Use of North American woody biomass in UK electricity generation: Assessment of high carbon biomass fuel sourcing scenarios

Summary report

Report for DECC
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1 Introduction

The UK Department of Energy and Climate Change (DECC) leads UK policy on measures that will influence deployment of biomass as a renewable energy source in the UK. Working with other UK departments and agencies, DECC sets the overall direction for renewable energy policy and specific measures that influence the development and operation of biomass power plants. In 2012 DECC published its approach to bioenergy in its UK Bioenergy Strategy, which included four core principles that act as a framework for UK Government policy on bioenergy. Among these is the principle that UK policies supporting bioenergy should deliver genuine carbon reductions.

Investors have responded to these bioenergy policies, making significant investment in biomass heat and power. In 2014, the use of wood pellets by the UK's major power stations accounted for more than 22% of all renewable energy sources and 36% of all bioenergy fuels used to generate electricity[1], including 4.75 million tonnes (Mt) of wood imported to the UK, 79% of which came from North America. Ofgem figures for 2013/14 report a total use of 5.4 Mt of wood/wood derived fuel used in electricity generation, of which approximately 3 Mt came from the USA and Canada (Ofgem 2015). Among the significant investments now and in the near future are those at Drax and Lynemouth power stations and the Teesside Renewable Energy Plant. Details of these are presented in Box 1.To put this demand in context, DECC analysis (Stephenson and MacKay, 2014) has projected UK demand for solid biomass for electricity generation to be 9 to 16 million oven dried tonnes (Modt) per year by 2020[2].

Box 1 Details of significant UK investment in Biomass plants that will import pellets[3]

Drax: Two units are converted to biomass (unit 1 was already enhanced co-firing) and a third 650MW electric (MW_e) to be converted in 2016. This third unit is already co-firing with biomass prior to full conversion. Total biomass use at Drax in 2014 was 4.09Mt (of which 3.26 was from North America)[4]. Total biomass demand from 2016: 7.5 Mt of wood pellets, most of which will be sourced from the EU, USA, Canada and Brazil. 2014 figures available from Drax indicate that supply from North America for their use was 3.26 Mt, of which 2.38 Mt were from Southeast USA and 0.88Mt were from Canada.

Lynemouth: planned conversion of 420MW_e unit to biomass to generate ~ 2.3TWh/y (terawatt hours per year) from wood pellets. This is estimated to represent a demand of 1.5Mt of wood pellets, most of which will be sourced from the USA.

Teesside Renewable Energy Plant: 299MWe Investment £650 million (US$1.02 billion) Fuel: an estimated 1.02 Mt of wood pellets from USA and Brazil.

Against this background, sustainability of biomass for power generation has attracted significant attention and many studies have been conducted in this area. Carbon emissions from energy are calculated using life cycle assessment (LCA), which accounts for all of the carbon inputs into the whole renewable energy system, from 'cradle to grave'. The core issue for carbon accounting for bioenergy is the principle that when biomass is burnt it releases the same amount of carbon dioxide into the atmosphere as was removed during plant growth. However, bioenergy is not carbon neutral, as there are emissions from fossil fuels used in their planting, harvesting, processing and transportation. It is also possible to account for the benefits of any other products produced, emissions from land-use change (LUC), both direct and indirect, and changes in carbon sequestration. This makes the understanding of bioenergy carbon reduction particularly complex.

[1] https://www.gov.uk/government/statistics/energy-trends-september-2015-special-feature-article-uk-and-eu-trade-of-wood-pellets

[2] There is a different between tonnes of wood, tonnes of pellets and oven dried tonnes. The latter reduces wood to no moisture content, allowing comparison between different types of wood and with other fuels. In general freshly harvested wood has a moisture content varying between 40 and 60% moisture depending on the growing conditions and type of wood. This can be reduced to 30-40% through roadside drying. Pellets are drier and tend to have a moisture content less than 10 - 12% (see http://www.biomassenergycentre.org.uk or CEN technical specifications for wood pellets). Many of the units in this report are given as quoted to us by the forestry industry. Frequently the forestry stakeholders reported quantities in m^3, which is the standard measurement for the sector. It is not straightforward to convert m^3 of wood to tonnes, but we have presented figures taken from MacQuarrie and Hudson (2013) to provide a guide for Canadian forests in Appendix 3 of the Technical Report. An alternative source is http://www.unece.org/fileadmin/DAM/timber/meetings/forest-products-conversion-factors.pdf

[3] This information comes from the developers' web sites and news articles e.g. http://www.pellet.org/wpac-news/drax-fires-up-biomass-power, http://www.businessgreen.com/bg/news/2396068/brussels-probes-uk-support-for-lynemouth-biomass-conversion , http://teesside.mgtpower.com/, http://www.power-technology.com/projects/tees-renewable-plant-teesside/

[4] Source: http://www.drax.com/media/56583/biomass-supply-report-2014.pdf

In 2013 DECC published sustainability criteria for biomass feedstocks supported under the UK Renewables Obligation (RO). These state that electricity from solid biomass subsidised by the RO must be proven to generate electricity with a greenhouse gas (GHG) emission intensity of less than 200 kg CO_{2e}/MWh (kilogram carbon dioxide equivalent per megawatt hour) from 2020 (DECC, 2013), calculated based on the Life Cycle Assessment (LCA) methodology set out in Annex V of the EU Renewable Energy Directive (2009/28/EC)[5]. This methodology considers the emissions from the cultivation, harvesting, processing and transport of the biomass feedstocks. It also includes direct land use change where the land use has changed category since 2008, e.g. from forest to annual crop land, grassland to annual crop land. However, the Renewable Energy Directive LCA methodology does not account for changes in the carbon stock of a forest, foregone carbon sequestration of land, or indirect impacts on carbon stocks in other areas of land.

To allow calculation of the impact of carbon emissions of biomass sourced from North America to generate electricity in the UK DECC commissioned the development of a calculator, the Biomass Emissions and Counterfactual Model (the 'BEAC' Model). This calculator was designed to include consideration of carbon storage in forests in North America when assessing the benefits and impacts of different supply strategies in order to provide information about which biomass resources are likely to have higher or lower carbon intensities. Analysis using the BEAC model and reported in Stephenson and Mackay (20114) showed that in 2020 it may be possible to meet the UK's demand for solid biomass for electricity using biomass feedstocks from North America that result in electricity with GHG intensities lower than 200 kg CO_2e/MWh, when fully accounting for changes in land carbon stocks. However, it also showed that there were other bioenergy scenarios that could lead to high GHG intensities (e.g. greater than electricity from natural gas or coal, when analysed over 40 or 100 years) but which would be found to have GHG intensities less than 200 kg CO_2e/MWh by the Renewable Energy Directive LCA methodology.

The BEAC model comprises a series of paired scenarios-and-counterfactuals that examine the additional carbon impact of demand for pellets from North America for use in electricity generation in the UK. Each scenario compares the carbon emissions of the supply and use of pellets to a *counterfactual* designed to represent what would have happened in the absence of pellet demand in forests in North America. In some situations more than one counterfactual is available.

The scenarios developed in BEAC examine strategies for delivering wood for pellets in North America, but do not assume that these strategies will necessarily happen. There are six sources of wood for pellets that are classified as:

- sawmill co-products (with the potential to displace feedstocks for other non-bioenergy products)
- forest residues without an alternative market
- diseased wood
- additional harvest from naturally regenerated forest (through more intensive harvest or harvest on additional land),
- roundwood (e.g. pulpwood) from existing plantations
- wood for bioenergy displacing non-bioenergy uses, causing additional wood to be imported (in this case into Southeast USA)
- additional wood harvest from establishing new plantations (energy crops and intensively-managed pine) on naturally-regenerated timberland in Southeast USA
- additional wood harvest from establishing new plantations (energy crops and intensively-managed pine) on abandoned agricultural land.
- conversion of naturally regenerated forest to plantation or short rotation coppice (SRC) and abandoned agricultural land converted to plantation or SRC.

BEAC examined the carbon implications for pellet fibre supplied from a specific source. However, it makes no detailed judgement on whether or not the supply chains modelled are occurring or are likely to occur in the future as a result of UK pellet demand. The detailed scenarios are provided in Stephenson and Mackay (2014) and summarised in Appendix 1 of the Technical Report. Table 1 provides a short description of each scenario in Stephenson and Mackay (2014). This study examined

[5] http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009L0028

29 scenarios that resulted in high GHG intensity. In Box 2 we have provided a definition of the terms used in Stephenson and Mackay (2014).

Box 2 Definition of terms used in BEAC (Stephenson and Mackay 2014)

Definition of terms used in BEAC

It is important to this work that the terms used in the BEAC tool and report are understood. These are provided in the BEAC report (Stephenson and MacKay, 2014):

Forest residues

Fine forest residues: Tree tops, limbs, non-merchantable harvested trees and tree components, and downed trees which are left over from traditional timber harvesting. Includes pre-commercial thinnings (described below). Diameter < 0.1 m (4 inches).

Coarse forest residues: as above, but diameter >0.1m

Round wood

Three categories are defined:

Sawlogs: Definition varies between different saw-mills. In Southeast USA, a saw log is usually defined as a log with a small end diameter greater than 5 - 8 inches (0.13 - 0.20 m).

Chip-n-saw: US term. Exact definition varies between different saw-mills. In Southeast USA, this consists of small saw logs and large pulpwood, with minimum diameters of 4 - 6 inches (0.10 - 0.15 m) and maximum diameters of 9 - 16 inches (0.23 -0.41 m).

Pulpwood: US term. Exact definition varies between different saw-mills. In Southeast USA, this consists of roundwood which has a small end diameter typically less than a saw log (5 - 8 inches), but greater than 2.5 inches (0.064 m) (also known as small roundwood in the UK), and low quality roundwood with dimensions of saw logs and chip-n-saw, that can't be used for sawn-timber

The GHG intensity of the scenarios examined in Stephenson and Mackay (2014) and listed above can be seen in the selected results in Figure 1 and Figure 2 below. These results show that subtleties are important. For example, analysis presented in Stephenson and Mackay (2014) shows that the use of residues from Boreal Canada represents a greater risk than the use of those from the warmer regions of the USA. Appendix 2 of the Technical Report shows the analysis for GHG intensity over 100 years.

Table 1 Summary of BEAC scenarios as examined in Stephenson and Mackay (2014). The analysis in Stephenson and Mackay (2014) examined potential pathways and their impact on carbon, not whether or not these scenarios are likely. Thus the list below may contain scenarios or counterfactuals that may not be likely. The scenarios that are classed as high greenhouse gas (GHG) intensity are those that were shown to produce emissions >200kgCO2e/MWh and are the scenarios that were considered in this study.

No.	Scenario description	Counterfactual description	Low or High GHG intensity
1	(a) Saw sawmill co-products in Southeast USA (no drying) (b) Saw sawmill co-products in Pacific Canada (no drying)	Burn as waste (no energy recovery)	Low GHG
2	(a) Saw-sawmill co-products in Southeast USA; dry from 25 wt% to 10 wt% moisture. (b) Saw-sawmill co-products in Pacific Canada; dried from 25 wt% to 10 wt% moisture[6]		
3	(a) Saw-sawmill co-products in Southeast USA; dry from 50 wt% to 10 wt% moisture. (b) Saw-sawmill co-products in Pacific Canada; dry from 50 wt% to 10 wt% moisture		
4a	Coarse forest residues, removed from forests in Southeast USA, continuously over the time horizon.	Leave all residues in the forest	High GHG
4b	Coarse forest residues, removed from forests in Pacific Canada, continuously over the time horizon.		
5a	Fine forest residues, removed from forests in Southeast USA, continuously over the time horizon.		
5b	Fine forest residues, removed from forests in Pacific Canada, continuously over the time horizon.		
6a & 7a	Fine and coarse forest residues, removed from forests in Southeast USA, for 15 years only (then residues are left in the forest again).		
6b & 7b	Fine and coarse forest residues, removed from forests in Pacific Canada, for 15 years only (then residues are left in the forest again).		
8	(a) Forest residues (both coarse and fine), removed from forests in Southeast USA, continuously over the time horizon. (b) Forest residues (coarse and fine), removed from forests in Pacific Canada, continuously over the time horizon.	Burn the residues at the roadside as a waste.	Low GHG

[6] In this context wt stands for weight and is a shorthand used to show the percentage moisture content on a weight basis.

