for specialist mechanisation for crops that are planted and harvested infrequently and addresses land manager concerns around husbandry of novel species.

Figure 2 shows the overall contract flows in an energy crop supply chain in the UK. The intermediate contract farming organisation may be set up by the end user or a separate entity acting in response to the end-user supply contract. It is also possible for the farmer/landowner to take the fuel supply contract direct from the end user and to invest in or to hire the required equipment to support crop planting and/or harvesting. This will simplify the contract flows to those just between the grower and

[5] Comminution is the processing of harvested material in the forest, normally chipping.

the end user. Figure 2 assumes that harvested material will go directly to the end user in the UK. In practice, some pre-processing (e.g. pelletisation) may be required, which will introduce the requirement for a contract with the pellet plant.

Figure 3 and Figure 4 show typical energy crop supply chains in the UK. For overseas supply, these are likely to be similar. However, they will include a densification stage, transport to the port, storage and loading at the port, freight to the UK, unloading in the UK and, as for UK supply chains, transport to the end user. As explained above, energy crops produced abroad may well be different species to those produced in the UK, depending on climate and agronomic conditions in the region where the energy crop is produced. So, for example, energy crops cultivated in the USA can include switch grass, energy cane and biomass sorghum as well as miscanthus and SRC. The analysis for this study has taken these differences into account. It also relies on estimates in the literature of available land, excluding land that is used for food production and has high biodiversity value or where water availability is insufficient for energy crop production. In this report, land for energy crops is described as 'marginal' land, but it is acknowledged that this is not a well-defined term, that is, researchers use it, but it often has varied meaning, including land in one study that is not included in another, or may simply be poorly defined. Current UK practice is to integrate the planting of energy crops with food crops, so that food-crop yield remains the same, but degraded land or land that produces poor food-crop yields is used for energy crops. Miscanthus grown in this manner is also used as a shelter for game birds across the UK. It may also be possible to use energy crops as wind breaks or to improve degraded land in the USA.

Figure 2 Examples of energy crop contract flows between the fuel supplier, aggregators and farmers

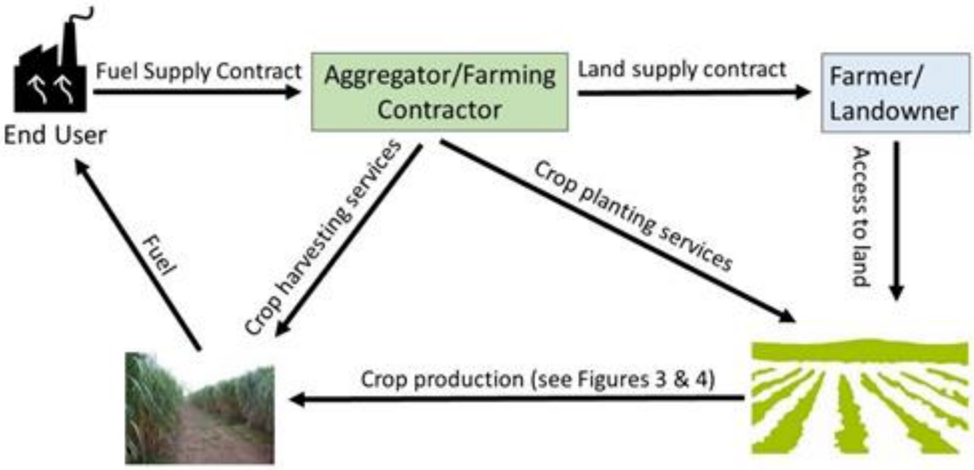


Figure 3 Schematic of a typical miscanthus supply chain

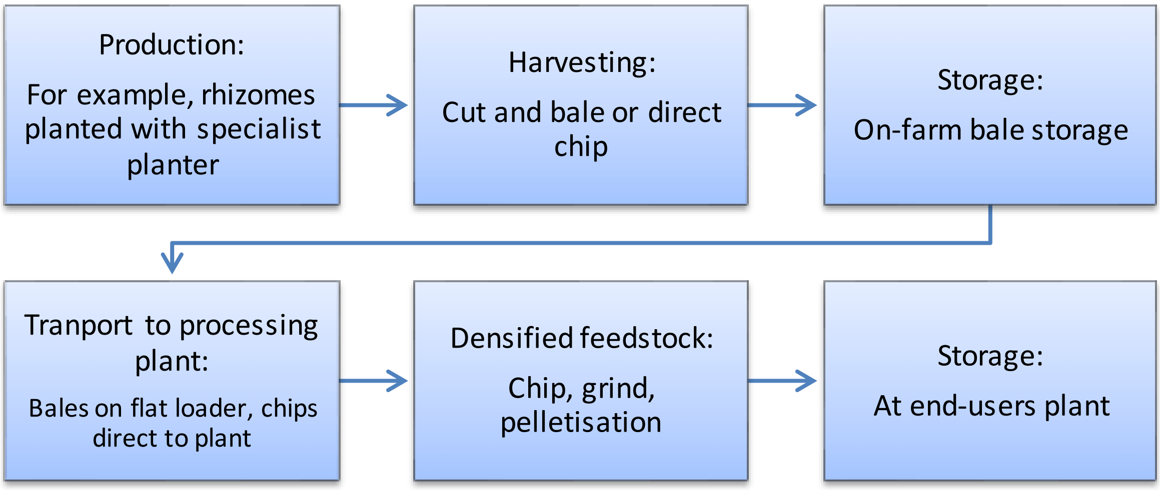
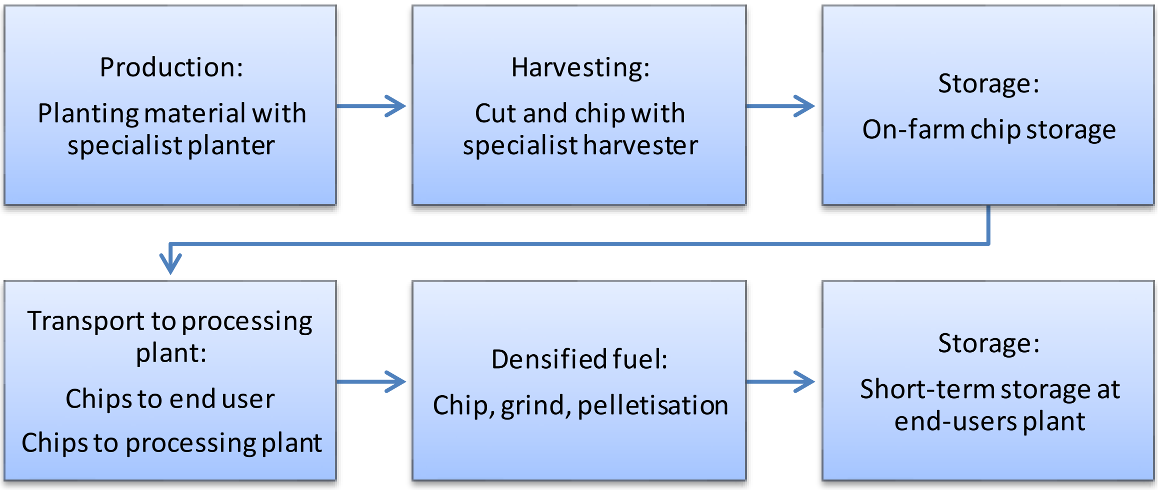


Figure 4 Schematic of a typical SRC supply chain



2.1.1.5 Gaps in supply chains.

This study examined whether there are gaps in the supply chains outlined above that can prevent their development.

Forestry supply chains

The 'sawmill residue to pellet supply chain' is well established and commercial in several regions (e.g. North America and Europe). While the use of forest residues is established in parts of Europe, outside of Europe, forest residues tend to be mixed with sawmill co-products to ensure that supply is economically competitive. However, there are significant regions where the forest products industry is established, but forest residues are not used for pellets, mainly because the distances involved result in poor economics. This means that there is a large resource that is not exploited globally, representing a large gap in the supply chain. This gap will include equipment needed for harvesting and collecting residues, transport infrastructure and the pellet production part of the supply chain. Although the harvest and collection of residues is probably the largest gap in such supply chains, there will be regions where pellet production does not exist at present and investment in pellet production and export infrastructure is also needed. As an example of the gaps in the supply chain for pellet production from residues, Table 2 lists gaps in the South African residue-to-pellet supply chain.

Energy crop supply chains

Energy crop potential is far greater than the resource being supplied at present. The gaps in the supply chain are in production of the crop for SRC. For energy grasses, such as miscanthus, the gaps are in supply and, often, in densification.

Energy cane is an interesting potential source. There is large potential to grow this crop in Southern USA and in Brazil. The Brazilians already use sugar cane residues as fuel for energy, although they do not densify this for export. They are also examining the use of high-yielding varieties of energy cane that could be used for sugar production and energy feedstock. Production areas are low, and expansion will depend on increasing confidence that the high yields obtained so far can be achieved more widely, that the varieties are not susceptible to pests or diseases and have no serious impact on water supplies.

The USA has similarly examined the potential of a number of lignocellulose energy crops and concluded that there is a large latent production potential. Lignocellulose is a generic term for the major part of a plant which is not normally used in food production, such as the stem, stover, husks etc. It is by far the greater part of current farm crops. Lignocellulose crops are those that are grown for this material instead of or as well as food production. Frequently these crops grow well in poor agricultural land. They include the energy crops mentioned so far. However, there are large gaps in this supply chain, as little energy crop has been planted to date beyond trials and demonstrations.

The barriers to addressing these gaps and expanding the supply chains are explained Section 2.2.

Table 2 Gaps between the historical sawmill residue and potential forest residue supply chains for pellet production from forest residue from plantations in South Africa

Supply chain stages	Gaps in the supply chain
Harvest	**Production of raw material:** forest residues are not harvested and mechanisms for harvest will need to be introduced. **Quality of raw material:** raw material quality, particularly trace components, will need to be understood. **Nutrient loss:** removal of residues may result in a loss of productivity. There is a need to understand the impact of removing residues on soil organic carbon, productivity and biodiversity, so that guidelines on how much residues can be removed are available.
Forwarding and processing in forest	**Plant and machinery:** machines designed for compacting residue and chipping are required. **Skills and capacity development:** to ensure a high level of productivity and consistency in the quality of plantation residue collected, there is a need to train staff and introduce quality control systems. **Supply agreements:** long-term supply agreements with forestry companies to collect plantation residue are required before removal of residues will be considered.
Forwarding/ transporting to processing plant	Infrastructure: integration of infrastructure such as road and rail with pellet plants may be important for where the residues are widely dispersed
Production of densified feedstock (pelletisation)	**Quality of pellets:** experience in the manufacture of pellets from processing and plantation residues is limited in South Africa. Pellets will need to meet export standards, so quality control systems will need to be introduced. **Plant and machinery:** fit for purpose, turnkey solutions are required due to the lack of experience in pellet production. **Selection of optimal location:** location can be a substantial influence on economic competitiveness. It is likely that proximity to biomass will be important to the economics of production.
Storage at plant	**Raw material:** separate silos will be required for different biomass (forest residue, wood offcuts, sawdust, etc.) to ensure consistent quality. **Pellets:** an enclosed warehouse facility capable of storing approximately 6,000t to 8,000t of pellets will be required at each pellet plant. **Loading systems**: onward transport (trucks or rail) will be required.
Transport to port	No gaps.
Storage and cargo handling at port	**Cost efficiencies**: for economies of scale, an enclosed warehouse facility and ship-loading systems that are designed to reduce handling time and demurrage[6] costs will be necessary.

[6] Port costs for failure to load or discharge the ship on time

Supply chain stages	Gaps in the supply chain
Transport to the UK	**Bulk carriers:** past pellet shipping from South Africa has used containers, but this increases unit cost. Optimisation of shipping (e.g. the use of dedicated bulk carriers) could be used to reduce transport costs if sufficient scale was achieved.

2.2 Key factors that influence global biomass supply

2.2.1 Financial barriers

A fundamental in the development of any market is the availability of finance on attractive terms that enables producers to achieve a return. For the biomass market is clearly linked to the cost of the resource and the price that can be achieved when selling it as a fuel.

Summary of financial issues

The major forms of funding for bioenergy supply chains are capital grants/government incentives, tax incentives, debt and equity. There are various needs for finance across the supply chain in different locations. In general, issues with finance are likely to be lower in stable markets such as the USA where the market for the biomass and the market price are clear. Additionally, the risks perceived vary by region, meaning that different sources of finance are more or less appropriate across biomass supply regions.

Passing the risks to the supplier often means that potential suppliers are reluctant to become involved. In the case of energy crops, the delay between initial investment in planting the crops and the return from harvesting is also a disincentive. Adoption by famers is likely to require good evidence that claimed yields are obtained in practice and returns at least match those that can be obtained from other land uses.

In the UK, the use of contractor services has decreased these risks for energy crops. In forestry, initiatives to support investment in the forestry sector can also be used to encourage sustainable harvest for bioenergy.