No.	Scenario description	Counterfactual description	Low or High GHG intensity
9	Salvaged dead trees, which have been killed by mountain pine beetle in Pacific Canada.	(a) Leave in the forest. (b) Remove and burn at the roadside.	Low GHG
10a	Additional wood (in comparison to the counterfactual) generated by increasing the rate of harvest of a naturally-regenerated hardwood forest in East Canada from every 100 years to every 50 years	Continue harvesting the forest every 100 years	High GHG
10b	Additional wood (in comparison to the counterfactual) generated by increasing the rate of harvest of a naturally-regenerated hardwood forest in East Canada from every 100 years to every 80 years.	Continue harvesting the forest every 100 years	High GHG
11	Additional wood (in comparison to the counterfactual) generated by increasing the rate of harvest of a naturally-regenerated conifer forest in Pacific Canada from every 70 years to every 50 years.	Continue harvesting the forest every 70 years	High GHG
12a	Additional wood (in comparison to the counterfactual) generated by increasing the rate of harvest of a naturally-regenerated conifer forest in boreal Interior-West Canada from every 100 years to every 50 years	Continue harvesting the forest every 100 years	High GHG
12b	Additional wood (in comparison to the counterfactual) generated by increasing the rate of harvest of a naturally-regenerated conifer forest in boreal Interior-West Canada from every 100 years to every 80 years.	Continue harvesting the forest every 100 years	High GHG
13a	Additional wood (in comparison to the counterfactual) generated by increasing the rate of harvest of a naturally-regenerated hardwood forest in Southeast USA from every 70 years to every 60 years.	Continue harvesting the forest every 70 years	High GHG
13b	Additional wood (in comparison to the counterfactual) generated by continuing harvesting a naturally-regenerated hardwood forest in Southeast USA every 70 years.	Reduce the rate of harvest compared to the harvest in the presence of pellet demand, to every 80 years	High GHG
14a	Additional wood (in comparison to the counterfactual) from intensively-managed pine plantation, in Southeast USA. Continue harvesting every 25 years	Reducing the frequency of harvest compared to the harvest in the presence of pellet demand, to every 35 years	High GHG
14b	Additional wood (in comparison to the counterfactual) from intensively-managed pine plantation, in Southeast USA. Increased demand for small roundwood results in the rotation length reducing to 20 years.	Reducing the frequency of harvest compared to the harvest in the presence of	High GHG

No.	Scenario description	Counterfactual description	Low or High GHG intensity
		pellet demand, to every 35 years	
15	15, 16, 17 = Same as Scenario 14, but with different counterfactuals.	Converted over 50 years to an even-aged naturally-regenerated pine forest that is harvested every 50 years.	Low GHG
16		Scenario 15,16 Converted over 25 years to a naturally-regenerated pine forest that is left to continuously sequester carbon, rather than harvested	Low GHG
17		Scenario 17: Converted over 25 years to agricultural land (e.g. cotton plantation).	Low GHG
18	Additional wood (in comparison to the counterfactual) from increasing the management intensity (and hence yield) of a pine plantation in Southeast USA that is harvested every 25 years (e.g. adopting optimal thinning practices and initial planting densities; Will et al., 2006).	Continue previous management regime	Low GHG
19	Pulpwood from Southeast USA, causing indirect impact of Eucalyptus plantation replacing Brazilian rainforest.	Pulpwood produced in Southeast USA used for non-bioenergy purposes	High GHG
20	Pulpwood from Southeast USA, causing indirect impact of Eucalyptus plantation replacing Brazilian abandoned degraded pasture land, which would otherwise revert to tropical savannah.	Pulpwood produced in Southeast USA used for non-bioenergy purposes	High GHG
21	Pulpwood from Southeast USA, causing indirect impact of increasing the harvest rate of naturally-regenerated coniferous forest in Pacific Canada, from every 70 years to every 50 years.	Pulpwood produced in Southeast USA used for non-bioenergy purposes	High GHG
22a	Additional wood (in comparison to the counterfactual) from the conversion of a naturally-regenerated coniferous forest in Southeast USA that is harvested every 50 years, to an intensively-managed pine plantation that is harvested every 25 years	Continue harvesting the forest every 50 years, and leaving to regenerate naturally	Low GHG
22b	Additional wood (in comparison to the counterfactual) from the conversion of a naturally-regenerated coniferous forest in Southeast USA that is harvested every 50 years, to an intensively-managed pine plantation that is harvested every 20 years.	Continue harvesting the forest every 50 years, and leaving to regenerate naturally	High GHG
23a	Additional wood (in comparison to the counterfactual) from the conversion of a naturally-regenerated hardwood forest in Southeast USA that is harvested every 70 years, to an intensively-managed pine plantation that is harvested every 25 years	Continue harvesting the forest every 70 years, and leaving to regenerate naturally	High GHG
23b	Additional wood (in comparison to the counterfactual) from the conversion of a naturally-regenerated hardwood forest in Southeast USA that is harvested every 70 years, to an intensively-managed pine plantation that is harvested every 20 years	Continue harvesting the forest every 70 years, and	High GHG

No.	Scenario description	Counterfactual description	Low or High GHG intensity
		leaving to regenerate naturally	
24a	Additional wood (in comparison to the counterfactual) from the conversion of a naturally-regenerated coniferous forest in Southeast USA that is harvested every 50 years, to an SRC hardwood plantation that is coppiced every 3 years. Conversion takes 3 years	Continue harvesting the forest every 50 years, and leaving to regenerate naturally	High GHG
24b	Additional wood (in comparison to the counterfactual) from the conversion of a naturally-regenerated coniferous forest in Southeast USA that is harvested every 50 years, to an SRC hardwood plantation that is coppiced every 3 years Conversion over 50 years	Continue harvesting the forest every 50 years, and leaving to regenerate naturally	High GHG
25a	Additional wood (in comparison to the counterfactual) from the conversion of a naturally-regenerated hardwood forest in Southeast USA that is harvested every 70 years, to an SRC hardwood plantation that is coppiced every 3 years. Conversion takes 3 years	Continue harvesting the forest every 70 years, and leaving to regenerate naturally	High GHG
25b	Additional wood (in comparison to the counterfactual) from the conversion of a naturally-regenerated hardwood forest in Southeast USA that is harvested every 70 years, to an SRC hardwood plantation that is coppiced every 3 years. Conversion takes 70 years.	Continue harvesting the forest every 70 years, and leaving to regenerate naturally	High GHG
26	Additional wood (in comparison to the counterfactual) from the conversion of abandoned agricultural land in USA that was previously annually ploughed, to an SRC hardwood plantation that is coppiced every 3 years. Assumed exported to UK from Southeast USA.	Abandoned agricultural land left to revert to sub-tropical, moist, deciduous forest.	High GHG
27	Additional wood (in comparison to the counterfactual) from the conversion of abandoned agricultural land in USA that was previously annually ploughed, to an SRC hardwood plantation that is coppiced every 3 years	Abandoned agricultural land left to revert to temperate grassland	Low GHG
28	Additional wood (in comparison to the counterfactual) from the conversion of abandoned agricultural land that was previously annually ploughed, to an intensively-managed pine plantation that is harvested (a) every 25 years, (b) every 20 years.	Abandoned agricultural land left to revert to sub-tropical, moist, deciduous forest.	Low GHG
29	Additional wood (in comparison to the counterfactual) from the conversion of abandoned agricultural land that was previously annually ploughed, to an intensively-managed pine plantation that is harvested (a) every 25 years, (b) every 20 years.	Abandoned agricultural land left to revert to temperate grassland	Low GHG

Figure 1 Summary of the resource of North American woody residues that may be available by 2020 and their GHG intensity over 40 years. (CFL: counterfactual) Source: Stephenson and Mackay (2014). The figure below is taken from the Stephenson and Mackay (2014) report. The 's' numbers below refer to the scenarios examined in that report and listed in Table 1. Cfl: counterfactual

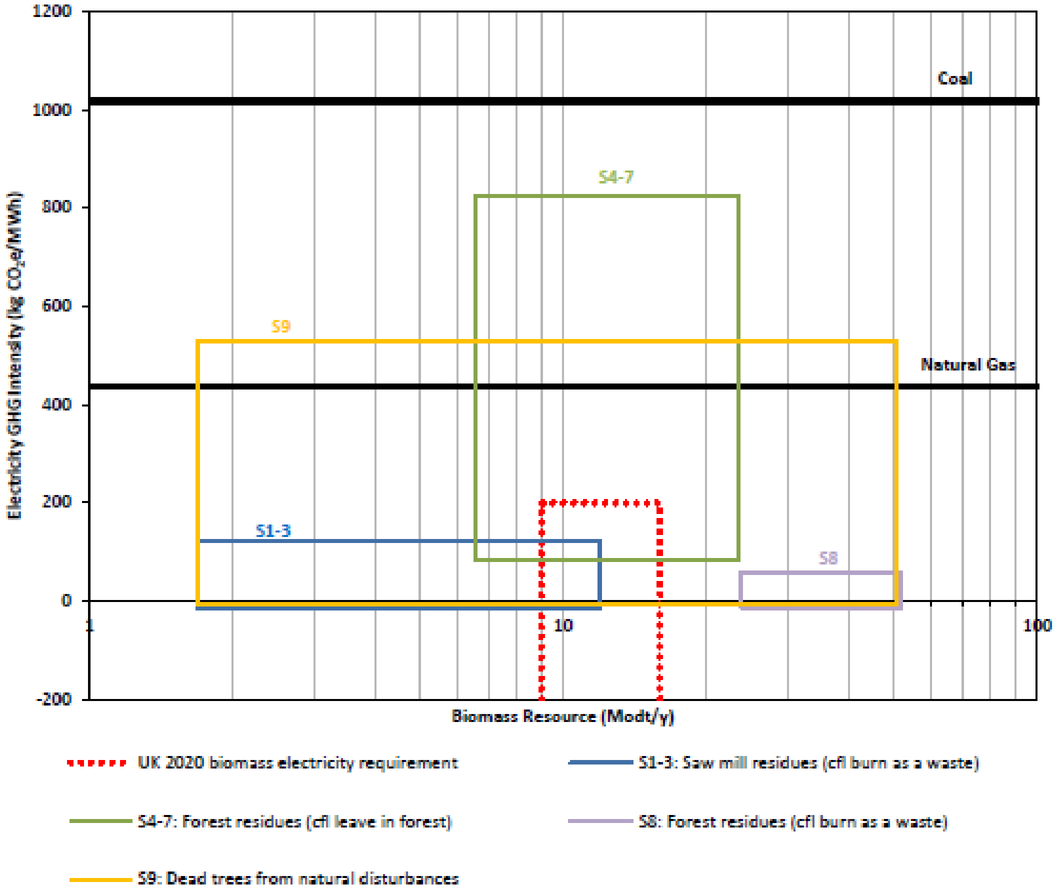
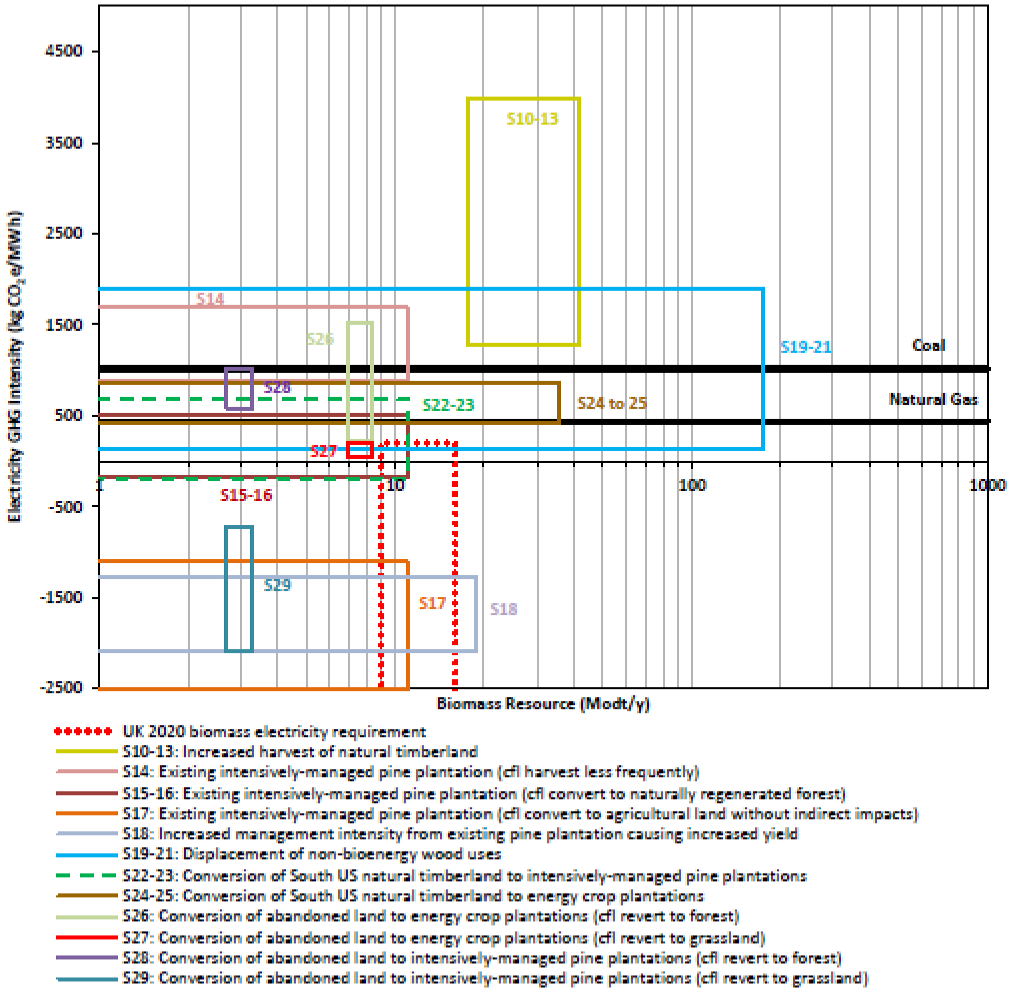


Figure 2 Summary of resource of North American round wood and energy crops that may be available by 2020 and their GHG intensity over 40 years. The figure below is taken from the Stephenson and Mackay (2014) report. The 's' numbers below refer to the scenarios examined in that report and listed in Table 1. Cfl: counterfactual



1.1.1 What does this study cover?

As indicated above the BEAC calculator does not provide an indication of the likelihood of the scenarios in detail as it does not include analysis of factors that might encourage or prevent a scenario from occurring. In order to understand the likelihood of the high GHG intensity scenarios resulting from the BEAC analysis, DECC commissioned this study. The **objectives** of this study were to:

- Develop an evidence base of qualitative and quantitative evidence on the likelihood of the selected BEAC biomass source scenarios associated with the highest greenhouse gas emissions from the literature review, from a questionnaire of stakeholders in the supply chain in North America and from modelling of the supply response to demand for fibre for pellets in Southeast USA
- Analyse this data to provide DECC with a qualitative and quantitative assessment of the likelihood of each relevant scenario.
- Provide an assessment of the strength of the data/uncertainty associated with the results of the analysis.

The subset of the BEAC scenarios examined in this study were those that the BEAC model calculated to have high carbon intensity scenarios. These are the scenarios shown as High GHG in Table 1. In addition we were asked to examine a further 11 scenarios that were not modelled in BEAC. These are listed in Table 2. They concern additional wood from plantations and from bringing unmanaged woodland into management[7]. We used the FAO definition of 'unmanaged' woodland as 'woodland that does not have a management plan'. We were also asked to consider each set of scenarios broadly. For example, for increased harvest rate scenarios (compared to the counterfactual), where we found relevant evidence, we have commented on the drivers or constraints on increases in harvest rate more generally and have not just focused on the exact rotation lengths described in the BEAC report.