2.2.1.1 Access to finance

Access to finance is a problem in many markets and many regions, and the biomass supply market is no exception. Lenders will want to understand the risks they are taking not only across the whole biomass supply chain, but also currency and region-related institutional risks. Rates of interest will be higher for those schemes where risk is perceived to be high, adding considerably to cost. The cost of, and/or barriers to, finance is a function of the other risks or barriers described in section 2.2. The lower the risks/barriers, and the more stable the institutional environment, the lower the perceived risk. This translates into lower cost of finance. In summary, the assessment of the financial barriers encompasses the other factors outlined. This can be a high burden on the development of biomass supply chains.

Options for financing biomass supply include government support (such as grants, environmental schemes to maintain land/ecosystems in good repair and support for tariffs), tax incentives (such as accelerated write-downs of investment) equity or debt finance, private equity funds and joint ventures (developed to share risks). The use of some of these options is examined below. The issues faced by developers in obtaining finance often relate to the region where investment is needed, the business model for development of the biomass supply chain (and how risk is shared) and general market conditions. At the core of this is the business model proposed – how the supply chain will be developed, who takes on supply risks and the experience of the stakeholders in the supply chain (including their experience of logistics, storage, handling, health and safety, etc.).

2.2.1.2 Risk management

Finance is particularly difficult for biomass supply in developing and emerging economies such as Africa or South America, where political or currency risk may be influential. But there are also issues in obtaining finance for developing biomass supply in most regions. This is because the supply is often developed on individual farms (requiring farmers to make decisions and establish the crop) or as part of forest management (requiring additional investment in equipment and skills at the harvesting stage in the forest). Often, the risks of supply are passed back to the farmers or foresters. For this reason, they can be reluctant to invest in supply and are wary of achieving a good return. In addition, smaller market players such as individual farmers and forester may find it difficult to access finance for the additional investment required. For example, until there are good demonstrated returns from turning land over to biomass supply, which compare favourably with returns from other uses of the land, farmers will remain reluctant to establish energy crops. This is important, as farming and forestry sectors control access to the resources required for biomass supply.

The technical and financial risks faced by the biomass supply sector include supplier performance, guarantees on pellet plants, offtake contracts, credit worthiness of the counter parties and price indexation. Regulatory and compliance trends also play a role. For this reason, governments may provide incentives to help establish supply. These can be in the form of attractive regional incentives (as in Box 3 on Uruguay) or incentives to the bioenergy plant that enable investment in the creation of supply chains. One well-known government investment to encourage large-scale biomass supply is the Brazilian production of ethanol – see Box 1 on RenovaBio[7]. Other governments, such as the UK Government, have provided support such as planting grants, tariff support, and research and development to produce bankable data. However, most analysts agree that the downside of such incentives is that government funding can be limited, and it may come with strict requirements such as sustainability reporting.

Box 1 Example of government investment in bioenergy: RenovaBio, Brazil

In 2016, the Brazilian Government invested in a new initiative, RenovaBio, to develop a bio-based economy in Brazil. There is an ambition to increase the production of energy from biomass sources for use in Brazil, to provide 18% of national energy needs, as well as increasing its role as a significant international supplier. This is part of the Government's plan to meet its commitments under the Paris Agreement to decrease carbon emissions by 37% by 2025 (compared to 2005). One of the targets under RenovaBio is for fuel distributors to cut fuel emissions by gradually increasing low carbon biofuels volumes. To meet greenhouse gas reduction targets, distributors will have to purchase Emissions Reduction Certificates (CREs) from biofuels producers. It is anticipated that this will do two things – decrease fuel GHG emissions and increase the use of local biofuels[8].

The major biomass crop in Brazil is sugar cane. A realistic conservative estimate for expansion of sugar cane production is that the area dedicated to sugar cane could at least double in the medium term. Principally, this could be achieved by extending sugar production to more land than is currently used for low intensity animal grazing and increasing livestock intensity in other areas to maintain current levels of production, in accordance with Brazil's agro-ecological zoning practice. This would need to be driven by a strategy designed to increase the overall supply of sugar (for food or as an ethanol feedstock) in-line with the RenovaBio strategy.

Energy crops are expensive to establish and provide returns over long periods after a 2 to 3-year delay. During crop establishment the upfront risks are important for farmers and the return often insufficient in the short term to attract equity finance. Consequently stakeholders in the energy crop

[7] For example, the Brazilians have announced a new federal programme recently, 'RenovaBio' that will give fuel distributors targets to cut emissions and force them to gradually increase biofuels volumes and will emphasise the importance of the bioeconomy in Brazil. https://www.reuters.com/article/us-brazil-ethanol-policy-analysis/new-brazil-ethanol-policy-should-boost-demand-ma-idUSKBN1AR22Q

[8] See, for example, http://www.udop.com.br/download/noticias/2017/24_07_17_artigo_renovabio.pdf and http://english.unica.com.br/in-the-media/18105453920311011093/brazil-weighs-biofuel-mandates-for-fuel-distributors-to-cut-emissions/

supply chain have suggested that financiers with a longer-term outlook, such as pension funds, may have a more appropriate approach for energy crops. For these investors to enter this market, they would need to be sure of a long-term market for energy crops in bioenergy and/or bio-products. This creates a major challenge for the development of large-scale energy crop supply – who funds the establishment of the supply chain, and who takes the risks of supply failure?

Some UK contractors have recognised and by-passed this issue by providing complete contracting services to develop energy crops, such as miscanthus, described in the 'UK energy crop contractor model' below.

Box 2 The UK energy crop contractor model

As with all energy crop production, the high cost of establishment and the protracted period of time from planting to harvest means that crops in the UK are often grown to contract. These contracts are usually with the end user. An alternative scenario involves an aggregator as an intermediate to balance supply and demand across a number of suppliers and end users. This 'aggregated' model also supports a contract farming approach, where a third-party contractor, supplies the planting material (rhizomes, seed material etc) and plants it using specialist planting equipment. The contractor then also uses specialist mechanisation to harvest the crop. In this contractor model, the land is effectively rented, and the farmer provides local crop husbandry input as the crop develops. This overcomes the barriers associated with the need for specialist mechanisation for crops that are planted and harvested infrequently. The way this model works is shown in Figure 2.

Often considerable investment is required to enter the biomass market. This includes the development of infrastructure and logistics. The allocation of risk along the pellet chain (e.g. for pellet standards, sustainability compliance and infrastructure failure) may be unaffordable in some regions, particularly in Africa and South America. In these cases, the allocation of risk in the contract may be unattractive to potential biomass producers. The failure of two pellet schemes in South Africa in recent years[9] has resulted in difficulty in financing new plants. A contributing factor to the failures were that the anticipated market for supply for electricity generation did not materialise as the power plants could not secure a power purchase agreement. While an export market to Europe was established initially, this subsequently diminished due to increasing logistical costs within South Africa and restricted purchasing power from Europe.

To overcome issues like this, Uruguay has addressed some of the risks of developing its forest products industry from local small-scale foresters by:

- Attracting investment from large international companies with the capacity to develop the country's forest resource.
- Allowing access to the same protection as national companies through tax incentives.
- Establishing duty-free zones.

This model transfers the risks for investment in forestry to the forest products companies. It also accesses foreign finance for energy generation (see Box 3 on foreign investment in Uruguay), but it means that the Uruguay Government may have little say in how these markets are developed. In this case, in deciding between export and domestic pellet markets, the forest companies can decide on the basis of which provides the best return.

Box 3 Foreign forest investment in Uruguay

Over recent years, forestry has become an increasingly attractive sector in Uruguay. This is due to Government incentives to encourage inward investment. A number of established forestry companies are now international. This approach has enabled the capacity of the sector to increase (through development of skills, provision of equipment, and investment in processing and logistics).

[9] This is examined in detail in Petrie, B. 2014. South Africa: A case for biomass? International Institute for Environment and Development, London.

Furthermore, several of these companies also contribute to energy generation within Uruguay using co-products from their activities. These companies include:

- UPM – installed capacity 161MW.
- Bioener, in Rivera – installed capacity 12MW.
- Weyerhaeuser Productos S.A. – installed capacity 12MW.
- Montes del Plata – installed capacity 170MW.
- Ponlar using residues from Dank S.A. – installed capacity 7.5MW.

Alternative models for biomass supply

In some regions, joint ventures with biomass producers or investment by the energy plant developers further up the supply chain in infrastructure or skills provides increased certainty in the supply chain. Ultimately, this is done with the intention of securing supplies or increasing cost efficiencies, but it can also provide an experienced partner in the supply chain to satisfy finance requirements and to lower risks in the supply chain. In the well-established Southeastern USA pellet market, the Drax Group Ltd has integrated into the pellet supply chain in the USA by purchasing pellet plants[10] and the US pellet producer, Enviva, has secured long-term contracts to supply pellets to Lynemouth and MGT Teesside Ltd in the UK[11]. This provides security around biomass supply. This is because although imported pellets may be more expensive than other types of biomass supply, they form a secure biomass supply chain that large-scale users can depend on. This enables the users to develop a range of contracts with different risk levels to meet their supply needs. Such investments answer the needs of financiers for a secure supply strategy before finance for the bioenergy plant is agreed. The larger the scheme, the more important this issue. For financiers, security of supply is an important issue – they often require a credible, financially secure supply partner with proven ability to meet supply needs. This is not easy in unproven markets, such as energy crops, where there is little experience globally. In addition, it is likely that pellets from energy crops will be more expensive than pellets from the forestry products sector. This may make it harder to create an attractive financial proposition from overseas energy crops in the wider biomass market.

Equity finance may overcome some of the issues, but results in the developers losing some control. Private equity companies have provided important investment in Canadian pellet supply but may find other regions riskier. Due diligence requirements are often high for venture capitalists and private equity. Some regions may find it difficult to meet these requirements due to lack of demonstrated viable supply in the first place and because institutional factors are not in place (such as sustainability certification).

US biofuels companies have been successful in exploiting another model for supply – by including the crop producers in the project in return for a share in the equity and a return on their investment if the scheme is successful. In this way, there is mutual interest in the supply of biomass to the energy plant and in the success of the plant. Likewise, Canadian forestry companies are now showing an interest in Canadian pellet plants using a joint venture model.

2.2.2 Other barriers to in-country biomass potential

In addition to financial barriers, a number of other potential barriers to the development of supply chains for biomass were identified in this study. For each of these, consideration was given to how difficult it is to overcome these barriers, given the establishment of a market and increase in price.

Barriers that have a large impact on supply and are difficult to overcome in the short term were ranked as 'high'. Those barriers that have a large impact on supply but could be overcome in the

[10] http://humberbusiness.com/news/drax-completes-27-5m-us-pellet-plant/story-5512-detail/story, http://biomassmagazine.com/articles/14335/drax-completes-acquisition-of-louisiana-pellet-plant

[11] https://www.linkedin.com/pulse/enviva-q2-results-highlight-long-term-offtake-pellet-celso-oliveira/ and http://biomassmagazine.com/articles/13579/tees-rep-finalizes-project-financing-enviva-off-take-agreement

medium term or addressed through price increase were ranked as 'medium'. Those barriers that are less restrictive on supply and can be addressed in the short term or by price increases were ranked as 'low'.

Section 2.2.2.1 discusses market, physical, technical and institutional barriers that were identified from analysing a variety of forest residue and energy crop markets in regions with the potential to supply the UK. This is followed by examining how difficult it is to overcome the most common or important of these barriers. Throughout this section, practical examples of barriers (and how to overcome them) have been provided for illustration.

Summary of other barriers

Apart from the barrier posed by lack of availability of finance, the most important barriers relate to market development, production of biomass (planting energy crops and harvesting forest residues), transport infrastructure and long-distance logistics because they are fundamental to the success of a supply chain. These barriers are relatively hard to overcome and require considerable investment of funds (e.g. in new or improved infrastructure) and the development of policy that will help to create a stable market. It is likely that overcoming them will take some time (i.e. they will only be fully resolved in the medium term).

Second-tier barriers relate to the understanding and introduction of sustainability and technical standards; infrastructure necessary for the biomass supply chain (harvesting equipment, storage, pellet plants, etc.); and capacity building (development of skills, provision of data/information or tools to understand the resource etc.). These barriers can all be addressed but require significant investment of funds and time to be overcome.

2.2.2.1 Market barriers

The most commonly cited market barrier is the **absence of a clear market opportunity for large-scale development of bioenergy supply**. The absence of this market is most important when bioenergy is in its early stage and still developing. In theory, it may have more impact for energy crop supply chains than more established pellet supply chains, but most stakeholders reported that the absence of large-scale markets inhibits the development of all supply chains. Stakeholders also said that this barrier is one of the most important and difficult to address. Price increases help but, most importantly, stable prices and a stable market that provides a return to all players in the supply and use chain are required.