Table 2 Additional scenarios considered in this study

No.	Scenario description	Counterfactual description
10Pa	Additional wood (in comparison to the counterfactual) generated by increasing the rate of harvest of a hardwood plantation in East Canada by decreasing the rotation period up to 50%	Leave plantation in previous management
10Pb	Additional wood (in comparison to the counterfactual) generated by increasing the rate of harvest of a hardwood plantation in East Canada by decreasing the rotation period up to 20%	Leave plantation in previous management
11P	Additional wood (in comparison to the counterfactual) generated by increasing the rate of harvest of a conifer plantation in Pacific Canada by decreasing the rotation period up to 20%	Leave plantation in previous management
12Pa	Additional wood (in comparison to the counterfactual) generated by increasing the rate of harvest of a conifer plantation in Boreal Canada by decreasing the rotation period up to 50%	Leave plantation in previous management
12Pb	Additional wood (in comparison to the counterfactual) generated by increasing the rate of harvest of a conifer plantation in Boreal Canada by decreasing the rotation period up to 20%	Leave plantation in previous management
13Pa	Additional wood (in comparison to the counterfactual) generated by increasing the rate of harvest of a hardwood plantation in Southeast USA by decreasing the rotation period up to 50%	Leave plantation in previous management
13Pb	Additional wood (in comparison to the counterfactual) generated by increasing the rate of harvest of a hardwood plantation in Southeast USA by decreasing the rotation period up to 20%	Reduced frequency of harvest with low demand for wood
30a	Additional wood (in comparison to the counterfactual) from the conversion of unmanaged forest into production in Southeast USA	Forest remains unmanaged
30b	Additional wood (in comparison to the counterfactual) from the conversion of unmanaged forest into production in East Canada	Forest remains unmanaged
30c	Additional wood (in comparison to the counterfactual) from the conversion of unmanaged forest into production in Pacific Canada	Forest remains unmanaged
30d	Additional wood (in comparison to the counterfactual) from the conversion of unmanaged forest into production in Boreal Canada	Forest remains unmanaged

2 Methodology

The study used three methods to obtain evidence (the limitations of each method are discussed in Section 4.1 below on evidence qualification):

- A questionnaire sent to stakeholders in the North American wood pellet supply chain that sought their views on the likelihood of the scenarios and asked them for the evidence they use

[7] For the purposes of the present report, Scenario 30 - bringing unmanaged land into production – is not the same as Scenario 30 in the 2014 BEAC model. It is instead based on Scenario 33 in that model, which considers what happens when UK broadleaf forests are brought back into production to produce small round wood for the heat market (through production of wood chips). It is difficult to transpose this system directly into North America. There are large areas of North American forest that are unmanaged but the term does not mean the same as in the UK and it is likely to have different meanings in the USA and Canada.

to inform this opinion and for information on key variables that might drive or constrain the scenarios.

- A literature review on forestry in the USA and Canada to provide evidence on key variables such as costs, constraints and forestry practice. The methodology and outcome of the literature reviews are provided in Sections 3 to 5 of this report.
- Modelling of the impact of pellet demand in Southeast USA, as the region considered to be most impacted by European pellet demand, using the Sub-regional Timber Supply (SRTS) model developed at North Carolina State University. Box 3 provides a short explanation of what this model does. It was used in this study to examine impact of pellet demand on inventory, removals, price, timberland area, forest types, inventory age distribution and carbon for a region in Southeast USA corresponding to the pellet supply region relevant to the UK. This evidence provided was used to understand the likelihood of supply strategies modelled in BEAC. Details on SRTS model is provided in Chapter 6 of the Technical Report.

2.1 Questionnaire

The questionnaire was refined using a pilot questionnaire sent to six selected stakeholders from different stakeholder groups. 156 stakeholders taken from the following groups were then invited to participate in the final survey:

- organisations from the forestry sector in North America
- government forestry officials
- academics
- the non-bioenergy forest products sector
- pellet producers
- pellet users and
- non-government organisations (NGOs) including trade associations and conservation organisations.

The development of the questionnaire and the questions asked are provided in Chapter 7 of the Technical Report, which also provides detail on how the results were analysed. The questionnaire provided options for ranking the likelihood of the scenarios and to specify what factors would encourage or prevent each scenario. It allowed respondents to comment on their ranking. It also asked separate questions on context and on the variables that might influence the development of pellet fibre supply in North America.

2.1.1 Treatment of uncertainty in the questionnaire results

It is important to understand that the ‘population’ of experts who have sufficient understanding to be able to comment on the scenarios envisaged in Stephenson and Mackay (2014) is relatively small. In some stakeholder groups this amounted less than five people. This precluded any in depth statistical analysis of the results, including uncertainty analysis. The detailed nature of the questionnaire and the subject also meant that respondents were required to have the necessary resources and time to consider the scenarios we were asking about. In addition we were asking respondents about their expertise in an area where their answers would be qualified by their personal experience (e.g. the region or type of forest they work in). Given this qualitative nature of the questionnaire we asked the respondents to rank their own confidence in their answer. These self-assessed confidence levels are taken into account in the analysis of the questionnaire.

56 respondents completed the questionnaire. These respondents represented the full range of the stakeholder groups in the North American pellet supply chain in the USA and most of the range in Canada (Canadian NGOs declined to participate). The two groups that were represented by a small number of respondents were the non-bioenergy sector and NGOs. We asked the respondents to provide a summary of their experience. All were intimately involved in the relevant forestry-pellet supply systems in North America. The majority of respondents had more than six years continuous experience relevant to the North American – UK pellet supply chain or the forests used in this supply chain. Where their individual experience was less than this their companies or organisations did have at least six years’ experience in the area. From this we have concluded that the respondents represent considerable hands on experience relevant to the North American – UK pellet supply chain.

This means that the conclusions to this study are based on the views of a relatively small number of experts. However, the level of expertise among these people is considerable. As indicated above there is a small population of expertise available and we believe that the respondents to the questionnaire represented key stakeholders in the pellet supply chain. A large number of these respondents spend considerable time (over 8 hours) completing the questionnaire and checking their responses and in doing so drew on other local expertise and published literature to support their answers.

2.1.2 Analysis of the results to the questionnaire

The results are brought together in an Analysis Tool developed to analyse the results of the likelihood questions in the questionnaire. In our analysis in order to ensure a balance of views across all stakeholder groups, equal weighting was applied to each group. This was done by analysing the responses from each stakeholder group first to provide an indication of the views of each stakeholder group and whether or not there was a consensus within the stakeholder group. Then the views of the stakeholder groups were compared to see if there was an overall consensus on likelihood across all stakeholders:

- if there was consensus across the stakeholders we accepted this consensus as the likelihood of the scenario.
- if the views were spread but there was a most common view, or two consecutive most common views, this was accepted as the likelihood of the scenario.
- if the views were widely spread the result was considered to be 'no consensus.' In addition where there was a significant number of 'don't know' responses for some scenarios these were also classed as 'no consensus'.

Further details are provided in Chapter 7 of the Technical Report.

In analysing the results it became apparent that the comments made by the respondents to support their response choices were important in qualifying their scores/ranks. They also provided literature evidence to support their views. In discussing the results (Chapter 8 of the Technical Report) we have also included a number of these qualifying statements to make the views of the stakeholders clear. In addition we have included the full list of the comments in Appendices 4 and 5 of the Technical Report.

2.2 Economic modelling in North America

In this study only Southeastern USA was modelled using a forestry economics model. No forest economics modelling was undertaken in Canada. The SRTS model used in Southeastern USA is described in Box 3. This model has been used to examine the dynamics of the forestry response to pellet demand in other studies (Abt et al 2014, 2014 a, b and Abt et al 2010).

The forestry landscape of Southeastern USA is largely privately owned and produces more timber than any other single country. The development of forest in the region is driven by market dynamics that drive land use, management intensity, and harvest responses for multiple products simultaneously making it difficult to look at any one factor in isolation. The outcome of increased demand for pellets on forest management in Southeastern USA will also be determined largely by market dynamics that can only be examined using market models. For example mill and logging residues from other markets can offset roundwood demand from pellets. It is also critical that the current state of the forest resource and existing demands be considered since any new demand will lead to responses across regions and other wood consumers.

Box 3 The SRTS Model

SRTS is a forest sector model developed to model forest resources in the Southeast USA, a key region for the supply of pellets to the UK. The SRTS model (Abt et al., 2009; Prestemon and Abt, 2002) is based on detailed forest resource information and relevant regional market parameters. It uses these together with economic factors to estimate forest resource dynamics, harvest response, and market consequences of product demand (in this case pellet demand). Product supply is modelled as a function of stumpage price and forest inventory. The product price and harvest levels by product and sub-region are simultaneously determined in market equilibrium calculations. In each year, the output from the market module is an equilibrium harvest by product for each region-owner combination.

In the model 'products' are defined depending on what is of interest to the study in question. In this study the products examined were

1) pine small roundwood (also known as pulpwood),
2) pine large roundwood (also known as sawtimber),
3) hardwood small roundwood, and
4) hardwood large roundwood.

The breakpoint between small and large pine roundwood was 22.5cm (9 inches) diameter breast height (dbh) for hardwood the breakpoint was 27.5 cm (11 inches) dbh. These definitions are consistent with USFS Forest Inventory and Analysis (FIA) sawtimber and non-sawtimber categories. In addition to the size distinction, 15% of pine material in the large pine roundwood category was considered to be of insufficient quality or size (e.g. tops, limbs) to be used for sawtimber and was added to small roundwood volumes. For hardwoods a 30% degrade factor was used to reflect the more heterogeneous species mix, tree form, and harvesting techniques employed. As in softwoods, this means that 30% of hardwood volume that was sufficient dbh to be considered large roundwood was assumed to be of insufficient quality for the large roundwood market.

Further information on SRTS modelling is provided in Chapter 6 of the Technical Report.

In this study the SRTS forest economics model was used to examine the impact of increased pellet demand at two levels compared to a baseline without pellet demand. The nature of the model and the full methodology is described in Chapter 6 of the Technical Report. In summary, the important boundaries and assumptions that were made are:

- The pellet market boundary (region) selected includes existing and announced pellet facilities as of 2014. This was a compromise between selecting the procurement area around individual pellet mills and modelling the entire Southeastern U.S. This market would include leakage outside of individual mill zones, but not beyond the coastal plain and Piedmont regions where pellet mills are located. This may result in higher projected prices than would be seen in the actual market, but provides a more focused resource analysis in the region where direct pellet demand impacts are concentrated. Since demand was price responsive, the model did reflect that higher prices might force some demand outside of the region (and vice versa), but the out-of-region impacts were not explicitly modelled.
- Forest dynamics (harvest, growth etc.) in the model are based on empirical forest harvest, growth, and age class distributions to model all forest types based on existing utilization patterns. This data was obtained from the latest forest inventory data available, but, crucially this does not include the last two years in which most pellet growth has happened. The start year of the model projections was 2011 to reflect the vintage of the data. Pellet feedstock consumption since 2011 was added so that existing pellet demand was fully incorporated.
- Demand for pellets was estimated on best available data from the power stations in Europe with plans for large scale bioenergy power generation, verified by other sources, such as data on pellet mill construction/operation plans in Southeastern USA. This is of necessity an estimate, so high and low demand were modelled.
- SRTS uses empirical land use models to estimate the impact of forest prices on forest composition and extent. The results vary over time and across regions. Detail of the outcomes is provided in Chapter 6 of the Technical report. The outputs described in the report focus on 2030 outcomes at a regional scale.

SRTS is partial equilibrium modelling, i.e. supply responses are modelled by introducing changes (in this case pellet demand) and allowing the modelled system to reach a new equilibrium. Use of this type of modelling is common in economics where there is more than one impact and feedback into a market resulting from a change in the market. The SRTS model was not developed to examine scenarios and counterfactuals, such as those described in Stephenson and Mackay (2014). However, it does provide important information on market responses to demand and in this way sheds light on the likelihood of some of the scenarios.

Why we did not model the Canadian response to pellet demand

Modelling of Canadian forest inventory was not undertaken for a number of reasons. Discussions with Canadian modellers indicated that no one model would address the needs of the project. Essentially the reasons were:

- The Annual Allowable Cut (AAC)[8] sets a cap on all forest harvesting, and the process for establishing the AAC is not primarily market-based but all-encompassing Sustainable Forest Management (SFM)-criteria based.
- The AAC has never been reached, so the potential supply is huge and so the sort of supply-demand curves that underpin the SRTS modelling in Southeast USA and response to demand will not be reliable in a modelling sense.
- Models that seek to simulate how wood pellet demand is likely to affect forest management or forest products markets in Canada are not expected to have any 'power' of interpretation or high probability of reliability since wood pellets do not drive forest management or harvesting activity[9].
- There may be severe limitations to conducting economic modelling the forest products sector in Canada as a result of the way the tenure system rather firmly establishes the relationship among land owner (the Crown), the forest manager (the company holding the tenure and Sustainable Forest Licence (SFL)) and the company making forest products out of the harvested timber (the same company holding the SFL and managing the forest).
    - Note that 'management' in this sense is primarily just harvesting stands inherited from Nature.
    - The combination of Crown ownership and forest tenure system and limited number of actors involved with supply and demand and the process for determining 'stumpage' prices by the Province (on behalf of the Crown) in compliance with the requirements of the 'Softwood Lumber Dispute" with the US means that the assumptions that underpin the SRTS model in the US – that is, response of the forest sector can be simulated through use of supply-demand curves and empirically validated – virtually totally breaks down.