Another barrier cited by stakeholders involved in pellet trade and discussed frequently in trade journals is **currency volatility**. A consequence of this is varying prices, which can result in price hikes or troughs on the spot market. For some exporting countries, this has been a critical issue that has impacted pellet export to Europe. This has affected supply from South Africa in the past and is important in the competitiveness of US imports compared to European imports[12]. Currency volatility is likely to be an important barrier in many developing and emerging economies and one that is not easy to address. UK companies importing large-scale pellet supplies from overseas have addressed this issue by agreeing long-term bilateral contracts and hedging against currency volatility. However, it also affects smaller scale imports from Europe. For example, European pellets are cheap on the spot market at the moment compared with those on the North American market because of the difference in exchange rates. Currency volatility also impacts freight prices, as these are usually priced in US dollars (USD).

Inter-regional competition may be important in determining whether regions develop supply potential, particularly in regions further from UK and European markets. For example, South African

[12] See, for example, Bingham J (2016) The global outlook for wood pellet markets, presented at WPAC annual conference, September 2016 https://www.pellet.org/wpac-agm/images/2016/JohnBingham-The-global-outlook-for-wood-pellet-markets.pdf

biomass supply is being investigated by Asian companies. This provides important competition for the UK because Asian markets can take chips, whereas the UK requires pellets (for phytosanitary reasons). South Africa is already set up to export chips for pulp and paper markets, so for the Asian biomass markets, investment in pellet production may not be necessary, at least in the early stages.

There may also be other **competition for the resource from other product markets**. For forest residues, there is competition for wood chips for pulp production or panel board. For energy crops, competition for the land may represent initial market competition. As energy crops become established, there may be other local markets, such as domestic energy and bio-products that use these lignocellulose feedstocks. The latter will be important in North America and Brazil. In Europe, rising renewable energy targets will result in increased demand from markets that have traditionally supplied pellets to the UK.

Likewise, **established forestry and agricultural markets are important influences on the availability of resources for biomass**. Markets for forest products drive forest harvesting activity and the sawmill co-products market. Availability of raw material for pellet production is highly influenced by these activities and their markets, because material from harvesting residues and sawmill co-products is be used for pellets. In this way, pellet production is closely linked to other, more valuable, supply chains for forest products. The production of pellets does not drive harvesting, as it is driven by higher value markets, such as the saw-log market.

Market conditions also influence farmer decisions regarding planting of energy crops. For example, Box 4 summarises the situation in the UK.

Box 4 UK experience of energy crop markets

The experience in the UK for SRC and miscanthus has been that promised market has not materialised. This is due to the failure of schemes to progress (e.g. Arbre project[13]) or that the product has been unable to compete on price grounds for large-scale schemes (e.g. miscanthus can be more expensive than straw bales or some imported wood pellets bought on the spot market for large-scale electricity production). It is also the case that the current small production volumes distributed over large areas mean that the cost of supply is higher than if the crop were in large-scale production. These factors combine to mean that there is no certainty in the market, especially around the returns that can be made by the grower. In a sector with a good understanding of and ability to track its traditional markets, the unknown nature of the energy market is seen as a long-term risk.

Several studies in the UK, Europe and North America have demonstrated reluctance to establish energy crops for all of the reasons above, but also down to:

- More familiarity with margins for other, annual crops.
- Reluctance to commit to long-term crops (i.e. lack of flexibility).
- Perception that there is not enough land available for bioenergy crops (or that suitable land is not available and that growing food crops is more important).
- Wish to preserve the cultural landscape.
- Issues related to water impacts.
- Distance to processing plants.
- Lack of knowledge of the crop.
- Suspicion that companies will not fulfil contracts to buy energy crops.

[13] Adams 2016 A critical appraisal of the effectiveness of UK perennial energy crops policy since 1990 Renewable and sustainable energy reviews 55 (2016).

To address these, Wilson et al (2014) call for 'mechanisms to address profitability, market risk, land suitability and land quality concerns, combined with issues of lack of knowledge of energy production amongst farmers in general, and the need for landlord permission on some tenanted farms. Policies supporting the production of energy crops on lower grade agricultural land, or land with lower agricultural or biodiversity potential must acknowledge issues of economic, tenancy and personal objectives if they are to succeed[14].' As with the other barriers above, the establishment of a stable market is important in overcoming the reluctance of farmers to commit to energy crops.

It is likely that other issues will also impact the production of energy crops in South America and Africa, including land rights/social-economic issues, the unknown nature of the crop and the potential for displacement of local food production. South Africa established a strategy for biofuels production that banned the use of food crops (such as maize), considered the use of water by potential biofuels energy crops, and banned crops (such as jatropha) on the basis of food security and because of fears that it will become invasive[15].

2.2.2.2 How easy is it to overcome these market barriers in international and UK supply chains?

The barriers listed in this section have a high impact on biomass supply chains and most of them are difficult to overcome. As discussed above, there are options to address currency volatility. In addition, established markets that influence biomass resource availability work in positive and negative ways on biomass supply chains, and are likely to influence prices and be influenced by prices. For instance, fluctuations in demand for paper and construction timber caused by a move away from the use of newsprint and fluctuations in the economy will impact on forest biomass resource availability. Similarly, weather impacts on global yields of fodder crops can impact on the production of annual energy crops (such as sorghum).

Most of these barriers can be addressed in the short to medium term. However, the impacts of regional markets that are closer to the biomass resource – particularly the emerging renewable energy markets in Asia and the influence of other, higher value, markets on biomass production – are likely to be long term.

2.2.3 Physical barriers

- The **cost of transport** for land and sea freight can be significant, particularly for resources from the Southern Hemisphere that are exported to Europe.
- **High logistics costs** – many forestry regions are remote (even in developed nations, such as Canada), so there may be a need to invest in roads or rail links to enable efficiencies in logistics. Distance from the UK can also be an issue for some regions.
- **A lack of necessary infrastructure**, such as roads, bridges or rail and lack of suitable handling and storage systems at the port. The potential risk of fire during pellet storage means that storage should be correctly designed to minimise the likelihood of fire and include detection and control systems.
- There may be a **lack of planting and harvesting infrastructure**, particularly for energy crops, but harvesting equipment and infrastructure are also important for forest residues.
- **Climate change** and other issues that may result in decreased growth and yield or increased mortality from pests, diseases and fire[16].

[14] Wilson P., Glithero N J and Ramsden S J (2014) Prospects for dedicated energy crop production and attitudes towards agricultural straw use: The case of livestock farmers. Energy Policy 74 101-120. See also: Jonsson A C., Ostwald M., Asplund T and Wibeck V (2011) Barriers to and drivers of the adoption of energy crops by Swedish Farmers: An empirical study. World renewable energy congress 2011, Linköping Sweden.

[15] Department of Minerals and Energy, South Africa (2007) Biofuels Industrial Strategy of the Republic of South Africa.

[16] This was mentioned as a concern in South Africa; but it is also a universal concern in agriculture, see, for example: Walthall et al (2012)'s report for the US Department of Agriculture.

2.2.3.1 How easy is it to overcome these physical barriers?

These physical barriers can have large impacts on supply. Cost of transport is a good example of this, particularly for resources that are a distance from the pellet plant. However, in developing countries, lack of infrastructure is an important barrier as well.

A lack of infrastructure at the port has an impact on cost efficiency, rather than being a barrier to participation in the market.

A lack of planting material has a large impact in the near term but can be addressed in a relatively short time. Likewise, a lack of harvesting equipment can have a significant impact in the short term, but can be resolved, given time and a stable market.

All these barriers can be addressed more quickly if the price increases.

Climate change issues are intransigent, and the biomass supply chain will have problems addressing them. However, suppliers may adopt different cultivation strategies to adapt and choose more resilient species, where information is available. Price increases for biomass pellets from forestry residues would not change this as adaptation will be driven by higher value forest products markets. Price increases for energy crops would make a difference as they would provide some funding for demonstrating different varieties.

2.2.4 Technical barriers

There are a number of technical barriers that need to be addressed for new supply chains. These include:

- **Standards**: UK/EU standards for domestic and industrial pellets may prove to be a significant hurdle in inexperienced markets in Africa and South America. These standards concern the production of biomass to fuel-quality standards; and complying with health and safety requirements for storing and handling.
- Energy crops: the **novel nature of the crops** and relatively low quantities grown globally mean that the crop is unfamiliar to growers. This creates capacity barriers – a lack of skills and understanding of what is required to grow the crop (including how to establish it), how to avoid disease or yield issues and how to harvest the crop.
- Energy crops: there is a **need to decrease establishment costs and increase yields**, including developing and demonstrating new varieties with promising yields. Potential growers will need to be confident that substantial yield increases can be achieved for long periods, and that they can be confident in the techniques for growing and harvesting these varieties.
- Forestry residues: it is known that extensive whole-tree harvesting, and removal can result in **nutrient depletion on site**, so it is necessary to understand the optimal level of residue removal for each site and to develop guidance on how residues can be used without harming the forest structure, biodiversity and productivity. This guidance is needed at the national or sub-national level as it needs to be related to specific local conditions.
- **Degradation of raw material**: this can occur in the supply chain pre-pelletisation and will lead to dry matter loss and potentially health issues. While stemwood and residues are relatively stable, some degradation due to microbial and fungal action will occur over time. If the material is harvested as chips, bacterial action on the liberated sap can cause heating and loss of dry matter. As a consequence of this, microbial spores can form that present health issues if the material is being stored in a confined space. Similar issues will also affect biomass crops. All of these can be overcome by pelletising the material quickly after harvest.
- **Lack of experience of pelletisation** of biomass and of the capacity needed to develop the market in some regions.
- Pelletisation: there is a need to **demonstrate efficient and economic performance of the pre-processing and pelletisation process.** This must be done for the full range of biomass

materials proposed and at a large scale. The performance of the pelletising plants can be sensitive to the nature of the raw materials involved and, for example, to their moisture content[17].

- **Demonstrating performance of energy crop pellets in designated end uses**: energy crops can have a high mineral content that can affect the combustion performance and may also impact biochemical and microbial processes. For example, anaerobic digestion processes need to take mineral contents into account because of potential residue issues. This will be overcome with the use of specially designed systems, but research is required in their development.
- **Pellet handling and storage**: degradation of the pellets during transport and consequent handling or health and safety problems.

2.2.4.1 How easy is it to overcome these technical barriers?

These technical barriers have a substantial impact on the establishment of supply chains in many regions. However, most are relatively straightforward to overcome in the short term, particularly those relating to pellet production, standards and forest management practices. Increased prices would enable this to happen relatively quickly. The exceptions are the technical barriers relating to growing energy crops. These have a significant impact that will take time to overcome without incentives.

2.2.5 Institutional factors

- Governance (e.g. corruption and bribery) can be important in some regions, adding additional costs or discrediting land-use policies.
- Lack of experience in and a proven track record of evidence for sustainability certification compliance.

2.2.5.1 How easy is it to overcome these institutional barriers?

These barriers all have a significant impact on biomass supply in some regions. Sustainability certification compliance and the lack of skills can be overcome given time and capacity building budget. However, the governance issues outlined above will be more difficult to address and could either prevent the establishment of a successful biomass supply chain or result in a discredited chain. This issue hit liquid biofuels crops in the 2000s and resulted in some of the land-use clauses for the sustainability requirements in the Renewable Energy Directive and the Renewable Transport Fuels Obligation. UK sustainability requirements in the Renewables Obligation and Renewable Heat Incentive adopted similar approaches in 2015.

2.2.6 Capacity building

- Lack of skills and technical know-how – particularly in the production of lignocellulose energy crops and pellets to European standards.

2.2.6.1 How easy is it to overcome these capacity barriers?

These barriers have a significant impact on biomass supply in some regions. Introducing biomass crops on a large scale may be feasible using trained contractors, but routine care for the crops will require training of farmers.

Removal of residues during forestry operations will require training of established forest harvesting teams.

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[17] For example there can be a number of economic and performance trade-offs associated with pre-processing options (see e.g. www.eti.co.uk/programmes/bioenergy/techno-economic-assessment-of-biomass-pre-processing). The ETI is currently supporting a demonstration project which aims to show how the removal of impurities and contaminated material from sustainable biomass could make bioenergy cheaper and more efficient (http://www.eti.co.uk/programmes/bioenergy/biomass-feedstock-improvement-process-project).

These barriers are probably greatest in the introduction of novel energy crops. However, novel crops have been introduced worldwide. Therefore, if the market is there, then it is likely that the supply chain will adopt methods to train potential growers in the medium term.

Boxes 5 and 6 examine how barriers have been overcome in Brazil and South Africa.