2.3 The literature review

The literature review was based on a rapid search of literature through available search engines, including Science Direct, Government, Provincial and regulatory web sites and other key sites that we thought would contain useful information, such as the web sites of non-governmental organisations active in the regions, the websites of relevant trade associations and the web sites of key companies involved in the North American-UK pellet supply chain. These sources were assessed against UK Treasury guidance on criteria for assessing literature sources in terms of quality of evidence. This was intended to cut out bias or poor quality data. If there was no sources of evidence on a particular topic we have said that there is 'no evidence' or 'evidence is lacking' on this subject.

The scenarios envisaged in Stephenson and Mackay (2014) are not supported in the literature, but factors that impact these scenarios e.g. forestry practice or economics are reported. We have used this indirect evidence to understand if the literature supports the practices described in Stephenson and Mackay (2014). If there was no data, the literature showed a wide range of results or if there was disagreement about specific issues we have judged the issue to be uncertain. This judgement of uncertainty combined with the amount of evidence is used to indicate the strength of evidence on an issue. So, for example, regulation and legal requirements are certain (because they exist) and cover a wide area. This means that we can assign regulation a high strength of evidence. However, evidence on specific issues, such as the removal of forest residues from a particular type of forest or region may be less well documented in the literature and therefore the strength of evidence would be lower (e.g. ranked as inadequate or inconclusive). Another example is the economics of pellet production. Most of the evidence on this in the literature is based on modelling that makes assumptions about the price of

[8] The Annual Allowable Cut (AAC) is the annual amount of timber that can be harvested on a sustainable basis within a defined forest area. The requirements that define sustainable are agreed in law and determined at Provincial Government level (see, for example, http://esrd.alberta.ca/lands-forests/forest-management/forest-management-facts-statistics/documents/AAC-CurrentFactsAndStatistics-2011.pdf)

[9] The same may be true of South USA. However, as this is a market driven forest system it is more viable to undertake market analysis of forest product demand through forest economic modelling.

the fibre for pellets. The assessment of these models would depend on the context of the model and the information provided on comparison with other data. The modelling may be of high quality, but the assumptions made may be based on less clear data: this may result in a downgrading of the data to inconclusive or inadequate.

2.3.1 Analysis of the literature review

The treatment of the literature review is described in 2.3. This was used to provide background information and data on the forestry sectors in the USA and Canada, including information on pellet production. The evidence gathered for the literature review was used to consider the likelihood of the scenarios:

- Where there is clear evidence on the likelihood of factors that would result in a scenario this has been noted.
- Where there is a lack of evidence on a scenario this is also recorded.

The conclusions on the likelihood of the scenarios based on literature evidence is summarised in the Analysis Tool and considered in our overall summary of likelihood.

3 High level summary of results

The results described in this report are a summary of the most significant results from our study. For more in depth analysis please refer to the accompanying Technical Report and the Analysis Tool developed for analysis of the evidence gathered in this study.

3.1.1 The literature review

The literature review provides important information on forestry in North America and on differences between the USA and Canada that impact the way the forestry sector may react to increased pellet demand. It was used to understand the way in which fibre for pellets is obtained or might be obtained in the future. It also examined the regulation and market for wood products in North America and other important factors that influence fibre supply for pellets. These findings are reported in Chapters 4 (USA) and 5 (Canada) of the Technical Report. The literature review showed important differences between the forest sectors of Canada and the USA. The essential elements are:

- Canadian forest is 94% State owned and regulated to take account of a complex set of variables that are important to stakeholders with an interest in the forest. The net result is that harvest is determined at Provincial level and forests are managed according to agreed forest management plans under licence or tenure contracts. The annual harvest allowance is known as the Annual Allowable Cut (AAC), which is a calculation of all of the functions the forest performs including biodiversity, socio-economic needs and financial return. In Canada the highest value markets are saw timber, paper and pulp and board products. Pellets are a very small part of the market. This means that reaction to pellet demand is likely to be relatively slow and require agreement at Provincial level[10].
- In the USA a much higher proportion of forest is privately owned, particularly in the Southeast where 87% of the 86 million hectares (ha) (212 million acres) of timber land is privately owned. Private ownership is in the hands of large corporations and a high number of small family forest owners. Although motivation for harvest is usually financial return, many small scale forest owners have other objectives to owning their land, including conservation, aesthetics, hunting, inheritance and other reasons. Over the past 60 years there has been considerable investment developing plantation management to improve yields and decrease rotation in the Southeast USA and the region now produces more than 90% of the wood and paper products in the USA. This market is characterised by relatively fast growth, high yielding plantations, longer growing valuable naturally regenerated forests and an ability to react relatively quickly to changes in

[10] The Provinces set stumpage prices because they have responsibility for Crown forests and they have to be incompliance with the regulations emanating from what is called the "US softwood lumber dispute". Each province does it differently. Its impact on forest management in the sense of BEAC scenarios would be negligible (other than affecting a company's profitability) since management and related harvesting rates and silvicultural systems would be determined through the forest management planning process required to be awarded a forest tenure licence and that sets the AAC, conservation goals, etc. See, for example: Government of Ontario (2016) and Government of New Brunswick (2008)

product demand. This has resulted in a quick reaction to pellet demand and considerable investment in and growth of pellet production over the past three to four years.

- There are important differences in the time it takes for forests to reach maturity between Canada and Southeast USA. Canadian forests are slow growing and take time to reach maturity, compared to the intensive plantation forests of Southeast USA.

The literature review considers issues that are relevant to the scenarios described in Stephenson and Mackay (2014). A key finding is that there is a lack of detailed information of fibre flows for pellets and on many of the details required to assess the scenarios in the published literature; in addition the published literature only provides a glimpse into forestry practices that may be used to provide roundwood for pellets in the future. More in depth on the ground knowledge is required to assess the most likely way that fibre would be provided for pellets.

3.1.2 High level summary of the results

Table 3 and Table 4 provide a high level summary of the results from the literature evidence, the evidence from the SRTS modelling and the analysis of the questionnaire for Canada and the USA respectively.

Table 3 Summary of results for Canada

Note: each of these includes a one line reminder of what the scenario is, but please refer to Table 1 for the full description.

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying Comments
4b	Removal of coarse forest residues.	Generally there was no consensus from survey results, although literature indicates it may happen sometimes, i.e. it is possible that it may happen.	All sources indicate removal of residues from forests in Pacific Canada is not extensive at present (less than 10% of forest residues and much less in some Provinces). The extraction of fine and coarse residues separately is not thought to be common in Canada, nor easy to do. Respondents said it is more likely that coarse residues would be extracted if they are extracted separately.	Leave all residues in the forest: Respondents thought that the counterfactual is an accurate representation of what might happen sometimes, depending on location and Provincial regulations (some Provinces have guidelines on forest residues, see the Canadian literature review, Chapter 4 of the Technical Report).	There is conflicting evidence in response to questions about the extraction of residues for pellets in the future at increased demand and prices. This is likely to be dependent on proximity to pellet mill, financial return and equipment available. There is evidence of marginal return on the use of forest residues for pellets at present in the literature.
5b	Removal of fine forest residues.	There was no overall consensus on this scenario in the questionnaire responses – there was a lot of uncertainty, including 'I don't know' responses from the forestry sector. Where a view was expressed it was thought to be unlikely.	Respondents said the extent of use of fine forest residues is not clear and would be dependent on the proximity of the site to pellet mills and the financial return from their removal. One respondent said that fine forest residues will not be used for pellet production as they are an explosion hazard. In Canada Provincial regulations on their removal are also important, although removal is allowed in Pacific Canada (see Chapter 4 in the Technical Report).	Leave all residues in the forest: The counterfactual is thought to be an accurate description sometimes, but will be dependent on location and Provincial regulations.	It was thought that fine forest residues were less likely to be used than coarse forest residues, because of the risk of contamination and the difficulty in separating coarse and fine residues. This is important because BEAC shows a higher carbon impact from the use of coarse residues. The extent of use and potential issues are as for 4b.

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying Comments
6b&7b	Removal of residues for a limited period.	In the questionnaire there was no consensus on whether these scenarios happen now due to a high degree of uncertainty. At higher prices in the future there was no consensus.	There was no evidence on the scenario in the literature.	Leave all residues in the forest: The counterfactual may be an accurate description some of the time, but will be dependent on location and may be difficult to prove.	Respondents to the questionnaire commented that “the use of forest residues for pellets is low in Canada (less than 10% of coarse and less than 5% of fine residues)” and “residues can only be removed once, at harvest, which makes the concept of removal over 15 years difficult.”
10a	Additional wood from naturally regenerated hardwood, East Canada.	The finding of the questionnaire is that this scenario is very unlikely to occur. Achieving additional harvest by increasing the rate of harvest of a forest (leading to a change of rotation length) is unlikely to be driven by pellet demand.	We could find nothing in the literature that supports this scenario based on the proposed rotation change. However, it is possible that additional wood could be taken at harvest. This wood is classified as forest residue or unmerchantable wood (Roach and Berch 2014), which would otherwise have been felled and left in the forest at harvest in Ontario. It is likely that such wood would only be used in the vicinity of pellet mills and that financial return from its use makes it unlikely to be used at scale. We could find no policy that supports this scenario. The financial return from pellets is unlikely to support the scenario.	Continue harvesting the forest every 100 years: The counterfactual is considered by respondents to the questionnaire to be accurate some of the time, but it is likely to depend on region and local regulations as well as agreed management plans.	Questionnaire respondents said that changing the rotation length by halving it is unlikely in Canada as trees are slow growing and would not be suitable for saw timber, which is the major forest product driver. Respondents said that the annual allowable cut (AAC) set by Provincial Government includes consideration of harvest, but is a complex equation of many other factors as well. Respondents thought that poor financial return would be an important factor in preventing this scenario happening. Respondents said that currently AAC is not exceeded in Canada so it is unlikely that rotation lengths

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying Comments
					or harvest rate increase would be driven by pellet production; instead additional harvest may happen by extending the AAC harvested.
10b	Additional wood from naturally regenerated hardwood, East Canada but under a different rotation to 10a.	The findings of the questionnaire is that this scenario is very unlikely to occur, although there was no consensus at higher fibre prices.		Continue harvesting the forest every 100 years.	Comments on this scenario are the same as for Scenario 10a (but note the lower decrease in rotation in this scenario).
11	Additional wood from naturally regenerated conifer forest in Pacific Canada.	Respondents to the questionnaire said this scenario was unlikely or very unlikely to occur, except at higher prices, where there was no consensus. (There were only 6 respondents to this question).	The literature indicates that current bioenergy in British Columbia uses sawmill co-products and forest residues (Roach and Berch 2014). There was no evidence from the literature that harvest would be extended in response to demand for pellets.	Continue harvesting the forest every 70 years.	Comments on this scenario were similar to scenario 10a.
12a	Additional wood from naturally regenerated conifer forest in Boreal Canada, resulting in short rotation.	Respondents to the questionnaire said this scenario was unlikely or very unlikely to occur, except at higher prices where there was no consensus. For some questions there were only 7 responses.	There is no evidence in the literature to support this scenario. There is no policy that supports this scenario. The financial return from pellets is unlikely to support the scenario.	Continue harvesting the forest every 100 years: The counterfactual is difficult to determine as Provincial Regulation will determine what happens in the absence of pellet demand. Currently AAC is not exceeded in Canada so it is unlikely that rotation lengths or harvest increase would be driven by pellet production. The counterfactual is accurate	Achieving additional harvest by increasing the rate of harvest of a forest (leading to a change of rotation length) is unlikely to be driven by pellet demand. Changing the rotation length by halving it is unlikely in Canada as trees are slow growing and would not be suitable for saw timber, which is the major forest product driver. The AAC set by Provincial

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying Comments
				some of the time, but is more complex than assuming that all the rotation length will decrease. It is likely to depend on region and local regulations as well as agreed management plans.	Government includes consideration of harvest, but is a complex equation of many other factors as well.
12b	Additional wood from naturally regenerated conifer forest in Boreal Canada, resulting in a decreased average rotation.	Respondents to the questionnaire said this scenario was unlikely or very unlikely to occur, except at higher prices where there was no consensus.		Continue harvesting the forest every 100 years:	Comments as for 12a, but note that the proposed decrease in rotation is shorter in this scenario.
10Pa	Additional wood from increase in harvest of hardwood plantation in East Canada, resulting in a shorter rotation.	Responses to the questionnaire lacked consensus on the occurrence of this scenario now (5 out of 11 respondents said 'I don't know') but it was thought to be very unlikely in the future or at higher pellet fibre prices.	The respondents and literature both suggest that intensive plantations are not common in Canada.	Leave plantation in previous management: The counterfactual was considered to be accurate most of the time.	Artificial seeding is used to ensure appropriate regeneration of managed forests. This could be considered a type of plantation, but such plantations will be slow growing (taking 60-80 years to mature) and cutting rotation length significantly would impact on the value of the saw timber. For this reason and because pellet demand is not a consideration in the determination of the AAC this scenario is unlikely. Financial return from pellets will not drive this scenario; regulation would prevent it.

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying Comments
10Pb, 11P, 12Pa and 12Pb	Additional wood from increase in harvest of hardwood plantation in regions in Canada resulting in shorter rotations.	Respondents to the questionnaire provided no consensus on the occurrence of these scenarios now (4 out of 8, 5 out of 10 and 4 out of 9 respondents who answered 'I don't know') but it was thought to be very unlikely in the future or at higher pellet fibre prices.		Leave plantation in previous management.	See 10Pa for comments.
30b and 30c	Bringing unmanaged forest into management in East and Pacific Canada.	Responses to the questionnaire indicated no consensus now and that this scenario is very unlikely in the future.	The literature indicates that these scenarios are definitely not occurring now. It is unlikely that unmanaged forest would be brought back into production as a result of pellet demand because AAC is not achieved in many regions in Canada (see Chapter 5 in the Technical Report). It is more likely that this would be exploited before management of unmanaged forests is considered.	Forest remains unmanaged: The counterfactual is considered by respondents to be an accurate description sometimes; the majority of unmanaged forest is remote and with little infrastructure in Canada.	The no consensus view is influenced by the small number of responses and the high proportion of 'I don't know' responses to the questionnaire.
30d	Bringing unmanaged forest into management in Boreal Canada.	Responses to the questionnaire indicated that this scenario definitely does not occur now and is very unlikely in the future.	The literature indicates that this scenario is definitely not occurring now (see Chapter 5 in the Technical Report).	Forest remains unmanaged: The counterfactual is an accurate description sometimes; the majority of unmanaged forest is remote and with little infrastructure in Canada.	It is unlikely that unmanaged forest would be brought back into production as a result of pellet demand because the AAC is not achieved in many regions in Canada. It is more likely that this would

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying Comments
					be exploited before management of unmanaged forests is considered.