Box 5 Strategies to overcome market, infrastructural and technical barriers in Brazil

Brazil is a global leader in bioenergy production and supply - the second largest ethanol producer globally, producing 28 billion litres of ethanol in 2016 (28% of global supply), mostly used internally as transport fuel[18]. It is also a significant producer of biodiesel (nearly 4 billion litres, over 10% of global supply), based largely on soy production. It is also an exporter of these fuels. In addition, bioenergy contributes strongly to electricity supply, providing 4% of electricity supply in 2015. This is seen as a strategically important complement to Brazil's hydroelectricity supply, which is sensitive to droughts that can cause supply interruptions. Brazil is also one of the leaders in global efforts to develop ethanol production based on the use of cellulosic residues, with a major interest in making ethanol from sugar cane production residues (bagasse). There are two operational commercial-scale plants in Brazil (owned by Raizen and Granbio).

There are also efforts to increase potential feedstock supply for such processes. For example, by collecting additional in-field residues from sugar cane production, improving sugar cane yields, and developing varieties ('energy cane'), which, in addition to having good sugar yields, have much higher overall biomass yields. The ethanol produced can then be used as a transport fuel and the residue used for energy. The potential for increasing exports of the chemicals produced is recognised in Brazil, which is using the ethanol as the basis for a bio-based chemical industry.

To achieve these changes, a series of barriers need to be overcome. For example, an improved understanding of the agronomy and yields of energy cane will be important. There will need to be investment in the harvesting of residues and the cane for sugar. Energy cane is not widely planted in Brazil and farmers will need to become familiar with this crop. Market structures for its harvest and aggregation will be required. Land will be needed to plant the energy cane. If the residues are to be exported for bioenergy, then infrastructure for densification, handling, storage and transport will be required.

To address this, Brazil is investing in research and development and has set up in a new initiative (RenovaBio), which sets ambitious new targets for the development of the bioeconomy in Brazil. Brazil has strong research and development competence in these areas. It has a long history of research in improved agricultural practice and mechanisation carried out by the Brazilian Agricultural Research Corporation (EMBRAPA), and strong research capability in organisations such as the Brazilian Bioethanol Science and Technology Laboratory (CNPEM/CTBE) and in its universities that will help this research and development.

The supply chain for sugar cane production and processing is largely managed entirely by the major sugar cane producers as an integrated operation – producing sugar, ethanol and electricity. This means that the control of the processes and the way in which innovations can be adopted can be rapid.

The contractual models for the export of solid biomass products are not yet mature. However, the model being developed by Cosan Biomassa for its pellet production plant – where a significant stake has been taken by Sumimoto, which has strong links to potential customers in Japan and Korea – may well become more common.

[18] IEA 2017a, IEA Market Report: Renewables 2017 https://www.iea.org/publications/renewables2017/

Box 6 Overcoming barriers: The example of South African wood pellet supply

Development of biomass export supply chains in South Africa will be influenced by:

- Availability of biomass in the country and the state of development of the supply chain.
- Existence of infrastructure.
- Institutional factors.
- General trading conditions.
- Moves to develop internal bioenergy markets.

Initially, it is likely that a sustainable pellet production industry would be based on thinnings from forest plantations and primary wood processing residues. In the future, this may be able to be augmented by agricultural residues and energy crops.

The barriers to unlocking this potential are the need for investment in equipment, skills and capacity to turn the available feedstocks into pellets for export. Logistics, especially in port storage and loading for biomass, need to be improved. Sea freight costs need to be reduced to make the export of pellets more competitive. Institutional barriers will also need to be addressed, particularly for environmental and social sustainability to be demonstrated. Finally, protocols for quality/standards specific to pellet production from plantation residues need to be developed. To overcome these barriers requires good governance and legislative structure; and finance to achieve the necessary investments.

Infrastructure and mechanisms for large-scale bioenergy export

South Africa's general port and cargo handling infrastructure is well developed and could provide a good platform to develop the required port biomass pellet storage and loading infrastructure. A number of ports are able to handle all categories of dry bulk cargo and are ideally situated. They are already handling substantial cargo for the wood products industry. However, there are no facilities at ports to store pellets to support cost-effective, large-scale export activities. The required investment will only come once a sustained large-scale pellet export market is in place.

Institutional factors

South Africa ranks 'fair' in terms of governance, ease of doing business and political risk indices. This makes it capable of becoming a long-term supplier of exported bioenergy. Legislation designed to support renewable energy use is already in place through the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). Carbon taxes will soon be introduced (South African Carbon Tax Bill due to be passed in 2018). Taken together, these pieces of legislation have the potential to stimulate interest in bioenergy production. Measures to ensure good forest governance have been implemented. Around 82% of South African plantations are Forest Stewardship Council (FSC) certified. This means that any biomass supplied can be within the required sustainability standards.

The REIPPPP and forthcoming carbon taxation means that any new interest in the production of bioenergy may be focused on its use in South Africa. This will be further stimulated by substantial increases in the price of electricity, diesel and fuel oil over the past decade in South Africa, which make bioenergy more attractive from a cost point of view.

Taken together, it is clear that South Africa has good bioenergy potential and the capacity to turn this potential into a stable supply of exported bioenergy given the availability of appropriate investment. The issue will be if the drivers to create bioenergy markets in South Africa will stimulate the development of a home market for biomass (so reducing the capacity to export) or if the need to earn foreign income will drive biomass export. This uncertainty represents a risk in terms of potential supply to the UK unless it is based on firm supply contracts through credible South African partners.

Other African countries also have similar potential to develop biomass supply chains, but without the same degree of institutional background and infrastructure. In these cases, more investment in infrastructure, skills and capacity would be required.

2.2.7 Biomass costs/prices

As part of this study, biomass prices were examined in two ways for a range of regions that could be used to supply the UK and European market. The first was to estimate current, or current potential, costs and the second was to look at how costs might develop in the future.

Figure 5 and Figure 6 show the results of the first approach, estimating the price of a resource that could be available in the near to mid-term using current forest resources or energy crop management practices. For forest resources, it has been assumed that most pellets will be manufactured using sawmill co-products with no other market or a mixture of these and some forest residues, as is current practice. For energy crops, costs have been estimated from current planting or potential estimated costs from the literature. The figures show that the total costs estimated in this exercise are generally within current biomass price ranges on the UK biomass market. They also show that on the basis of the cost data used for the price estimates, UK energy crops could be available at a price that is competitive with forestry resources from some other regions.

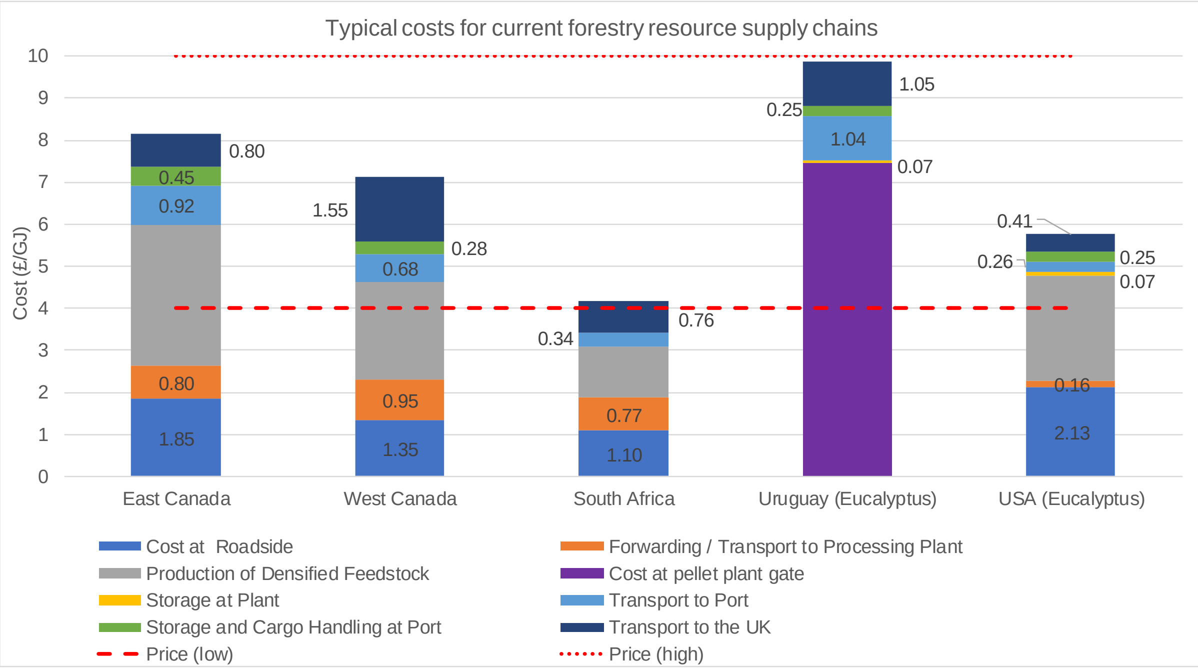
Comment on costs in Figure 5 and Figure 6

There is little data on the costs of biomass supply chains in regions studied in this work. The following comments are important to understanding the costs presented in Figure 5 and Figure 6:

1. Cost at roadside or sawmill is usually a price not a cost. This means that it includes margin to the producer.
2. Cost for pellet production is calculated from cost estimates. However, sometimes data on the price at the pellet mill have had to be used. In general, costs have been used and these do not include pellet mill margin.
3. Transport costs represent costs and, in general, do not include margin to the transport operator.
4. Freight costs are prices and include margin.

Overall, this means that the costs provided are not full prices and margin will need to be added.

Figure 5 Typical costs for forest resources supply chain for selected supply regions[19]
(red lines show the range of typical biomass prices on the UK market)



Note: costs for production, harvesting and forwarding were not available for Uruguay, so the cost at the pellet gate includes these costs as well as pellet production.

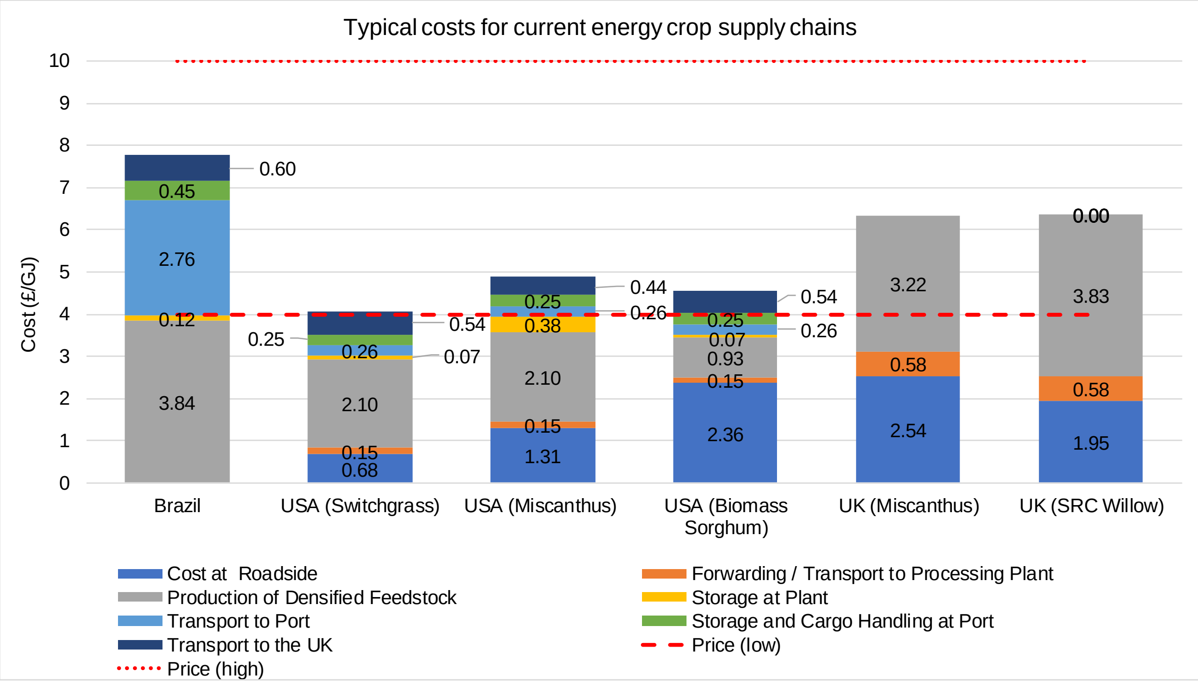
Sources: Canada: Boukherrob et al (2017), Roser (2016), Ricardo Energy & Environment (2016), IEA Bioenergy (2013), Hoque et al (2006), Mobini et al (2013), Sokhansanj (2015); South Africa: Schroeder and Guilgoyle (2017), Ackerman et al (2012) and Petrie (2014), Ricardo Energy & Environment (2017); Uruguay: Singh et al (2016), US Dept of Energy (2016)

These figures indicate that transport and production of densified feedstock are major influences on current supply chain costs. In some regions, transport of biomass to the pellet plant can also be a significant cost. These cost centres are where it would be most effective to make savings and efficiency improvements. However, as biomass is often a dispersed and bulky resource, making transport cost savings may prove difficult.

Costs for an increased supply situation were examined. This was achieved by looking at the potential to bring additional resources to market (i.e. forest harvest residues and additional energy crops). Figure 7 and Figure 8 show the results, which indicate that additional biomass supply might have a slightly higher price as the cost of the resource at the roadside is slightly higher (as the lowest cost resources will have been exploited first for current supply). For most regions, the increase is small (1% to 5%) and the estimated biomass prices are still within the current biomass price ranges on the UK biomass market.

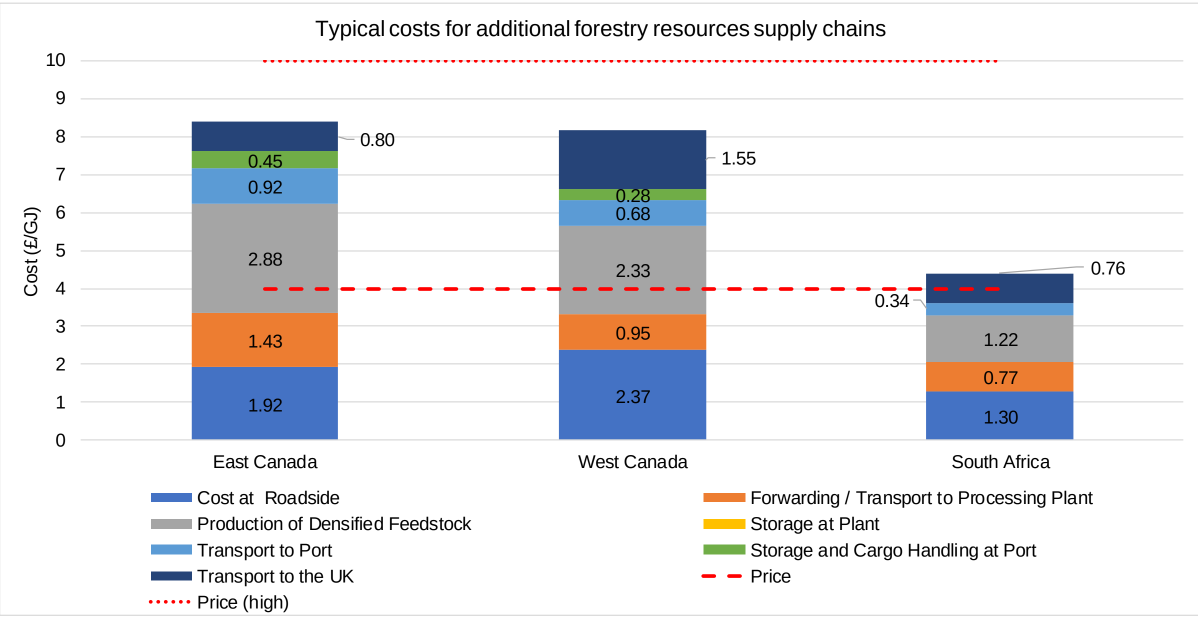
[19] It is not always easy to obtain costs, particularly for sawmill and forest residues, as data are normally for the price at the forest roadside or sawmill. Therefore, some of these 'costs' are, in reality, prices to the pellet plant operator.

Figure 6 Typical costs for energy crops supply chain for selected potential supply regions (red lines show the range for biomass prices on the UK market)



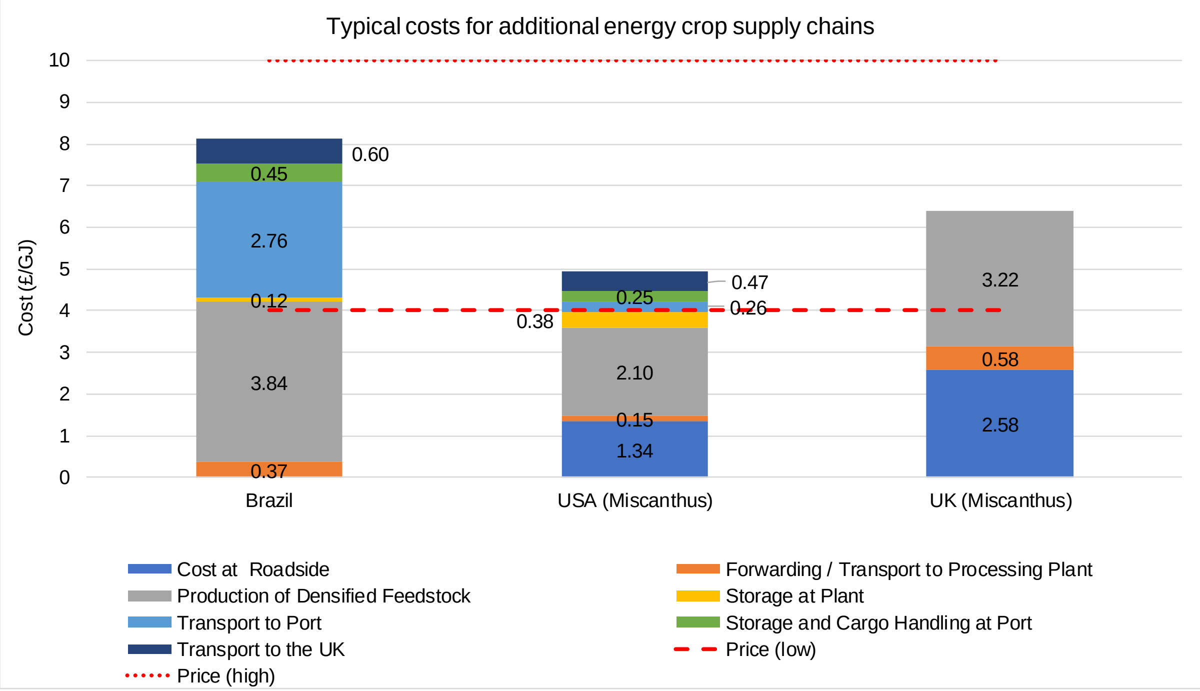
Cost at roadside: refers to the cost at the farm gate or forest roadside.
Sources: US DoE (2016), Nix (2014), ETI (2016), NFU (2016), Junqueira et al (2017)

Figure 7 Costs for biomass production using additional forest resources in potential supply regions (red lines show the range for biomass prices on the UK market)



Sources: Canada: Boukherrob et al (2017), Roser (2016), Ricardo Energy & Environment (2016), Deloitte (2008), Yemshanov et al (2014), Maure (2015), IEA Bioenergy T40 (2013), Singh (2017), Hoque et al (2006), Mobini et al (2013), Sokhansanj (2015); South Africa: Schroeder and Guilgoyle (2017), Ackerman et al (2012) and Petrie (2014), Ricardo Energy & Environment (2017)

Figure 8 Costs for biomass production using additional energy crop resources in potential supply regions (red lines show the range for biomass prices on the UK market)



Sources: US DoE (2016), Nix (2014), ETI (2016), NFU (2016), Junqueira et al (2017)

Figure 7 and Figure 8 show that transport and production of densified feedstock remain the major cost for biomass supply chain in some regions. However, the estimated cost of production of energy crops in the UK and USA is also a significant cost to the supply chain. There are opportunities to decrease these costs by developing higher yield varieties and improving establishment and harvesting costs. Carver (2017) and Hastings (2017), for example, indicate that there is potential for significant decreases in the cost of miscanthus planting material (resulting in costs up to 60% lower in the long term). Moving to 'contract farming' for SRC is also estimated to decrease costs by up to 30% in the right circumstances. These cost decreases will apply to the costs at the farm gate.

The Canadians have shown that innovation in supply can result in economic supply chains even over long distances. In British Columbia it has been demonstrated that forest residues can be used economically when mixed with sawmill co-products. The Canadians have also considered long-distance transport and mitigated costs by situating pellet mills close to the source of fibre and then using efficient rail transport logistics to decrease the cost of forwarding to the port. Consequently, it is envisaged that efficiencies in logistics would make it possible to decrease costs in transport (IEA Bioenergy, 2013). These efficiencies will depend on market conditions for biomass, which influence investment decisions.

2.2.8 Impact of global biomass expansion on global biomass prices

2.2.8.1 The global biomass market

The global biomass market has expanded considerably over the past two decades (IEA Bioenergy 2017). Current international trade in solid biomass is mainly wood pellets, but there is also trade in wood chips in Northern Europe and into Asia. Market analyses[20] of the way in which prices have developed indicate:

[20] See, for example, the work done by IEA Bioenergy Task 40 http://task40.ieabioenergy.com/ (e.g. the recent Global Wood pellet industry and trade study http://task40.ieabioenergy.com/wp-content/uploads/2013/09/IEA-Wood-Pellet-Study_final-july-2017.pdf). Data are also available from various national web sites (e.g. www.propellets.at , www.pelletshome.com and AEBIOM, www.aebiom.org).

- There are two separate markets – one for small-scale use (e.g. domestic or district heating scale) and one for large-scale electricity generation or CHP, where economies of scale can be exploited and where plant can be designed to use a wide range of biomass. The former tends to see higher prices than the latter (generally prices in the former tend to be between GBP[21]9.5 – GBP11.6/GJ but can rise to around GBP16/GJ in winter. In the latter, prices are generally less than GBP9/GJ at the plant and closer to between GBP5/GJ and GBP7/GJ for cost at the port (referred to as cost, insurance and freight, CIF[22]). There is no indication of convergence in these markets.
- There are regional price trends (rather than overarching global trends) that are related to trade and movement of biomass between neighbouring regions/countries. These trends tend to be seen mainly in small-scale biomass heat markets, although larger scale (district heating and CHP) Nordic markets appear have their own regional trends as well (perhaps this is also related to the impact of heat demand on these markets). Eurostat data indicate that cross-border pellet trade has increased since 2009 (IEA Bioenergy 2016[23]), so more significant international trends may begin to become more apparent in the future.
- Overall, biomass prices have tended to be relatively stable (particularly in comparison with fossil fuels). In the long term, as the 'easy to obtain' resources are used and more difficult to obtain resources are drawn into the market, price trends may increase to a new, relatively stable level, offset by the economies brought about by additional investment.

Commentary on regional markets is given in the Box 7.

Austrian and German data indicate prices decrease in late spring/early summer compared to mid-winter by about 8%. This is related to winter use and limits in storage capacity available to most consumers.

Another observed trend is associated with currency movement. The relatively strong USD at present has resulted in decreased imports to Europe, while the devaluation of the Russian rouble (RUB) increased trade into Europe.

This report is concerned mainly with global trade. There are two models for purchase on this market:

- Bilateral agreement between users and producers for large-scale biomass supply to electricity generators. This develops into a single supply chain, with contracts negotiated for a number of years, updated annually using pre-agreed indices. UK pellet distributers involved in the smaller scale pellet heat market often form close links and contracts with pellet producers in Europe, enabling trade into the UK from the Baltic and Portugal.
- Spot market trade, where prices are monitored at ports to produce indices. These include the Argus CIF ARA[24] indices or the Baltic FOEX index[25]. These spot markets show some convergence and similar trends, perhaps because shortages in one area may result in supply from another.

Despite the development of European trade since the late 1990s, few clear trends are visible.

Trade on the pellet market does not easily lend itself to long-term trend analysis because of the short time that prices have been monitored and a general lack of transparency. Observations are:

- Prices have tended to be relatively stable because installed pellet production capacity generally exceeds demand, so there is (generally) capacity to expand as demand expands.

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[21] Where GBP is the UK pound.
[22] CIF represents the cost at the port in the importing country, but not unloaded. The costs represented in Figures 5 to 8 are equivalent to a CIF price, plus the cost of unloading, handling and storage at the port.
[23] IEA Bioenergy (2016) The European wood pellet market for smalls-scale heating.
[24] Cost at the Amsterdam, Rotterdam and Antwerp ports.
[25] This is the cost at Baltic ports, which is monitored separately to those at Amsterdam, Rotterdam and Antwerp.

This means that the biomass market price has not been as volatile as heating oil prices. Analysts have not been able to correlate trends between prices for pellets and oil.

- The large-scale pellet market has generally been contracted bilaterally between user and producer, as indicated above, without the pellets being traded on an open market. This market and price movements within it are not transparent.
- The absence of common sustainability and contamination standards, which was perceived as a barrier to establishing a wood-pellet spot market, led a group of large European power generators to develop the Sustainable Biomass Partnership.
- Indices for spot prices tend to be relatively new, so there are insufficient data on which to base long-term trends.

Despite this general stability, there have been a number of short-term 'spikes and troughs' in prices, which have been correlated mainly with weather trends/events. For example, harsh winters in the mid-2000s resulted in increased prices and more recent mild winters (2014-2016) resulted in lower prices. In 2017, the mild winter resulted in difficulty accessing forests in the Baltic region, resulting in shortages in supply and price increases. As indicated above, the other factor that has influenced import prices is currency fluctuations.