Table 4 Summary of results for the Southeast USA

Note: each of these includes a one-two line reminder of what the scenario is, but please refer to Table 1 or the full description.

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
4a	Use of coarse forest residues in Southeast USA.	Evidence from all sources is that this scenario is likely.	Respondents said the extent of use of coarse forest residues is not clear and is dependent on how respondents define residues, the proximity of the site to pellet mills and the financial return from their removal. The opportunity to remove residues was not thought to be large except near pellet mills. In some locations it may be very unlikely.	Leave all residues in the forest: Questionnaire respondents thought the counterfactual is correct most of the time, but it will vary from location to location and may be difficult to prove.	Some respondents classify all non-merchantable wood as 'residue'. This means that any wood that does not have an immediate market is classed as residues, including diseased or poor growth trees. In some States in Southeast USA Best Management Practices (BMPs) and certification schemes require that a proportion of logging residues be left in the forest. In the future expansion of the use of logging residues will depend on proximity to pellet mill, financial return and regulations or BMPs adopted. The literature provides supporting evidence of use (or potential use) of forest residues, although the cost of extraction and transport is important (see chapter 4 in the Technical Report). Financial return on the use of residues from forests for pellets is not sufficient to encourage changes in forest practice, so their removal would only happen in

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
					circumstances where it can be integrated into the management of forests for other products. Some respondents are concerned that demand for pellets is increasing the use of residues that would otherwise have been left in the forest in some regions.
5a	Use of fine forest residues in Southeast USA.	Overall evidence is that this is moderately likely to occur but would not be extensive (i.e. it would only happen in a small number of places and/or at a small scale). There was a lack of consensus in respondents to the questionnaire on how this would develop in the future or at higher prices.	Respondents said the extent of use of fine forest residues is not clear and is dependent on how respondents define residues, the proximity of the site to pellet mills and the financial return from their removal. It was thought that fine forest residues were less likely to be used than coarse forest residues, because of the risk of contamination and the difficulty in separating coarse and fine residues. This is important because BEAC shows a higher carbon impact from the use of coarse residues. The extent of use and potential issues are as for 4a.	Leave all residues in the forest: The counterfactual may be correct, but it will vary from location to location and may be difficult to prove.	The literature does not provide any evidence that coarse and fine residues would be collected separately.
6a&7a	Use of forest residues for a set period in Southeast USA.	Moderately likely now, but with a degree of uncertainty. At higher prices in the future there was no consensus.		Leave all residues in the forest: The counterfactual is thought to be accurate most of the time, but will be dependent on location and may be difficult to prove.	No evidence on the scenario in the literature. Responses to the questionnaire demonstrated confusion about this scenario, concerning “why extraction of pellets would be stopped

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
					after 15 years" or "how we would know in year 1 that extraction will only go on for 15 years."
10a	Additional wood from naturally regenerated hardwood, East Canada.	The finding of the questionnaire is that this scenario is very unlikely to occur. Achieving additional harvest by increasing the rate of harvest of a forest (leading to a change of rotation length) is unlikely to be driven by pellet demand.	We could find nothing in the literature that supports this scenario based on the proposed rotation change. However, it is possible that additional wood could be taken at harvest. This wood is classified as forest residue or unmerchantable wood (Roach and Berch 2014), which would otherwise have been felled and left in the forest at harvest in Ontario. It is likely that such wood would only be used in the vicinity of pellet mills and that financial return from its use makes it unlikely to be used at scale. We could find no policy that supports this scenario. The financial return from pellets is unlikely to support the scenario.	Continue harvesting the forest every 100 years: The counterfactual is considered by respondents to the questionnaire to be accurate some of the time, but it is likely to depend on region and local regulations as well as agreed management plans.	Questionnaire respondents said that changing the rotation length by halving it is unlikely in Canada as trees are slow growing and would not be suitable for saw timber, which is the major forest product driver. Respondents said that the annual allowable cut (AAC) set by Provincial Government includes consideration of harvest, but is a complex equation of many other factors as well. Respondents thought that poor financial return would be an important factor in preventing this scenario happening. Respondents said that currently AAC is not exceeded in Canada so it is unlikely that rotation lengths or harvest rate increase would be driven by pellet production; instead additional harvest may happen by extending the AAC harvested.

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
10b	Additional wood from naturally regenerated hardwood, East Canada but under a different rotation to 10a.	The findings of the questionnaire is that this scenario is very unlikely to occur, although there was no consensus at higher fibre prices.		Continue harvesting the forest every 100 years.	Comments on this scenario are the same as for Scenario 10a (but note the lower decrease in rotation in this scenario).
11	Additional wood from naturally regenerated conifer forest in Pacific Canada.	Respondents to the questionnaire said this scenario was unlikely or very unlikely to occur, except at higher prices, where there was no consensus. (There were only 6 respondents to this question).	The literature indicates that current bioenergy in British Columbia uses sawmill co-products and forest residues (Roach and Berch 2014). There was no evidence from the literature that harvest would be extended in response to demand for pellets.	Continue harvesting the forest every 70 years.	Comments on this scenario were similar to scenario 10a.
12a	Additional wood from naturally regenerated conifer forest in Boreal Canada, resulting in short rotation.	Respondents to the questionnaire said this scenario was unlikely or very unlikely to occur, except at higher prices where there was no consensus. For some questions there were only 7 responses.	There is no evidence in the literature to support this scenario. There is no policy that supports this scenario. The financial return from pellets is unlikely to support the scenario.	Continue harvesting the forest every 100 years: The counterfactual is difficult to determine as Provincial Regulation will determine what happens in the absence of pellet demand. Currently AAC is not exceeded in Canada so it is unlikely that rotation lengths or harvest increase would be driven by pellet production. The counterfactual is accurate some of the time, but is more complex than assuming that all the rotation length will decrease. It is likely to depend on region and local	Achieving additional harvest by increasing the rate of harvest of a forest (leading to a change of rotation length) is unlikely to be driven by pellet demand. Changing the rotation length by halving it is unlikely in Canada as trees are slow growing and would not be suitable for saw timber, which is the major forest product driver. The AAC set by Provincial Government includes consideration of harvest, but is a complex equation of many other factors as well.

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
				regulations as well as agreed management plans.	
12b	Additional wood from naturally regenerated conifer forest in Boreal Canada, resulting in a decreased average rotation.	Respondents to the questionnaire said this scenario was unlikely or very unlikely to occur, except at higher prices where there was no consensus.		Continue harvesting the forest every 100 years: as for scenario 12 a	Comments as for 12a, but note that the proposed decrease in rotation is shorter in this scenario.
13a	Additional wood by increasing the rate of harvest of a naturally-regenerated hardwood forest in Southeast USA resulting in decreased rotation.	Respondents to the questionnaire said that this scenario was not occurring now but there was no consensus on the future or on increased pellet fibre prices. Respondents did not think that the proposed rotation changes would happen. 12 out of 27 respondents said the scenario was definitely not happening now, and a number of respondents answered sometimes to this scenario, but qualified this by saying sometimes meant rarely or occasionally. One stakeholder group (4 respondents) thought the additional		Continue harvesting the forest every 70 years: The respondents thought that the counterfactual is accurate most of the time, although it is not easy to define rotation length for naturally regenerated forest in Southeast USA.	As noted by the respondents the concept of a rotation age does not apply to most naturally regenerated forests. In SRTS projections, 20 percent of pellet demand was defined to be hardwood. Applying this level of demand across the region led to a very small reduction in average age of the inventory relative to the no pellet demand counterfactual. This is partially due to increased harvest of older hardwood stands where most hardwood harvest occurs. It is also due to the resulting increase in younger hardwood stands so that the average age decreased. This is not directly comparable to the BEAC discrete shift in from one

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
		harvest of these woodlands as a result of pellet demand was likely, and there was a lack of consensus in other stakeholder groups. The concept of rotation was thought to be particularly difficult for hardwoods and this was confirmed in the literature review.			fixed rotation age to another. This does better reflect how hardwood forests are managed in the region. The SRTS results suggests a small change in the age class structure of the hardwood resource.
13b	Additional wood by increasing the rate of harvest of a naturally-regenerated hardwood forest in Southeast USA compared to longer rotation in counterfactual.	No consensus.	Nine out of 26 respondents said the scenario is definitely not occurring now and five said sometimes. A number of these five said that by sometimes they meant rarely or occasionally. Six respondents said 'I don't know' and four said it is happening most of the time.	Reduce the rate of harvest compared to the harvest in the presence of pellet demand, to every 80 years: The respondents thought that the counterfactual is accurate most of the time, although it is not easy to define rotation length for naturally regenerated forest in Southeast USA for the reasons above.	The concept of rotation was thought to be particularly difficult for hardwoods and this was confirmed in the literature review. The SRTS modelling results and the evidence on scale is as for 13a. The comments relating to tracking in 13a also apply here.
13Pa and 13Pb	Additional wood generated by increasing the rate of harvest of a hardwood plantation in Southeast USA resulting in decreased rotation length.	The most common view in the questionnaire was that these scenarios are definitely not occurring now and are very unlikely in the future. Five of 16 respondents answered 'I don't know'.		13Pa Leave plantation in previous management, 13Pb Reduced frequency of harvest with low demand for wood: The counterfactual is thought to be accurate most of the time.	Hardwood plantations are rare in Southeastern USA. Demand or financial return from pellets is unlikely to change this, nor is it likely that regulation would drive it. There was no evidence on this scenario from SRTS

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
					modelling or the literature review.
14a	Additional wood from intensively-managed pine plantation, in Southeast USA, harvesting at 25 years.	The overall assessment was that it is unlikely in the future at current prices and only becomes likely at higher pulpwood prices.	The majority of respondents to the questionnaire felt that the practices were occurring now (so the counterfactual is not accurate). Survey respondents thought that scale was minimal at present. Evidence from the literature indicates that pellet production is only financially viable when there are incentives for bioenergy.	Reducing the frequency of harvest compared to the harvest in the presence of pellet demand, to every 35 years: The counterfactual was not thought to be accurate as rotation length is already around 25 years and it is unusual to have a 35 year rotation for intensively managed softwood plantations in the Southeastern USA.	There is good evidence from the literature review, SRTS modelling and survey that pellet demand will affect harvest from intensively managed softwood plantations in Southeastern USA but it is not likely to drive a change in rotation length. In other words there will be additional harvest due to pellet demand (often envisaged to be increased thinning or additional small roundwood being diverted to pellets), but final rotation for intensively managed plantations will not change, except in response to the saw timber market (see Chapter 4 in the Technical Report). Optimal rotations are set by a combination of the saw timber market and owner objectives. Financial return from pellets is unlikely to change this. Scale is not easy to determine as local conditions will influence harvest patterns. In regions where there is demand for sawtimber, small roundwood and pellets harvest patterns may be affected by the total

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
					market demand, but this is not likely to be a common situation.
14b	Additional wood from intensively-managed pine plantation, in Southeast USA, reducing rotation to 20 years.	Responses to the survey indicate that this is not occurring now and is unlikely in the future (becoming less unlikely at higher pulpwood prices).	Scale is not easy to determine as local conditions will influence harvest patterns, but it was thought to be minimal by most survey respondents. Evidence from the literature indicates that pellet production is only financially viable due to incentives.	Reducing the frequency of harvest compared to the harvest in the presence of pellet demand, to every 35 years: The counterfactual was not thought to be accurate as rotation length is around 25 years and it is unusual to have a 35 year rotation for intensively managed softwood plantations in the Southeastern USA.	There is good evidence from the literature review, SRTS modelling and survey that pellet demand will affect harvest from intensively managed softwood plantations in Southeastern USA but it is not likely to drive a change in rotation length. In other words there will be additional harvest due to pellet demand (often envisaged to be increased thinning or additional small roundwood being diverted to pellets by forestry stakeholders), but final rotation for intensively managed plantations will not change, except in response to the saw timber market (see Chapter 4 in the Technical Report). Rotation length is unlikely to be reduced to 20 years as a result of pellet demand. Optimal rotations are set by the saw timber market and owner objectives. Financial return from pellets is unlikely to change this.
19	Small roundwood from Southeast	Responses to the questionnaire	There is no evidence that this is happening in the literature.	Pulpwood produced in Southeast USA used for non-	Respondents thought financial incentives from