Box 7 Current European wood pellet markets

In Europe, growth in biomass use is mainly related to renewable energy policy and associated incentive schemes, although volatility in the price of oil has stimulated uptake of biomass in central Europe in areas where there is no gas grid. Two major European markets are the central European market (Austria, Germany and the Czech Republic) and the Baltic market (Baltic countries and Sweden, Finland and Denmark). These markets are generally concerned with heat and have developed gradually over a couple of decades. These regions trade biomass within their region and tend to respond to related trends, particularly in heat demand during cold spells. France is also increasing biomass production and use.

There are also major import markets in the UK, the Netherlands and Denmark, and an increasing import market in Italy. These markets are fed predominantly by pellets from the Baltic states, North America and Russia. The Dutch, Danish and UK markets are related predominantly to the import of pellets for electricity generation; while the Italian market is a small-scale heat market.

North American market prices

The North American pellet market is geared to export, but pellets are being increasingly used in the USA. IEA Bioenergy (2017) estimates that US wood biomass consumption is around 1 exajoule (EJ) per year (IEA Bioenergy 2017). USA domestic market prices are provided by the US Energy Information Administration (EIA) on a regional basis[26]. In 2017, supply in the domestic market ranged from GBP6.5/GJ to GBP7.1/GJ (mainly in the Northeast and Western USA) and for exported pellets GBP4.3/GJ to GBP6/GJ free on board (FOB) (mainly produced in Southeastern USA), also demonstrating the existence of regional markets in the USA. Canada also demonstrates regional trends, but prices for export (FOB) are reported to be GBP4.3/GJ to GBP5.2/GJ, while domestic bagged pellets are GBP6.2/GJ to GBP8.5/GJ.

The **Asian market** for pellets is also developing (mainly in South Korea and Japan). This market mainly buys from Vietnam and West Canada. The Japanese market is estimated to increase to around of 15Mt/year in the mid-2020s.

Note: FOB: free on board (or freight on board) – this represents the price at port (i.e. in this case, the harbour in the USA).
Sources: own data, IEA Bioenergy (2017)[27], EIA

[26] https://www.eia.gov/biofuels/biomass/#table_data
[27] Thrän et al. 2017. Global Wood Pellet Industry and Trade Study 2017. IEA Bioenergy Task 40. June 2017.

The IEA Bioenergy Agreement Task 40 routinely analyses the market and suggests that more data are needed (IEA Bioenergy 2017), recommending:

- A harmonised approach for the collection of residential wood pellet prices in consumer markets.
- Stronger efforts in the provision of other wood pellet related data such as traded quality types, as well as monthly consumption and production quantities and inventories. The IEA Bioenergy Agreement Task 40 says that despite vast improvements in wood pellet trade data collection and availability (e.g. by statistical institutions), there are still data gaps and heterogeneous data qualities.
- Monitoring the small-scale and large-scale pellet markets to look for indications of convergence.

Task 40 also discusses commoditisation trends for wood pellets and comments that the remaining major shortcomings of the international markets are a lack of full liquidity and competitiveness. As the market expands, Task 40 believes that this may change, and pellets may 'achieve full characterisation as a commodity and the benefits associated with this status e.g. trust in the product qualities, product availability and power equilibrium through a plethora of actors as well on the supplier as on the buyer side'.

2.2.8.2 The impact of the global market expansion on biomass prices

It is difficult to know how the global market expansion will impact biomass prices, but from the above trends and analysis, it is expected that:

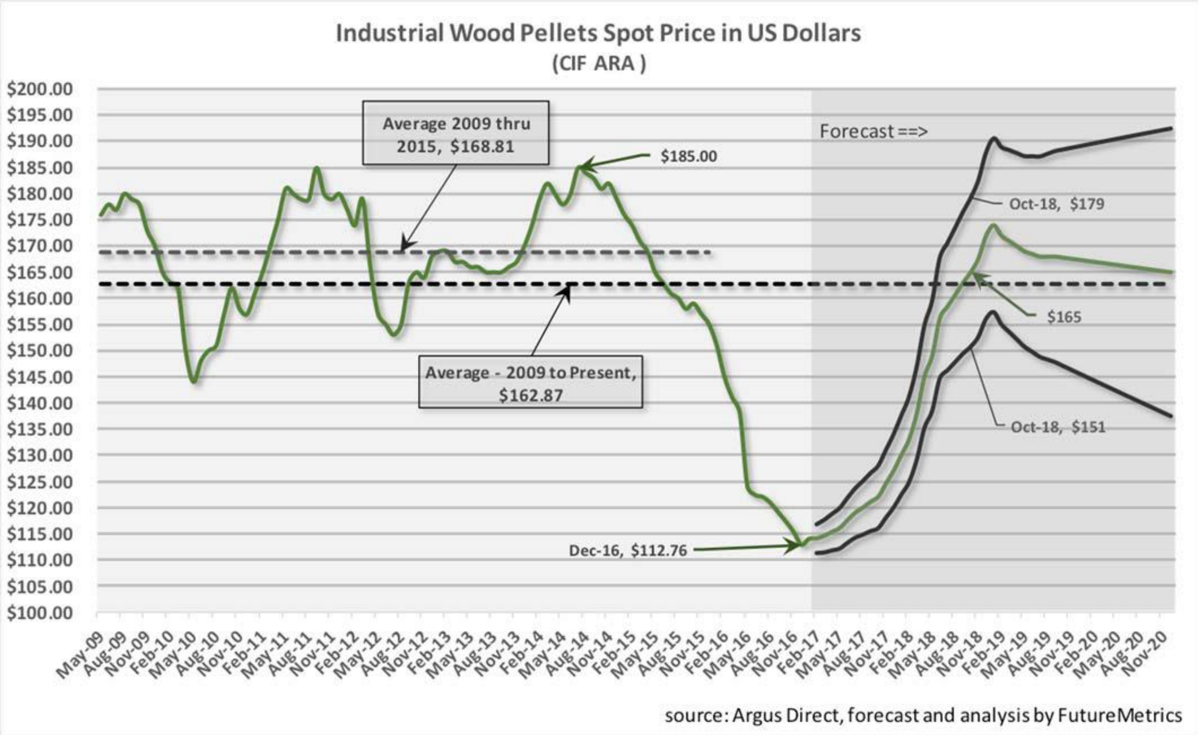
- Market dynamics are likely to change over the next decade or so, with increased use in Asia and potentially elsewhere (Australia? Africa?).
- The market will be influenced by freight cost and distances; and currency exchange rates. These will be particularly important for trade from developing and emerging economies.
- Transport distances keep European and Asian markets generally separate, except in areas where supply might overlap, such as Africa.
- Prices tend to stabilise as the market itself stabilises. This is because increased demand will allow for increased investment as the market grows more confident resulting in lower investment risk premiums. Long-term price trends to 2050 are likely to result from two opposing pressures. As the cheaper sources of biomass feedstock are used up and more expensive feedstock (such as forest residues and energy crops) come onto the market, it is expected that prices will increase. Conversely, as the market stabilises, it is expected that investment will be made in areas where costs can be saved, resulting in a downward pressure on prices. Pellet producers have been demonstrated to be good at strategies to minimise cost increases by mixing feedstock where possible (such as sawmill co-products with forest residues to allow increase in volume at minimal cost). It may be possible to mix in woody energy crops in this way, although this would be limited by bark content. However, it will not be feasible to mix grassy energy crops into wood pellets, as this is likely to impact pellet specification too much. Danish modelling of biomass prices to 2050 (Bang et al 2013) indicated that low prices are likely to remain stable, but that the range in prices is likely to increase, meaning that high prices will increase in time.
- Prices may be hit by occasional spikes, related to weather and factors that prevent harvest, and lower prices, related to mild winters that result in a decrease in demand.

Figure 9 shows analysis by Future Metrics indicating a range in forward prices of about USD140/t to USD190/t (CIF), which is equivalent to about GBP6.4/GJ to GBP8.7/GJ[28]. The forecast is wide,

[28] Assuming an exchange rate of GBP0.757 per USD (average for year ending March 2018 from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/696926/average-year-to-march-2018.csv/preview) and a minimum net calorific value for pellets of 4.6MWh/t (16.56GJ/t) as specified by ENplus standards.

relating to uncertainties in even short-term forecasts. IEA Bioenergy (2017) commented on future trends, saying that cost reductions may be possible through supply chain integration (e.g. upstream investments) and optimisation strategies to reduce the cost of pelleting and transport, but achieving CIF-ARA prices under USD113/t (GBP5.2/GJ) or lower are difficult to achieve. Like Future Metrics, IEA Bioenergy believes that prices will rise over the next couple of years due to increasing demand in Asia.

Figure 9 Industrial wood pellet historical and future price trends (source: Future Metrics, 2017)



Note: CIF ARA is price on board ship (i.e. before unloading) in ports of Amsterdam, Rotterdam and Antwerp
Source: WPAC, https://www.pellet.org/wpac-news/global-pellet-market-outlook-in-2017

There is no mention of sustainability reporting in these analyses. Where sustainability reporting is not required, its introduction will add costs to pellet supply chains. These costs are likely to hit small-scale suppliers disproportionately[29] who do not have the resources to respond to the needs of auditing. However, the introduction of the Biomass Suppliers List in the UK and development of sustainability monitoring in the USA have not added major costs to the pellet prices.

2.3 Impacts

A condition of Government support for biomass use in the UK is that the biomass, whether produced domestically or imported, must meet minimum sustainability standards. This requires it to achieve minimum greenhouse gas (GHG) savings and to demonstrate that it has been produced sustainably. Sustainability requirements include ensuing that harvesting rates are sustainable, biodiversity has been protected and land-use rights for indigenous populations are respected. Any expansion of biomass supply needs to continue to meet these criteria. Therefore, this section examines the environmental impacts that might be associated with an expansion of biomass supply, and the ways in which these might be mitigated. These include GHG emissions, impacts on soil and water, and on biodiversity. Impacts on air quality are not examined as these are mainly associated with the

[29] This is examined in Netherlands Agency (2012) Selecting a biomass certification system – a benchmark on level of assurance, costs and benefits, see https://english.rvo.nl/topics/sustainability/sustainable-biomass/publications-results

combustion of biomass at its point of use and this report is concerned with supply of biomass. A review of these combustion impacts is provided in the Air Quality Expert Group's 2017 report[30]; strategies for reduction in these emissions is also being examined as part of the Clean Air Strategy[31]. Socio-economic impacts and the impact that increased use of biomass for energy might have on alternative uses are also considered.

The specific impacts associated with the supply of biomass are dependent upon the type of biomass – forestry residues or energy crops have very different impacts – and its provenance. Impacts vary by and within regions and are dependent on cultivation and harvesting practices. Therefore, this study examined the impacts associated with the supply of a variety of types of biomass from a number of regions.

2.3.1 Greenhouse gas emissions

GHG emissions can arise from all stages of the supply chain – cultivation and harvesting; transport of feedstocks and pellets by road, rail and ship; and the pelletisation process. They arise from the use of fossil fuels in these processes – the emissions associated with the production of agricultural inputs to the process (e.g. production of fertilisers) and from biological processes (e.g. soil nitrous oxide (N_2O) emissions associated with applying nitrogenous fertilisers during cultivation and from soil degradation). Finally, there may be emissions if there is any land-use change associated with cultivation of energy crops or, in the case of forestry products, if the production of biomass for bioenergy leads to changes in the carbon stock of forests.