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
	USA, causing indirect impact of Eucalyptus plantation replacing Brazilian rainforest.	indicated a high level of uncertainty that this is occurring now (6 out of 15 responses were 'I don't know') but consensus was that it is very unlikely in the future.		bioenergy purposes: The counterfactual is an accurate description most of the time.	pellet demand are not sufficient to drive this change.
20	Small roundwood from Southeast USA, causing indirect impact of Eucalyptus plantation replacing Brazilian abandoned degraded pasture land.	Responses to the questionnaire indicated a high level of uncertainty that this is occurring now (7 out of 15 responses were 'I don't know') but consensus was that it is very unlikely in the future.	No evidence that this is happening from the literature.	Pulpwood produced in Southeast USA used for non-bioenergy purposes: The counterfactual is an accurate description most of the time.	Respondents thought financial incentives from pellet demand are not sufficient to drive this change and said Brazilian paper and pulp production predates pellet demand in Southeastern USA.
21	Small roundwood from Southeast USA, causing indirect impact of increasing the harvest rate of naturally-regenerated coniferous forest in Pacific Canada.	Responses to the questionnaire indicated a high level of uncertainty that this is occurring now (7 out of 15 responses were 'I don't know') but there was an overall consensus was that it is very unlikely in the future (with a significant proportion of 'I don't know' responses).	There is no evidence that this is happening from the literature.	Pulpwood produced in Southeast USA used for non-bioenergy purposes: The counterfactual was felt to be an accurate representation most of the time.	Respondents thought that financial incentives from pellet demand are not sufficient to drive this change and that pellets cannot out compete non-bioenergy products. A number of questionnaire respondents said there was no connection between paper and pulp production in Pacific Canada and Southeastern USA.
22a	Additional wood from the conversion of naturally regenerated	The overall evidence is that this is likely to happen sometimes at present, but there was	Respondents said that the extent of conversion of naturally regenerated coniferous forest to intensive coniferous plantation is	Continue harvesting the forest every 50 years, and leaving to regenerate naturally: The counterfactual	The rotation length will be determined by saw timber demand, not pellet demand. Financial return from pellet

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
	coniferous forest in Southeast USA (harvested every 50 years) to intensive pine plantation (harvested every 25 years).	no consensus in the future or on the impact of higher demand and prices.	determined by local saw timber, small roundwood demand, agricultural commodity markets and owner objectives, rather than solely pellet demand. One respondent said that the cost of conversion is considerable and pellet fibre prices do not offer sufficient return. There was also a comment that most of the lands suitable for conversion have already been converted.	is an accurate description sometimes. Forest inventory (FIA) data was quoted by respondents to the questionnaire as evidence that rotation lengths average 41 years, shorter than that suggested in the counterfactual.	production is unlikely to change this now or in the future. SRTS modelling shows that under certain circumstances (small roundwood) prices could have an impact on conversion of naturally regenerated forests to plantations. The difference between housing demand scenarios had a bigger impact on conversion than pellet demand. But, the scenarios where housing demand remained low and pellet demand was high increased the influence of pellet demand on management intensity. For this to happen the price of small roundwood has to be relatively high compared to saw timber. This is a situation that has not been seen historically but current price differences between pine small and large roundwood are at historical lows. Continued low large roundwood demand and high small roundwood demand would delay return to historical price

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
					relationships. However, discounted cash flow analysis results in the modelling section indicate that even if small roundwood prices double they would not be sufficient to justify the current cost of timberland conversion. The questionnaire responses indicated that a doubling of small roundwood prices would impact pellet producers business plans, so this is an unlikely but not impossible situation.
22b	Scenario as for 22a, but with shorter rotation plantation.	The responses to the questionnaire were definitely not or sometimes occurring now, but respondents commented that by ‘sometimes’ they mean rarely or occasionally, so the overall rank could be regarded as ‘rarely’.	The extent of conversion of naturally regenerated coniferous forest to intensive coniferous plantation is determined by local saw timber, small roundwood demand, agricultural commodity markets and owner objectives, rather than solely pellet demand.	Continue harvesting the forest every 50 years, and leaving to regenerate naturally: The counterfactual is an accurate description sometimes. Forest inventory (FIA) data provides evidence that rotation lengths average 41 years, shorter than that suggested in the counterfactual. This would mean that the carbon implications differ from what Stephenson and Mackay (2014) suggest.	There was no consensus on the future or higher prices. The rotation length will be determined by saw timber demand, but a 20 year rotation is unlikely. Financial return from pellet production is unlikely to change this now or in the future. SRTS modelling results are as for scenario 22a. However, there was no evidence from the modelling on the shorter rotation length.

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
23a	Additional wood from the conversion of naturally regenerated hardwood forest in Southeast USA to intensive pine plantation.	The responses to the questionnaire were definitely not or sometimes occurring now, but respondents commented that by 'sometimes' they mean rarely or occasionally, so the overall ranking could be regarded as 'rarely'. There was no consensus in the future, with stakeholder groups split in opinion between unlikely or very unlikely and very likely.	Respondents said that the extent of conversion of naturally regenerated hardwood forest to intensive plantation is determined by local saw timber, agricultural commodity markets and owner objectives, rather than pellet demand.	Continue harvesting the forest every 70 years, and leaving to regenerate naturally: The counterfactual is an accurate description sometimes, although the concept of 'rotation' does not apply to naturally regenerated hardwood forests. Evidence in the literature is that conversion to plantation would be driven by sawtimber demand, not pellet demand (see Chapter 4 in the Technical Report).	SRTS modelling results are for scenario 22a. However, the majority of land conversion to pine plantations comes from natural and mixed pine-hardwood forests due to site conditions.
23b	As for 23a, but with shorter rotation plantation.	The responses to the questionnaire were definitely not or sometimes occurring now (14 out of 16 responses). Respondents commented that by sometimes they meant rarely or occasionally, so the ranking could be regarded as 'rarely'. The questionnaire indicated that the scenario is unlikely or very unlikely in the future, but there was	The extent of conversion of naturally regenerated hardwood forest to intensive plantation is determined by local saw timber, agricultural commodity markets and owner objectives, rather than pellet demand. A rotation length of 20 years is unlikely.	Continue harvesting the forest every 70 years, and leaving to regenerate naturally: The counterfactual is an accurate description sometimes, although the concept of 'rotation' does not apply to naturally regenerated hardwood forests. Evidence in the literature is that conversion to plantation would be driven by sawtimber demand, not pellet demand.	SRTS modelling results are for scenario 22a. However, the majority of land conversion to pine plantations comes from natural and mixed pine-hardwood forests due to site conditions.

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
		less consensus at higher fibre prices.			
24a	Conversion of naturally regenerated coniferous forest to short rotation coppice (SRC).	The responses to the questionnaire were definitely not occurring now and unlikely in the future. Financial return from pellets unlikely to drive this change.	There is little short rotation coppice (SRC) in Southeastern USA and evidence from the survey and literature indicates that it is unlikely that this will change.	Continue harvesting the forest every 50 years, and leaving to regenerate naturally: The majority view in the survey was that the counterfactual is an accurate description sometimes, although for naturally regenerated pine FIA data indicates rotation length is on average 41 years.	SRTS does not model SRC.
24b	As for 24a, but with gradual conversion over 50 years.	The responses to the questionnaire were definitely not occurring now and very unlikely or unlikely in the future. Financial return from pellets are unlikely to drive this change.	There is little short rotation coppice (SRC) in Southeastern USA and evidence from the survey and literature indicates that it is unlikely that this will change.	Continue harvesting the forest every 50 years, and leaving to regenerate naturally: The majority view in the survey was that the counterfactual is an accurate description sometimes, although for naturally regenerated pine FIA data indicates rotation length is on average 41 years.	SRTS does not model SRC.
25a	Conversion of naturally regenerated hardwood forest to short rotation coppice (SRC).	The responses to the questionnaire were definitely not occurring now and very unlikely/unlikely in the future. Financial return from pellets unlikely to drive this change.	There is little SRC in Southeastern USA and evidence from the survey and literature indicates that it is unlikely that this will change.	Continue harvesting the forest every 70 years, and leaving to regenerate naturally: The majority view in the survey was that the counterfactual is an accurate description sometimes.	SRTS does not model SRC.

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
25b	As for 25a, but with gradual conversion over 70 years.	The responses to the questionnaire were definitely not occurring now and very unlikely/unlikely in the future. Financial return from pellets unlikely to drive this change.	There is little short rotation coppice (SRC) in Southeastern USA and evidence from the survey and literature indicates that it is unlikely that this will change.	Continue harvesting the forest every 70 years, and leaving to regenerate naturally: The majority view in the survey was that the counterfactual is an accurate description sometimes.	SRTS does not model SRC.
26	Conversion of abandoned agricultural land to SRC.	Respondents to the questionnaire said that this scenario is either definitely not occurring or sometimes occurring now. They qualified this by saying that 'sometimes' means rarely or occasionally, so the overall rank could be regarded as 'rarely'. Respondents thought it is very unlikely in the future The main reason for the opinion that this is unlikely in the future is that the financial return on pellets is sufficient to drive this change and would not compete with the return on planted pine for saw timber. The literature does not provide any evidence to contradict this.		Abandoned agricultural land left to revert to sub-tropical, moist, deciduous forest: The counterfactual was not considered accurate in most locations in Southeastern USA.	Conversion of agricultural land is not modelled in SRTS.

Scenario	Description	Likelihood	Extent	Counterfactual	Qualifying comments
30a	Bringing unmanaged forest into management.	Responses to the questionnaire indicated this scenario is sometimes occurring now but there was no consensus on the future (views were widespread).	The responses to the questionnaire and the literature indicate that there are two types of forest that may be affected by this scenario: a) forests that are legally protected from harvest, via conservation easements or wetland or wilderness designation or similar, and b) forests that are owned by family forestland owners because they like owning forestland (for aesthetic or other purposes). Neither category is being harvested now, but category a) are legally protected and will not be harvested under any circumstances, while category b) are the forests that might come into production if the price increases enough (or if ownership changes) (see Technical Report Chapter 4).	Forest remains unmanaged: The counterfactual is thought to be an accurate description sometimes, but there were difficulties in agreeing with it because management will depend on forest owner objectives, which would determine what happens in the absence of pellet demand. There was little information on bringing private small scale forest back into management in the literature but surveys of small scale owners confirm the results to the questionnaire (in fact a number of respondents quoted these surveys).	The lack of consensus in the questionnaire reflected a lack of consensus on the meaning of the term unmanaged forest. This was defined as “forest that has no management plan”. From the responses to the questionnaire there is a possibility that sawtimber demand would drive harvest (management) of these forests but there is no evidence that pellet demand would. There was no evidence from SRTS modelling on this scenario.

The evidence above indicates that 15 out of 38 of the high carbon scenarios identified in BEAC are not occurring and are not likely to occur in the future, even with high pellet demand or higher fibre prices. For these scenarios there was good agreement between the respondents that they are unlikely now or in the future and no evidence in the literature that they occurred. The main dissent tended to be the 'I don't know responses' in the questionnaire.

18 out of the 38 scenarios were "no consensus" ranking, as a result of a wide spread of answers or because there were a relatively high number of 'I don't know' responses.

Two out of the 38 scenarios were considered likely now and in the future; three of the scenarios were considered likely or moderately likely now but with less consensus for the future or at higher fibre prices. Of these 5 most were considered to be a low scale means of pellet supply and one was considered to be a potentially high supply of pellet fibre (Scenario 4a). All supply is likely to be local to pellet plants, depending on transport costs. Leakage or spill over into other areas may happen as a result of local displacement of other uses of this fibre, although some pellet plant owners told us that they chose areas where other small roundwood demand is low or decreasing to site their plants.

Four of the five scenarios considered to be likely or moderately likely to be occur as a result of increased pellet demand are high carbon scenarios, as follows:

- The **use of forest residues** (scenarios 4a and 5a) (depending on the definition of forest residues and the financial return from pellets); this is considered more likely in the USA than Canada (where there was no consensus), so only the US scenarios were ranked likely. The extent of this scenario depends on location and definition of residues. In Southeast USA the use of forest residues could be significant near pellet mills but not common over the whole of the Southeast. In Canada this practice is also only likely in the vicinity of pellet mills, but it was not thought to be as likely as in the USA and was thought to be likely to be slow and modest in development. Respondents did not think that coarse and fine residues would be separated, but if they were then it was more likely that coarse residues would be used. This is important because the BEAC tool indicates higher carbon impact from coarse than from fine residues. In the questionnaire it was clear that a large number of the stakeholders regarded residues as any part of the forest that has no economic value at the time of harvest. This means that unmerchantable trees, branches and any small wood not used for other purposes are included in this definition and could be used in pellet production. Regulations in both the USA and Canada could restrict the amount of residues removed (although this is less likely in the USA). Removal of residues may be controlled through sustainability certification and Best Management practices (BMPs) in Southeast USA. Both Canadian and US stakeholders thought saw sawmill co-products would increase if timber demand increases and that this would decrease the need for other residue use (although it may also be mirrored with increased use at the mills). This was supported in the literature and in SRTS modelling. A number of literature studies indicated that the use of forest residues is marginally economic, although location with respect to the pellet mill is key.
- **Additional wood from intensively managed pine plantations** in Southeast USA (Scenario 14a). All sources provided evidence that it was likely that additional wood from coniferous plantations would provide fibre for pellets and so we have ranked this scenario as likely. Sources could be thinnings or small roundwood. However, the respondents to the questionnaire did not think that the counterfactual to this was realistic. We recommend that this is examined to see if it makes a difference to the carbon outcome.
- **Bringing unmanaged forest into management in Southeast USA** (Scenario 30a). There was a range of views from the stakeholders on this scenario and a lot of accompanying text to clarify what is meant by 'unmanaged'. This is important because a large proportion of naturally regenerated timberland in Southeast USA belongs to families who own a few acres. The definition used for 'unmanaged' in this study was the UN Food and Agriculture definition as that which 'has no management plan'. Few of the small scale family owned private forests in Southeast USA have management plans, so strictly speaking all of the forest could be regarded as 'unmanaged' using the FAO definition. In fact it is likely to have been harvested in the past and respondents to the survey suggested a better term would be 'under-managed'. This forest is likely to be brought back into productive use at harvest time, if harvest can be regarded as management (there is not likely to be a management plan). In addition new ownership may result in changes. Estimating the extent of this practice is not easy. Most survey respondents

thought that it is likely that some pellet fibre will be produced from these forests, but unlikely that pellet demand alone will drive this harvest (it will be driven by saw timber demand, but pellet demand could add additional pressure). This scenario is considered likely only under these conditions. There was no evidence that designated forest (e.g. conservation forest) would be brought under management as a result of pellet demand. The literature review concluded that no "land set aside for conservation would be brought into timber production, because many of these lands are legally protected from harvest."