Typical GHG emissions associated with the production and supply of pellets from different types of biomass in a range of countries that could potentially export to the UK are shown in Figure 10. These emissions have been calculated using the UK Solid and Gaseous Biomass Carbon Calculator[32] and, to allow comparison on as common a basis as possible, are for pellets as delivered at a UK port (imported biomass) or for pellets at the pellet plant gate (UK production). For the countries and feedstocks considered, GHG emissions range from 5g to 20g of carbon dioxide (CO_2)/MJ of fuel delivered. Delivery of pellets to end users will add about another 0.47g CO_2 for every 100km transported. The significant variation in emissions is due to a number of factors:

- It is assumed that pellet producers will use heat produced by combusting biomass for the pelletisation process. Electricity used in the process is assumed to be the average grid mix for the country for 2015[33]. This has a strong influence on overall emissions with pellets from countries where carbon emissions associated with electricity generation are high (such as South Africa, where there is a high proportion of coal-based generation). So, for example, South African pellet production would have much higher emissions than countries such as Canada and Uruguay where grid electricity is much less carbon intensive. Emissions from this pelletisation stage could be reduced by using electricity from a low-carbon source (e.g. a biomass CHP plant at the pelleting plant) and may reduce in the future as countries decarbonise their electricity grids.
- Emissions from the transport stages assume distances for road or rail transport and for shipping that are typical for regions from which pellets might be exported to the UK. Shipping emissions are not insignificant (ranging from 2.6g to 8.4g CO_2/MJ) and can become the predominant source of emissions where emissions from other stages are low. Shipping emissions could be reduced if biomass is transported in larger ships and if fossil-based

[30] Air Quality Expert Group (2017) The potential air quality impacts from biomass combustion. Report for Defra https://uk-air.defra.gov.uk/assets/documents/reports/cat11/1708081027_170807_AQEG_Biomass_report.pdf

[31] The Clean Air Strategy is currently being drafted, see: https://consult.defra.gov.uk/environmental-quality/clean-air-strategy-consultation/

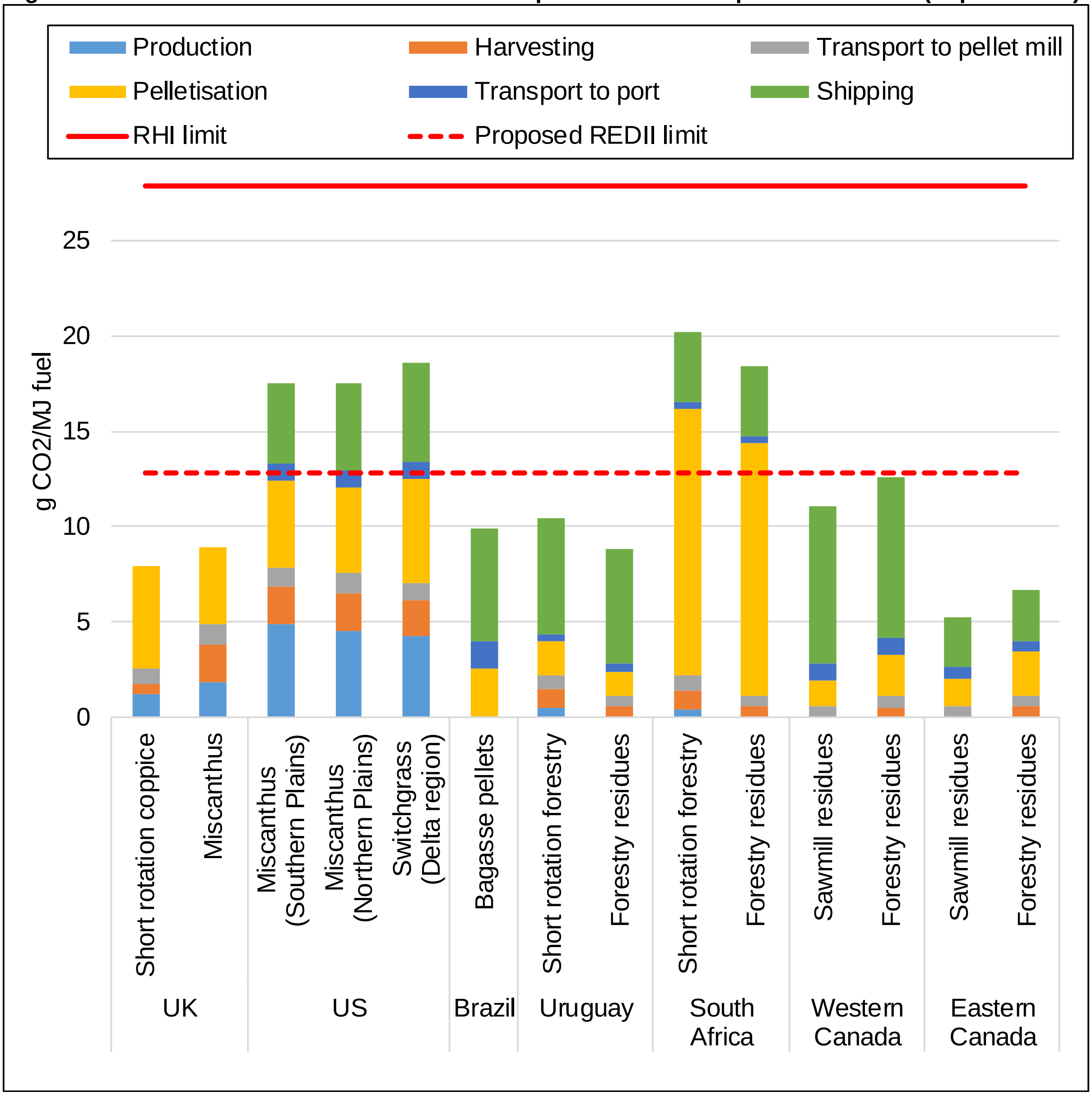
[32] https://www.ofgem.gov.uk/publications-and-updates/uk-solid-and-gaseous-biomass-carbon-calculator.

[33] CO_2 emissions from electricity generation are taken from 'UK Government GHG Conversion Factors for Company Reporting' (2017 version).

transport fuels are replaced by sustainable biofuels in the road, rail and marine sectors, and in agricultural and forestry machinery.

- Emissions associated with cultivation of feedstocks also vary, with energy crops (such as SRC, miscanthus and switch grass) showing higher emissions in production than forest residues due to agricultural inputs, particularly during the establishment phase. Figure 10 shows that energy crops grown in the USA have higher nitrogenous fertiliser applications[34] than those for miscanthus in the UK. This leads to higher emissions due to the larger carbon footprint form fertiliser production and from increased soil N_2O emissions. As bagasse, forestry residues and sawmill residues are classified as residues or by-products, no emissions from cultivation of the main product are allocated to them in the Renewable Energy Directive methodology.

Figure 10 Estimated GHG emissions for examples of UK and imported biomass (at port in UK)



Note: The Renewable Energy Directive (RED) and proposed RED II limit shown above refer to criteria for heat and assume a boiler efficiency of 80%

Fuel used by RHI participants must meet a lifecycle GHG emissions target of 34.8g CO_2 equivalent per MJ of heat or 60% GHG savings against the EU fossil-fuel average. Assuming that fuel is used in boilers with

[34] Fertiliser application rates for energy crops in the UK are based on data in US Department of Energy (2016) Billion Ton Study.

an 80% efficiency, then this equates to the fuel having lifecycle GHG emissions of 27.8g CO_2/MJ, so all of the examples below would comfortably meet this. The limit proposed in the recast of RED (RED II) is stricter than this (16g CO_2/MJ heat, equating to 12.8g CO_2/MJ fuel) and would not be met by some of the imported pellets shown below unless emissions from some parts of the supply chain could be reduced.

2.3.2 Soil and water

2.3.2.1 Energy crops

Compared to arable crops, perennial energy crops convey significant benefits on soil quality (Holland et al 2015, Milner et al, 2016). This is due to the characteristics of the energy crops (such as deep root systems providing increased below-ground biomass carbon stocks and high litter input (where there is leaf fall)) and the management practices (such as long harvesting cycles, limited fertiliser inputs and fewer routine operations). The benefits include reduced soil bulk density, improved porosity, improved microbial activity and biomass content, improved invertebrate population, and improved fluxes of water, air and heat. Reduced cultivation leads to higher and more stable soil carbon. To maximise these benefits, harvesting operations must be carried out in appropriate conditions and using appropriate machinery (e.g. the potential for soil compaction and the creation of depressions and gulleys that could lead to increased soil erosion and rutting during harvesting can be minimised by equipping harvesting machinery with low impact tyres).

Miscanthus and SRC can have high water use during the growing season, so can have a negative impact in water-stressed areas, particularly if a large area is planted in the same river catchment (Holland, 2015). However, the high water use, and long growing season of the crops can be a positive feature in flood prone areas, where SRC in particular can help to reduce flooding by a mix of land drying, soil stabilisation and physical slowing of water flows. Other crops (e.g. energy cane) may have higher water requirements and require irrigation. When planted on agricultural land, many perennial energy crops (e.g. SRC, miscanthus) have positive effects on water quality. This is due to the low level of fertilisation required for these crops, so reducing nitrate leaching. The perennial nature of the crops also leads to soil stabilisation and reduces erosion and river turbidity and sedimentation.

2.3.2.2 Forestry residues

Impacts on soils from removing forest residues (tips and branches typically left in the forest when trees are harvested for saw logs or precommercial thinnings) can vary widely and are dependent on the amount and type of residues removed, site characteristics, species and harvesting methods. Potential impacts typically occur when too high a proportion of residues are removed and can include (Lattimore et al 2009, Ralevic et al 2010):

- Soil disturbance, compaction and erosion.
- Reduced levels of soil organic matter and soil carbon storage.
- Changes in substrate and microclimate for soil microorganisms.
- Reduced soil nutrients and depletion of base cations (ions of calcium, magnesium, potassium and sodium) in the soil, resulting in soil acidity.
- Decreased water retention.

Mitigation of these impacts is best achieved from understanding site-specific impacts and creating specific sustainable forest management plans that prevent the removal of too many residues. For example, evidence from South Africa suggests that nutrient loss due to residue removal can have detrimental effects on stand growth in intensively harvested short-rotation eucalyptus (Ackermann et al, 2012). An ameliorative strategy in such cases can be to include intensified fertiliser applications to replace nutrients. In the UK, the UK Forestry Standard highlights the importance of considering all impacts before harvesting forest residues.

2.3.3 Biodiversity

2.3.3.1 Energy crops

The biodiversity impacts of energy crops can be positive or negative depending on how they are grown, previous land use, what type of land they are grown on and the scale of production. For example, growing energy crops on marginal or degraded land can support restoration of the land, with increased biodiversity (Immerzeel 2014). Compared to intensive agricultural cultivation, perennial energy crops provide refuge from agrochemicals and a less disturbed environment, which is more beneficial to insects and birds, and leads to more diversity of flora/fauna. Crops such as SRC willow allow the development of understorey flora, significantly enhancing habitat creation compared to normal food crops and resulting in, for example, increased insect populations. However, these benefits are dependent on reduced intensity of management that could be in tension with achieving the highest yields. Benefits could also be offset if intensification of agricultural production elsewhere is required to release land for energy crops, potentially reducing the biodiversity of that land.

The scale of planting also determines impacts. While small-scale energy crop production (at perhaps 5% to 10% of farm area) can provide diversity in the landscape and provide wildlife corridors between fragmented habitats, large-scale production can reduce diversity within the landscape. For example, large areas of non-native crops (e.g. miscanthus) may have the same potential negative impact as large areas of cereal, but post-harvest there may be some benefits to some ground-nesting bird species.

2.3.3.2 Forestry residues

It is widely acknowledged that residues have a significant role in the ecology of the forest, productivity, soil nutrient and physical properties, and soil carbon (Vance et al 2017, Roach and Bearch 2014[35]). However, the impact of the removal of residues is variable and site dependent, suggesting that management of residues needs to be flexible and evidence based. Removal of too much residue can reduce the amount of deadwood needed for the survival of some species, remove niche habitats, and lead to the proliferation of invasive species and loss of nutrients, so reducing diversity. On the other hand, in some circumstances, large quantities of residues can negatively impact forest health and productivity (e.g. by increasing risks of wildfire, pests and disease, and impeding forest regeneration (Vance et al, 2017)).

It is probably most appropriate to deal with this issue at national or sub-national regional level, through work by appropriate forestry bodies. This can provide evidence-based guidance generated through local research on how much residue can be removed without compromising ecosystem services. Then, compliance with this guidance can be specified in national or international management standards or certification[36].

2.3.4 Socio-economic: food security

The interactions between bioenergy and food security are complex, and a full consideration of them was outside the scope of this study. The main concern is that bioenergy crops may be grown on agricultural land, displacing food and fodder production, and thus impacting food security. In some regions where there is already conflict over land rights/land ownership, the acquisition of land for conversion to bioenergy can add to pressures on land rights if not properly handled[37]. However, there

[35] This is dependent on the circumstances under which bioenergy crops are developed and the stakeholders considered. For example, the World Bank (2010) says that investments in bioenergy plantations in Africa (and South-East Asia) need to be carefully managed in ways that reduce the potential for land conflicts and negative effects on the poor and calls for local participation.

[36] US and UK guidance on the role of forest residues can also be seen in Evans et al (2010) Revised assessment of biomass harvesting and retention guidelines (for the USA), https://www.forestguild.org/publications/research/2009/biomass_guidelines.pdf and for the UK: Forestry Commission (2011) Environmental effects of stump and root harvesting, https://www.forestry.gov.uk/pdf/FCRN009.pdf/$FILE/FCRN009.pdf

[37] This is a highly complex subject that depends on traditional farming, land rights and tenure systems, Government attitudes and the ever-changing agricultural environment against a backdrop of rapid population increases. The UN summarise the current situation in

can be synergies between bioenergy and food security allowing bioenergy to be developed in a sustainable way (Kline et al, 2017; Scope, 2015).

In the case of perennial energy crops, these can be grown on less productive and marginal land. Locating them on this type of land will minimise competition with food production, preventing impacts on food security. Similarly, some arable land can become no longer required for food and fodder production due to improved productivity on other arable land or because of degradation. Using this land for energy crops should not have impacts on food security and, indeed, may even lead to improvements in the land allowing it to return to food production in the future.

Annual energy crops production can also be integrated with crop production systems (intercropping). Nevertheless, care should be taken in the definition of marginal land to ensure that food security is not impacted.