The fifth scenario considered likely or moderately likely is scenario 22a, which has a negative GHG intensity over a 40 year period:

- **Additional wood from the conversion of a naturally regenerated coniferous forest in Southeast USA to an intensively managed pine plantation that is harvested every 25 years** (Scenario 22a). There was evidence, particularly from SRTS modelling, that pellet demand together with sawtimber demand would be a driver for some conversion of coniferous forest to plantation. Some respondents to the questionnaire said that conversion of forests to plantations occurs for a number of commercial reasons and it is unlikely that conversion would happen as a result of pellet demand alone, because financial return is not adequate and sustainability requirements would not allow this change. It was clear that respondents did not think that rotation would be shortened as a result of pellet demand. An additional consideration if the length of time that the power stations will operate on pellets. This will be linked to bioenergy incentives. For a plantation conversion to be driven by pellet demand alone there would need to be an incentive duration of at least 20 years for the plantation to develop to harvest. We have concluded that there is a need to study this further and to clarify the scale at which this is happening or likely to happen. (This scenario was included in the study as one half of a pair of scenarios, the other being 22b, which has a positive GHG intensity over 200 kg CO2e/MWh and where the harvest rotation is only 20 years. Scenario 22b was considered by respondents to be unrealistic for softwood raw timber use[11].)

The SRTS projections were sensitive to demand profiles. In the past sawtimber demand has been the key driver of harvest (levels and timing). However, the current recession in construction has led to historical low large roundwood prices relative to small roundwood prices. In the case that small roundwood demand continues to increase, and sawtimber demand does not, then then model projections show an increasing influence of small roundwood on management. Though under these circumstances small roundwood demand becomes more important, discounted cash flow analysis showed that even if small roundwood prices doubled, it would not be sufficient income to justify conversion of land to intensive small roundwood only management. The SRTS modelling also provided perspectives on economics and the overall regional carbon impact of pellet demand. This did not provide any evidence that overall regional carbon impacts are greater in the presence of pellet demand.

The scenarios above apply to the Southeast USA. One important comment from respondents in this region is that financial return is important in motivating harvest and financial return is highest from saw timber. Evidence is presented in Chapters 4 and 8 that saw timber return is significantly higher than pellet financial return. This means that pellet demand is unlikely to drive rotations or harvest alone. It is more likely that the supply response to pellet demand is likely to be integrated into other supply chains (e.g. through increased planting resulting in increased thinning).

The current forest inventory in Southeast USA is a result of historic trends: it takes time to grow trees (even fast growing plantations) and these forests were planted before pellet demand rose to current levels. Inventories are higher now that they have been for some time, which is due in part to increased planting to meet forest product demand (US EPA 2013, Smith et al 2010)[12]. The development of

[11] From Stephenson and Mackay (2014): "owing to the increased growth rate, an intensively-managed Loblolly plantation that is harvested every 20 years, has a similar non-soil carbon stock to a naturally-regenerated Loblolly forest that is harvested every 50 years (Scenario 22b), whereas an intensively-managed Loblolly plantation that is harvested every 25 years, has a greater non-soil carbon stock than a naturally-regenerated Loblolly forest that is harvested every 50 years (Scenario 22a)."

[12] There are many reasons for the size of the current inventory: (i) The existence of publically owned natural forests that produce little timber and therefore have large Growth:Drain ratios (Smith et al., 2010). The area of reserved forest doubled between 1953 and 1997 (USDA, 2001). (ii) Tree planting and conservation efforts in the 1970s and 1980s (US Environmental Protection Agency, 2013); (iii) The movement of agricultural land from the East to the Mid-West since the 1950s, resulting in marginal agricultural land in the East reverting to forests (Smith et al., 2010; Fernholz et al., 2013; USDA, 2012). Overall, the total US forest land area increased by 4% between 1987 and 2007 (Smith et al., 2010). (iv) The age distribution of US forests. Significant areas of forest had not yet reached their equilibrium carbon storage in 2010, and were therefore continuing to grow. However, the new forests which have been established on the previous agricultural land in the East are now approaching maturity, therefore growth is slowing down (USDA, 2012); (v) Increased wood recycling and increasingly efficient wood processing techniques, reducing the wastage of wood.

intensive plantations in the Southeast USA means that this region is dominant in the forest products market. These plantations were developed to supply the pulp and paper and fibre board sectors, as well as saw timber and these markets are still the major driver for their planting. Currently, forest inventory data in the Southeast US indicates that growth exceeds removals for all forest types and regions. The increase in forest inventory has happened simultaneously with the abandonment of agricultural land as returns from agriculture decreased. However, land owners are likely to consider long term financial return when replanting after harvest and as agricultural commodity prices or urbanisation pressures increase these may become viable alternatives. There is some evidence from the survey and the literature review that in the Southeast USA a more robust market for forest-related commodities (including pellets) will increase the value of the land from forestry and reduce the likelihood that private land will be sold and converted to another land use. There is also evidence in the literature (Butler et al 2007, 2008) that landowner objectives are diverse and include aesthetics, inheritance and conservation, such that making generalisations about management of forest in the Southeast USA difficult.

Inventory data for the Southeast USA indicates that pine removals currently occur predominately in the 20-30 year age class, while hardwood removals are predominately in 50+ year old lowland hardwoods.

This study did not find any justifiable link between pellet demand and impact on conservation (this was not part of the remit of the study and was not investigated in depth), but we did find that there are concerns by some stakeholders that conservation impacts have not been fully considered. In particular bottomland hardwood forests are ecologically important. There is little evidence from this study that pellet demand alone drives the harvest of these forests: but it may result in increased harvest (the evidence is drawn from statements from NGOs, which need to be substantiated). What it does not do is decrease rotation in comparison to the counterfactual by 10 years or greater in the way that BEAC models. If it impacts rotation smaller changes in average rotation are more likely, although a number of respondents commented that rotation is most meaningful for plantations and large estates and less relevant to small scale natural forest holdings. We have suggested that further work is needed to understand the extent of these impacts and to ensure that important ecosystems are not impacted.

None of the ‘likely’ scenarios listed are from Canada. This is because the majority of fibre for pellets in Canada is from sawmill co-products and respondents thought this would continue to dominate the picture. Supply strategies for pellet fibre in Canada that had no consensus in the questionnaire but are considered in the literature include:

- **The use of forest residues**: this will be very dependent on economics and there are analyses that show the financial return to be poor. We suspect that this supply would be dependent on harvest techniques and proximity to the pellet mill.
- **Extension of harvest within the AAC**: pellet demand alone would not be sufficient to drive this, but increased small roundwood demand in general, including pellet demand could result in this occurring in the vicinity of the pellet mill.
- **The use of unmerchantable wood** in the vicinity of pellet mills. Both of the points above could also be regarded as covering this type of wood. Its treatment in Canada is not clear, possibly because this depends on circumstances, but there is evidence that it could provide a source of pellet fibre in the right location.

A key factor that affects the likelihood of the scenarios in Canada is the regulation of forest in Canada, including the way in which the AAC is set. This is discussed in Chapter 5 of the Technical Report. Essential elements are that calculations are based predominantly on the financial return from high value products (i.e. the harvest needs for these products), conservation requirements (as set by Provincial regulations) and socio-economics. Carbon stock is not currently a factor but this may change. Pellet demand is low compared to other forest products in Canada and its supply unlikely to change AAC (i.e. it is unlikely to change the harvest or management strategies that are set in the AAC). Furthermore the AAC has set a limit on harvest that has not been achieved for some years. Current forest inventory in Canada is due to planting and regeneration of forests some time ago. Pellet demand was not considered in this regeneration and it has not driven current trends. However, the literature survey did provide evidence that bioenergy supply has been considered by Provincial Governments and that there

US saw-mills have reduced the amount of wood incinerated as a waste from 41 - 45% in 1940 to less than 1% in 2005 (Fernholz et al., 2013); (vi) Increased productivities, and hence wood outputs from intensively-managed plantations, reducing pressure on other forests (Fernholz et al., 2013; US Environmental Protection Agency, 2013); (vii) Decreased harvest during the recession (Ince and Prekash, 2012); (viii) A diverse wood industry resulting in it being economically competitive for private land owners to grow trees (Fernholz et al., 2013).

is some biomass from forest used for bioenergy in Canada, which provides an indication of how fibre for pellets might be obtained.

In both regions pellet markets are small compared to other forests products markets. In Canada most fibre for pellets comes from sawmill co-products and only a small amount (<5%) comes from roundwood or other forest wood. In the USA the proportion from forests is larger, but sawmill co-products remain significant. Drax (2015) reported 80% of their pellet fibre came from forest residues[13], thinnings and storm salvage in 2014 and that around 16% came from sawmill co-products and sawdust). The current recession in the construction sector in the USA means that sawtimber harvest is relatively low. However, as saw timber demand grows the availability of saw timber residues will increase and an increased proportion may be used for pellet fibre.

Additional sources of pellet fibre that may occur are:

- Increased harvest of naturally regenerated forests.
- Increased thinnings in intensively managed plantations in Southeast USA. A number of respondents suggested that this would be a management strategy that could be considered in the short term to meet demand for pellet fibre. One suggestion is that plantations will be planted more densely to allow additional thinning within a few years.
- Additional wood could also be achieved by taking more roundwood for pellet production. Stakeholders did not think that rotation length would be shortened as a result of pellet demand. One respondent said that depending on market and growing conditions rotation may be shorted by up to 3 years, and that pellet demand would be part of the market conditions considered in this.

4 Key messages

4.1 Evidence qualification

The evidence provided needs to be qualified by the following:

- Literature: Few of the scenarios are envisaged in the literature. Instead we have examined policy, economic conditions and potential forest management responses that may encourage or prevent the scenarios.
- Stakeholders: There are a relatively small number of stakeholders who are qualified or experienced enough to comment on the scenarios. These do not make up sufficient numbers to allow statistical analysis. Instead we have relied on assessment of their views of the scenarios in the questionnaire (for our methodology see Chapter 7 of the Technical Report).
- Interpretation of results in the questionnaire: In interpreting the results to the questionnaire we have attempted to avoid bias caused by different numbers of respondents in each type of stakeholder group. Although we attempted to achieve a good response rate from stakeholders in each group, it is not possible for us to know what coverage we have in terms of percentage of the whole population of each group. For some stakeholder groups there were a limited number of respondents with knowledge of the sector. Therefore rather than using a most common view from all of the individual responses, we assessed the results in a way that presents the views of each stakeholder groups on an equal basis. The reason we felt that all stakeholder groups should receive equal weighting is that each group brings a different kind of experience and knowledge to the sector, all of which are important in understanding the likelihood of the scenarios. We did not want any of those views to be lost amongst the survey responses simply because there were not many forest managers operating in a particular region, for example. See Chapter 7 in the Technical Report for a more detailed discussion of the method.
- Impact of interpretation of scenarios on the results: In some cases the scenarios are open to interpretation and nuances are important. We also provided limited options for scoring the

[13] Note that the definition of forest residues is different for different stakeholders and the Drax definition may not be the same as other stakeholders.

likelihood. Respondents pointed this out and qualified the scores they provided with comments. These comments are an important part of the evidence. For example when asking if the scenarios are currently occurring we provided the responses definitely not, sometimes, yes always, most of the time and I don't know. Respondents criticised the lack of a response such as 'rarely'. Often they selected 'sometimes' but qualified this by saying that the scenario may occur occasionally or rarely so 'definitely not' was not the correct response, but neither was 'sometimes'.

- Interpretation of SRTS modelling: The SRTS model is limited in the way it can examine the potential likelihood of the scenarios described in Stephenson and Mackay (2014). Its most important contribution to this project was an evaluation of the way in which the market responds to additional pellet demand. Even so, the modelling undertaken did not examine the impact of area on market response. For the study the region studied was restricted to that impacted most by pellet mills in operation or development in Southeastern USA. Consequently the impact of 'leakage' of roundwood supply outside of the region examined, both for small roundwood supply and pellet supply is not considered. This means that small roundwood price response shown in the modelling may have been higher than would happen in reality. This is important because it may result in an apparent higher demand than in reality. Since demand was price responsive, the model did reflect that higher prices might force some demand outside of the region (and vice versa), but the out-of-region impacts were not explicitly modelled.
- Another factor that is important in the SRTS modelling is that the current small roundwood/sawtimber demand rations are higher than they have been in the past, due to the construction downturn in Southeast USA. One consequence is that the model is showing responses that have not been seen in the past especially in scenarios where housing does not recover quickly. These factors mean that the SRTS modelling has to examine a situation that has not been witnessed before, which is important for a model based on historic econometric relationships.

4.2 Comments on the scenarios examined in the study

- The scenarios examined in this study were limited to those that showed high carbon impacts in the study of North American pellet production (Stephenson and Mackay, 2014). Our aim was to identify if any of these high carbon scenarios (or similar types of scenarios) might happen in reality. Stakeholders commonly commented that some of the practices described in the scenarios did not make economic or technical sense to them and they consequently had difficulty understanding what the scenario meant or they felt some other action was far more likely. This has influenced some of their responses to the questionnaire. In these cases we have taken the approach of reporting their comments to demonstrate their difficulty in interpreting the scenarios, rather than simply saying that the scenarios are unlikely.
- Respondents also commented that the low carbon scenarios were likely to be the key scenarios for pellet production, but we have not examined the likelihood of these scenarios in this study.
- Respondents commented that the term 'additional wood' as used in a number of BEAC scenarios was ambiguous. Stephenson and Mackay (2014) use average rotation length as the modelling parameter to represent rate of harvest of forests. In the questionnaire it was clear that some stakeholders found this difficult. Some thought that additional harvesting may happen as a response to pellet demand, but it is not likely to change rotation lengths where they are known because these are determined by saw-timber or paper and pulp markets. Others believed that pellet demand will not change this. Additionally naturally regenerated forests are not managed on a constant rotation basis. In the questionnaire responses this resulted in the forestry sector focussing on the rotation lengths mentioned in scenarios concerning naturally regenerated forests, rather than whether or not additional harvest is happening. Other stakeholder groups concentrated on additional harvest rates because they were less knowledgeable about rotation. The important issue of additional harvest was therefore difficult to assess using the questionnaire results.