Use of forestry residues for pellet production is unlikely to cause any impacts on food security as extraction is from existing forest or, where afforestation is planned, is typically on low productivity, rather than arable land. Development of the pellet supply chain can deliver positive socio-economic impacts through job creation (Cambero and Sowlati, 2016, ETI, 2017).

2.3.5 Alternative uses of biomass

The main alternative market for energy crops, forestry residues and crop residues that could be used in the UK market is use in the country of production for heat and power generation. In the future, they could also be used as feedstocks for second-generation biofuels. If current research on breeding modified crops, which are more amenable to processing in a biorefinery, is successful, then energy crops could be processed in a biorefinery to produce higher value bio-products (such as chemicals and biochemicals)[38] and energy.

Use of forestry residues for bioenergy does not compete with the main wood products industry, which uses larger diameter timber. Use of forestry products for bioenergy can improve the economic viability of timber production by providing a new market for thinnings and residues that are not suitable for use as timber, in addition to current markets such as the wood panel industry.

www.un.org/en/Africa/osaa/pdf/pubs/2013africanagricultures.pdf. Bioenergy crops will add to pressures for land use change and pressures on land rights if not handled properly. Pressures on traditional agriculture in Africa are reviewed in Miyake et al (2012) and Jayne et al (2014).

[38] For example, Canada has recently developed a strategy for a forest bioeconomy, Canadian Council of Forest Ministers (2017) A forest bioeconomy framework for Canada (http://www.ccmf.org/pdf/CCFM%20Bioeconomy%20Framework%20-%20Discussion%20Paper%20-%20Feb2017.pdf)

3 Discussion

This study has shown that while there are considerable biomass resources available from a number of sources, the limits and barriers to developing supply chains must be understood if we are to have accurate forecasts of what can be achieved. Through the examination of potential biomass supply chains in a variety of regions, the study provides information about a number of factors that influence biomass availability and price, and how these may vary regionally. It also sets out key factors and issues that must be considered to ensure an appropriate, sustainable supply.

3.1 Key barriers to the development of biomass supply

A number of important specific and cross-cutting barriers have been identified in this report that apply to the development of biomass supply in many regions of the world. Understanding how feasible it is to overcome these barriers, and what is required to do this and over what timescale, is important in improving the estimates of future biomass supply to the UK. This understanding can also help to define what needs to be done to develop supply globally. Importantly, the analyses in this report also show that fundamental to the development of sustainable biomass supply chains is the development of long-term market opportunities for biomass use.

The key barriers that could have a large impact on supply, which exist in most regions, have been summarised. These are presented in Table 3. Many of these barriers relate to market issues that can have a high impact on the development of biomass supply, but that can be resolved given the development of a secure market and transparent market data.

For supply to the UK, one of the most important market barriers will be in-country and regional competition for the resource. Other barriers include physical, technical and infrastructural issues. It is considered that most of these can be addressed given a sustained market opportunity and investment or higher prices. However, there are some difficult barriers, such as climate change impacts on yields, and productivity and corruption in some regions, with the latter leading to a lack of trust in sustainability data. Even these issues could be addressed by the end user taking more control of the supply chain and in diversifying supply across regions. This will also increase options and address security of supply.

3.1.1 Regional factors

Regional differences can be important when developing biomass supply. Factors that are likely to show significant regional variation are the need for skills and capacity building, issues in obtaining finance, and the understanding of and reporting of sustainability (as required for UK bioenergy).

Against this background, regions that have been identified in previous bioenergy resource modelling as having the potential to be a substantial exporter of biomass are shown in Table 4, together with a short commentary on potential regional barriers to supply and initiatives being used to overcome them.

The ease with which potential biomass resource can be accessed varies by region, within regions and over time. For example, in areas such as Southeast USA, additional resource is likely to be accessible and viable in the short term. However, in others, such as Africa, there may be increasing domestic competition for the resource in the long term. Refining the way in which these regional differences are modelled in estimates of bioenergy resources would lead to more robust estimates.

Table 3 Summary of key barriers to developing global biomass supply

Type of barrier	Key barriers	Difficulty in overcoming barriers	Timescale to address barriers
Market	Absence of large-scale market Currency volatility Interregional competition Competition from other product markets Lack of familiarity with energy crops along the whole supply chain	These are hard to overcome without the development of long-term market opportunities. If long-term market opportunities are in place, most market barriers can be overcome, given a stable market and investment. In-country and regional competition may be difficult to address without significant price increases.	Most can be resolved in the medium term, given the development of long-term market opportunities
Physical	Cost of transport High logistics costs Lack of necessary infrastructure (transport, and for planting and harvesting) Reduced productivity due to climate change	Infrastructure, storage and logistics issues can be overcome given investment. Climate change issues may be hard to overcome, although research could identify energy crop species more adapted to changed climatic conditions.	Apart from climate change, these issues can be resolved in the short to medium term, given investment or price increases Price increases could allow funding of demonstration of different varieties
Technical	Meeting UK/EU standards for pellets Unfamiliarity with energy crops	These include introducing standards, developing densification and installing pellet handling and storage – all of which can be addressed through investment. Energy crops present more difficult barriers, as these crops are not familiar to farmers and establishment costs, yield and factors that influence productivity need to be understood.	Many technical issues can be overcome, in the short term and with investment Energy crop barriers are more difficult, but can also be addressed as the supply chain grows in the medium to long term
Institutional		These include governance, absence of evidence of sustainability certification compliance (and auditing skills). These should be of low to medium difficulty to overcome, except in regions of entrenched corruption.	These barriers can be addressed given good market opportunities and the will/incentive to introduce good practice

Table 4 Examples of regions with significant potential biomass resource and potential barriers to supply

Region and potential production in 2050[a]	Particularly significant barriers and examples of initiatives to address them
North America Forestry: 690TWh Energy crops: 2,840TWh	Financing obstacles have been overcome in a number of ways (e.g. joint ventures with biomass producers, securing long-term contracts for supply (which reduces risk) and use of equity finance). Use of equity finance is feasible in these regions because risk is lower as there is an established viable supply, and institutional requirements, such as sustainability certification, are in place and robust.
EU Forestry: 730TWh Energy crops: 1,470TWh	Strong competition for EU production from other EU Member States.
Russia Forestry: 250TWh	Additional infrastructure and development of supply chains may be required to access some potential resources and transport to ports for export may be an issue in some regions. Likely to be competition for this resource from other EU countries. Successful export to the UK (and EU) will requires a robust system of sustainability certification. A weak evidence base or poor governance of the system could lead to lack of confidence.
Africa and Latin America Forestry: 240TWh Energy crops: 2,400TWh	Development of significant potential could be restricted by lack of skills, infrastructure and finance. Training and skills development can be undertaken by developers. However, more costly investments (such as infrastructure) may need to be done in partnership with governments. Raising finance may be particularly difficult because of higher political risks or currency risks. Allocation of risk along the pellet supply chain may make investment unattractive to potential producers. One country has attempted to overcome this by encouraging inward investment from international forestry companies that then take on the risk. Governance is important – developing secure biomass supply chains cannot take place without a thorough understanding of land ownership and rights. Land ownership and rights is a complex socio-economic issue that needs to be addressed at many levels – local and national. Successful export to the UK (and EU) will require an understanding of sustainability issues and a robust system of sustainability certification. A weak evidence base or poor governance of the system could lead to lack of confidence or opposition to biomass production. Wherever biomass supply is proposed, whether this is by commercial developers or as part of government strategy, sustainability and consultation with local stakeholders and environmental non-governmental organisations

Region and potential production in 2050[a]	Particularly significant barriers and examples of initiatives to address them
	(NGOs) should be considered from the start. It is possible for governments to set the framework for this[39].
Southeast Asia and Australasia Forestry: 330TWh Energy crops: 1,150TWh	Strong competition for supply from demand in the Far East and high cost of transport to the UK mean that supply more likely to be traded with neighbouring regions rather than transported to UK.

Notes: Values from UK and Global Bioenergy Resource Model (v8.9)[40] are estimates under a high investment scenario of potential production within forestry for bioenergy and estimates of potential energy crop production given availability of land no longer required for food or fodder production. Domestic demand for this production means that quantities available for export may be significantly less.

Forestry resources from managed forests can be increased by accessing residues as well as stem wood, but the potential is limited (depending on the level of forest inventory) and can be costly (depending on distance from the pellet plant). Additionally, for this resource, there are environmental concerns that must be considered. These include the need to maintain the productive capacity of the site to ensure that water impacts are considered, and that important biodiversity is not affected. Ultimately, access to this resource is in the hands of the forest owners and the harvesting contractors with both being influenced by the market for other higher value wood products. More detailed work on the impact of distance, investment required and environmental constraints on realising potential biomass resources would improve understanding at regional levels.

In general, bioenergy developers can mitigate risk by ensuring that their supply is not dominated by one region. This means that problems in a specific region do not result in supply issues.

3.1.2 Summary of environmental impacts

Biomass production can have important impacts on soil, water and socio-economic factors. However, this does not need to be the case as there are options to mitigate impacts depending on local conditions. Given this conclusion, the development of clear guidelines on the production of biomass resources and ensuring that these guidelines are incorporated into sustainability certification and best management practices, is fundamental to ensuring that any increase in supply is achieved in a sustainable way that minimises environmental impacts.

3.1.3 Logistics

Logistics can be a significant part of the cost of supply, but there are opportunities to deliver efficiencies at all stages. A particular area where efficiencies could be delivered is at ports, where investment is often required to standardise the supply chain, improve handling and take advantage of economies of scale. An example of the latter would be improvements that enable optimally sized ships to be used, reducing the unit cost of freight transport. How these improvements would affect biomass price could be determined through financial modelling, allowing assessment of the impact on biomass price of such improvements. The ease of investment in different supply chains may be an important differentiator.

[39] See, for example, the guidance for sustainability indicators for bioenergy development by GBEP, http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/Indicators/The_GBEP_Sustainability_Indicators_for_Bioenergy_FINAL.pdf

[40] https://www.gov.uk/government/publications/uk-and-global-bioenergy-resource-model

Different biomass types require different logistics. To date, logistics development has focused on the wood supply chain, but energy crops and agricultural residues also require logistics development. This investment is only feasible if a long-term secure market exists.

Logistics must include health and safety considerations. This increases cost in the short term but is liable to improve security of supply in the long term.

3.1.4 Biomass costs and prices

The study estimated the price of biomass for a range of countries that could be used to supply the UK, using production and logistic price estimates from these countries. The results reveal that imports of pellets derived from forestry resources and energy crops can be competitive in the current UK market. The modelled price of pellets produced from UK energy crops was also within the current market range and was competitive with forest resources sourced from some markets currently supplying the UK. Expansion of supply from these regions in the future is expected to lead to a slightly higher biomass price (typically, 1% to 5%) as the cost at the roadside of additional resources was marginally higher. However, the estimated biomass prices are still within the current biomass price ranges on the UK biomass market.

There may be opportunities to reduce future costs through efficiencies in the pelletisation process and transport logistics, and in the case of energy crops, the development of higher yielding varieties, improved establishment and harvesting costs, and the move to contract farming.

Long-term price trends to 2050 are likely to result from the impact of improved efficiencies throughout the supply chain and the expansion of supply in response to increased demand, which means that more expensive supply areas may be considered. These two factors will act in opposing ways on the overall price. As the cheaper sources of biomass feedstock are used up and more expensive feedstock, such as forest residues and energy crops come onto the market, it is expected that prices will increase. Conversely, as the market stabilises it is likely to encourage investment in areas where costs can be saved, resulting in a downward pressure on prices.

3.1.5 Policy insights

There are several energy crops with good potential, but finance for their development is difficult without long-term stable policy to support this. There are a number of models of energy crop development that are showing potential for success, such as contract farming. Most importantly, any development model has to decrease the risk to the farmer and not seek to substitute the farmer's core food market.

The resolution of land-use issues associated with energy crops could also help enable their development. For example, a clear definition of marginal land; an understanding of how energy crops can complement rather than replace food crops; and the introduction and enforcement of requirements that protect vulnerable environments, habitats and people are all options to address land-use concerns.

More generally, policy to underpin the development of and investment in supply chains could result in an acceleration of production. A clear accompanying sustainability framework and a long-term support framework are likely to be the most effective policy interventions.

It should also be recognised that biomass is supplied as part of either agricultural or forestry business practice. Therefore, biomass is best developed as part of a multi-functional supply chain (i.e. it should be an integral part of a product market for the producer, rather than an isolated market not linked to other options). A systematic view of the energy and agricultural system can help to ensure that biomass is developed in the right place and makes best use of land add resources. Patterns of land used can change quite rapidly in response to changes in, for example, agricultural support schemes or international agricultural markets. Estimates of the potential production of energy crops are very dependent on estimates of the current and future availability of suitable land not required for feed and fodder production. Ensuring that these estimates of land availability are revisited at intervals and reflect current trends is important in maintaining an accurate forecast of the potential availability of energy crops.

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