4.3 Limitations to SRTS modelling in Southeastern USA

There are a number of limitations to the SRTS modelling as used in this study:

- Equilibrium modelling land scenario development and subsequent interpretation and analysis is time consuming. This limited the number of runs that could be done in the study
- The SRTS model was developed to show how inventory structure and markets may change in response to demand changes over time, not to model pair-wise counterfactuals such as those provided in Stephenson and Mackay (2014). It can be used to comment on likely changes and relate these to certain scenarios, but there are limitations, particularly for scenarios that deal with energy crops or change of management regimes.
- SRTS is a partial equilibrium model of one region, it does not control for other variables potentially impacting on price
- The choice of spatial temporal scale affects results. The region of study was fixed as the region influenced by pellet mills, which means that neither mill-level impacts nor US wide impacts such as leakage) were explicitly modelled. The focus on a 20 year outlook also limits consideration of longer term impacts.
- Indirect impacts are not considered in the model; and. Since demand was price responsive, the model did reflect that higher prices might force some demand outside of the region (and vice versa), but the out-of-region (leakage) impacts were not explicitly modelled

However, we were able to draw on the considerable experience of the US team in associating the model results to the scenarios and in accessing their experience of past analysis using this model.

There were also limitations in the input data:

- Demand was based on best available data, but there has been no comprehensive study on pellet demand that we could use
- Some of the variables, such as price elasticity responsive of an emerging industry (pellets), were estimated from the literature because there is insufficient empirical data

The results from the SRTS modelling presented in Chapter 6 of the Technical report should not be seen as forecasts of a most likely outcome. They represent an attempt to capture first order ecological and economic dynamics over a plausible range of demands to see how the system will respond to additional demand for one component of the forest. The result puts pellet demand in the context of current utilization of the forest. The result is not necessarily a change in rotation age but a *pulse* that is large enough to cause a price impact and a supply response. By increasing harvest of lower valued products it affects the extent and age class distribution of pine plantations. If the key market driver (pine saw timber) does not recover quickly, its marginal impact could be locally significant. In this case the importance of small roundwood demand to landowner rents (and small roundwood consumer costs) is higher, but forest carbon increases. The results showed small reductions in inventory age are shown for hardwoods, the effect of which is larger in the high pellet demand scenarios. The overall impact on regional natural forest carbon is a slight decline but plantation forest carbon increases.

Increased demand for forest products in Southeaster USA since the 1950s has been associated with increases in management intensity, reduced loss of timberland and increasing regional forest carbon stocks, because demand increases lead to larger price changes than harvest change (due to price inelastic supply) and forest extent is affected by returns to timberlandSoutheast . Our results show that in some scenarios pellet demand could contribute towards the continuation of that trend on a regional level, mainly due to increases in faster growing plantations, rather than non-forested rural land. There are at least three important caveats; 1) these relationships are stronger in pine markets than hardwood markets, 2) there is large variability in local market conditions (both supply and demand). Region-wide projections of a pine dominated increase in demand will not capture this local variability[14], and 3) indirect (outside the market) carbon effects are not modelled.

The BEAC model estimates forest carbon adjustments of discrete paired scenarios primarily as changes in rates of harvest (modelled using rotation lengths) and differences in forest growth rates of different forest types in fully regulated forests. The forest area is fixed in each BEAC scenario and the implied spatial scale is the forest base required to supply a pellet mill.

As mentioned above SRTS does not allow modelling of specific BEAC scenarios. However, it does provide results that are relevant to some scenarios. These include the following impacts of higher pellet demand:

[14] For example there may be significant differences between regions close to pellet mills and those much further away.

1. Conversion of natural regenerated stands to pine plantations
2. Increased harvest of natural stands
3. Pellet demand (in the presence of low pine sawtimber demand) can lead afforestation on the margin relative to no pellet demand

4.4 Evidence on prices and resilience to price increase

As part of this work we included questions on pellet prices in the questionnaire and examined the evidence in the literature. Pellet prices are confidential to actors in the pellet supply chain, but some evidence was provided in the questionnaire. Often the pellet user and pellet mill have bilateral contracts, negotiated annually against pre-agreed indices. These are not published or made generally available. The literature is limited in that it tends to depend on economic modelling, interviews with producers and spot prices. Evidence such as Pöyry's work on capacity to pay (2014) provides some of the best indications on price that can be paid, but this still relies on unpublished data.

Prices quoted for pellets in the questionnaire and in the literature range from £6.3-8.3/GJ at the port (Cost, Insurance and Freight - CIF)[15]. Evidence was provided in the questionnaire that pellet producers cannot afford high increases in prices they pay for fibre (on average)[16] and cannot compete with other uses of small roundwood/fibre. This was supported in the literature (Pöyry, 2014). Evidence from the UK is that pellet users cannot afford to pay much higher prices for their pellets. It was estimated in the responses to the questionnaire that there is a 'ceiling' on pellet prices that is not more than 20-30% more than current prices. Current UK policy means that incentives are unlikely to increase. A number of factors that will affect the price of fibre for pellets and price of pellets all along the supply chain were identified in the questionnaire responses, including stumpage, labour costs, diesel (for equipment or transport), currency exchange rates and the costs of implementing sustainability. Some of these costs may decrease, but the general consensus from the questionnaire is that they are more likely to increase. Evidence presented in the questionnaire and literature indicates that the financial return of all other forest products, including pulp and paper, fibreboard and saw timber exceeds that for pellets. This means that pellets are likely to complement (i.e. provide more margin to) these products rather than displace them. In summary these key points related to price and affordability are:

- Fibre price is a major cost in pellet production and this is a function of a number of variables
- Fibre price for pellets is not sufficient on its own to drive harvest
- The impacts of a number of variables on pellet prices are location-dependent. So it is not possible to extrapolate from one region to another
- Pellet producers cannot afford a 20-30% sustained increase in price without having to reconsider their business model.
- Pellet fibre availability is a function of saw mill residue availability and small roundwood demand. Pellet production impacts the market of other wood products that rely on these feedstock, but only moderately and a number of respondents said there was there was no impact.

4.5 Application of BEAC

There are some messages from this work on the application of BEAC:

- The BEAC model does not include an economic element: it is based on a carbon life cycle analysis of scenarios twinned with counterfactuals. Our work has shown that financial return (i.e. economics) is important in determining whether or not the scenario happens. Respondents to the questionnaire frequently commented that it might be possible for a scenario to occur in theory, but it would be unlikely in practice because it does not make economic sense based on

[15] This price does not include delivery within the UK.
[16] This is a complicated situation. In some specific areas where stumpage price is low and the distance to the pellet mills is short there may be room for significant stumpage price increases and commentators may report increases in prices due to pellet demand. However, pellet mills cannot afford for average prices to increase significantly. This is discussed in Chapter 8 of the Technical Report.

the returns that pellets provide, their limited market compared to other forest products and the potentially limited period that demand for fibre for pellet production is expected to last.

- The counterfactuals for a number of scenarios are difficult to prove. For example, respondents commented that for scenarios 10-13 it is not possible to know the exact age of a forest or how it would be managed in the absence of pellet demand. They said it is not correct to assume that the forest would be harvested on a longer rotation. Faced with a better financial return from converting the land in some other way land owners in the USA may opt for different choices. Some respondents found it difficult to relate to this counterfactual.
- Other counterfactuals questioned by respondents were those for scenarios 14 and 22. Respondents said in their experience (and drawing from forest inventory data) the rotations are typically shorter than suggested in these scenarios. For BEAC the important change is a shortening of the rotation relative to the counterfactual, but it is important to ensure a realistic counterfactual is used.
- In Canada forestry laws and regulations have been negotiated over more than two decades and are designed with the intension of ensuring sustainable forest management. This continuing process provides the back drop to pellet supply strategies. Permitted harvest is determined as a balance of a number of objectives including economic return and social and environment objectives. Considerable time and resources are used to draw up agreed management plans. Canadian respondents to the questionnaire found some of the scenarios in Stephenson and Mackay (2014) difficult as they are contrary to the Canadian forest management process.
- Definitions are important and should not be open to interpretation, but we found difficulties with some definitions in Stephenson and Mackay (2014), particularly those for forest residues. Although most respondents agree with the BEAC definition of forest residues, it is clear that some grades of residues e.g. unmerchantable wood in particular are classed differently by different stakeholders. The importance of the definition for forest residues is provided in Box 4.

Box 4 The need for clarity on the definition of residues

BEAC distinguishes residues based on size (greater or less than 10 cm), and says that the larger residues have a greater GHG impact because of their size. However, there is another distinction that is also meaningful with respect to GHG emissions: whether or not the tree would have been left standing but for the bioenergy harvest. This is difficult to define, because a pre-commercial thinning might be associated with sawtimber harvest (so the trees would not have been left standing, since harvesting them is a by-product of timber stand improvement), but if the market for bioenergy is robust, then these pre-commercial thinnings will eventually be valuable on their own. If they become the prime motivator for the harvest, then they should not be called “residues.” Different residues are likely to have different carbon impacts, so need to be categorised further, not just by size. .

5 Conclusions

From the results to the questionnaire and the literature the most likely supply strategies uncovered in this work (aside from sawmill co-products, which were not examined because their use was low carbon in Stephenson and Mackay (2014)) were:

- The use of forest residues (however they are defined: there may be more than one scenario here). In Canada this was considered to be small in scale. In the USA the likelihood was related to the definition of forest residues and to proximity to the pellet mill (both from questionnaire and literature evidence). Elsewhere it was thought that this supply strategy was unlikely.
- The use of thinnings. This is not examined in Stephenson and Mackay (2014).
- The use of roundwood for pellets when/where there is no alternative higher value market and in the vicinity of pellet mills (our evidence is that coniferous plantations in Southeastern USA are a potentially an important source for pellet fibre).

- Conversion of naturally regenerated coniferous forests to plantation, although a number of questionnaire respondents said that this conversion was unlikely to happen as a result of pellet demand alone, as the financial return was not sufficient.

These sources were all confirmed in the literature and the use of roundwood from coniferous plantations was confirmed in SRTS modelling.

In Southeast USA respondents said that in the presence of financially viable sustained demand for pellet fibre one likely supply strategy is to plant more trees for thinnings in plantations and to do two sets of thinnings rather than one. This would require a financially viable sustained demand for some years, at least until the first thinning.

Respondents to the questionnaire also thought diversion of non-bioenergy pulpwood to pellets would occur. It was not clear what form this displacement would take. In some cases small roundwood demand is decreasing in some areas and pellet supply may take over as other demand slips; in other cases non-bioenergy small roundwood demand may move to neighbouring areas. The potential use of this small roundwood was also seen in the SRTS results. There was no available evidence that pellet demand would displace small roundwood and other non-bioenergy uses to other countries.

Our evidence for Canada shows that saw sawmill co-products will remain important, but additional harvest, integrated with harvest for non-bioenergy products and the use of logging residues were seen as being the most likely supply strategies. This evidence comes from the questionnaire responses and the literature.

Overall the most likely supply strategies are those that can be integrated with other higher value product supply chains, requiring little change or investment. Evidence from the questionnaire was that pellet demand is unlikely to drive rotations or harvest alone. This is because pellets are regarded as a low value product that improves margins but does not drive forest practice and such strategies are likely to be the most financially viable. This evidence for this comes predominantly from the questionnaire responses. In the longer term this might change if the pellet market increases, but not at current levels or prices. Respondents to the questionnaire said that investment in the pellet supply chain requires sustained demand, a stable policy environment and relatively low price fibre. It is unlikely that pellet demand will result in changes to harvest rotation, although it may increase harvest rates.

One scenario that is not adequately represented in the BEAC modelling is bottomland hardwoods. Some respondents expressed concern about this forest system, but it did not fit easily into any of the scenarios examined.

5.1.1 Issues with methodology

Life cycle assessment: This study has exposed problems that are common to life cycle assessment (LCA) in an area as complex as forestry. Data provided for these models always relies on past history and projections of the future: this limits their usefulness in understanding the way a new product would interact with current markets. However, LCA such as the BEAC model are useful in defining where potentially high emissions may be expected and allowing development of strategies to avoid such situations. It is important to understand that high carbon scenarios defined in LCA studies are not necessarily representative of the situation on the ground. If LCA studies are brought closer to what is happening on the ground it will be more plausible that forestry practice can be developed to avoid practices that result in high carbon emissions.

SRTS modelling: The results from the SRTS modelling (presented in Chapter 6 of the Technical report) should not be seen as forecasts of a most likely outcome. They represent an attempt to capture first order ecological and economic dynamics over a plausible range of demands to see how the system will respond to additional demand for one component of the forest. The result puts pellet demand in the context of current utilization of the forest. The result is not necessarily a change in rotation age but a *pulse* that is large enough to cause a price impact and a supply response. By increasing harvest of lower valued products it affects the extent and age class distribution of pine plantations. If the key market driver (pine saw timber) does not recover quickly, its marginal impact could be locally significant. In this case the importance of small roundwood demand to landowner rents (and small roundwood consumer costs) is higher, but forest carbon increases. The results showed small reductions in inventory age are shown for hardwoods, the effect of which is larger in the high pellet demand scenarios. The overall impact on regional natural forest carbon is a slight decline but plantation forest carbon increases.

The use of modelling: Foresters and the forest products market must understand the scenarios modelled and should be a necessary component of their development. It is clear from this work that some of the high carbon scenarios modelling in Stephenson and Mackay (2014) were not understood or recognised as common practice by foresters. One key need identified is for data on the real management responses of forestry practice under a range of market conditions that can be used to develop market based LCA scenarios.

Reliance on carbon impact as the sole metric of impact: Carbon is not the only impact and experts with a clear understanding of other impacts (e.g. on biodiversity, water or local socio-economic conditions) are important partners in the development of pellet supply strategies.

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